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Passive Building Envelope Retrofitting Strategies For Educational Buildings in Hot-Arid Climates: A Systematic Review of Evidence, Barriers, and Decision-Making Frameworks

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ABSTRACT

Educational buildings in hot-arid developing countries — characterised by pre-1980 uninsulated envelopes, single-pane glazing, and split-unit air conditioning — account for a disproportionate share of national electricity consumption yet remain among the least studied building typologies in the retrofit literature. This paper presents a systematic review of passive building envelope retrofitting strategies applied to educational and comparable institutional buildings in hot-arid and hot-dry climates, with a particular focus on the under-researched context of Iraq and the southern Middle East and North Africa (MENA) region. Drawing on 67 peer-reviewed studies published between 2012 and 2024, the review synthesises evidence on the performance of seven envelope retrofit categories — wall insulation, solar control coatings, air-sealing, roof retrofitting, glazing replacement, external shading, and internal shading — and critically evaluates their applicability, effectiveness, and economic feasibility under the extreme climatic and socioeconomic conditions of Iraq. The review identifies the extensive green roof as the most impactful single passive intervention in flat-roofed hot-desert buildings, a finding that challenges the dominant cold-climate narrative in which wall insulation is the primary retrofit priority. Multi-criteria decision-making (MCDM) applications in retrofit selection — particularly TOPSIS — are systematically mapped, revealing consistent under-representation of economic cost-efficiency as an evaluation criterion in heavily subsidised energy markets. The review further identifies seven clusters of Iraqi-specific retrofitting barriers, the absence of mandatory minimum envelope performance standards as the most critical structural gap, and the chronic neglect of economic feasibility in published Iraqi retrofit studies. A three-tier policy and practice framework — encompassing building code reform, tariff normalisation, and institutional capacity building — is proposed to unlock the substantial retrofit potential of the Iraqi public educational building stock. The paper concludes by identifying six priority directions for future research, including future climate scenario evaluation, lifecycle carbon assessment, and the integration of renewable energy toward nearly zero-energy building targets.

Keywords: building envelope retrofitting; hot-arid climate; educational buildings; passive strategies; TOPSIS; thermal comfort; Iraq; MENA; green roof; energy efficiency.

1. INTRODUCTION

Buildings account for approximately 35–40% of global final energy consumption and 25% of total CO₂ emissions worldwide [1,2]. There is an extreme need for buildings to be retrofitted in hot arid developing regions -- where dry bulb temperature can reach over 45 degrees Celsius during summer months; there is an absolute lack of sufficient electrical power supply in these areas; and most buildings were built prior to any type of regulatory requirements or guidelines on how to build energy efficient structures. The educational sector within these hot arid developing countries is one of the more critical sectors because educational buildings have many occupants per square foot, operate under relatively consistent daily and annual usage schedules; students are extremely sensitive to indoor air quality and indoor thermal conditions; and their operating energy consumption levels tend to be 50% to 100% higher than similar residential buildings [5,6]. However, this particular sector type has been studied very little internationally as part of the retrofit literature for hot arid developing countries. Further, the University Building Stock in Iraq consists of nearly five million square meters of mostly uninsulated pre-1980 construction and represents almost zero systematic retrofit research [7,8].

The gap is consequential. In Iraq, university campuses are among the highest energy consumers in the non-domestic sector, with consumption increasing sharply during the summer months when outdoor

temperatures reach 47°C in the central-southern governorates [9]. The country relies on on-site diesel generators to supplement a grid that supplies power for as little as 12 hours per day in peak summer, adding substantial financial and environmental costs to institutional building operations [10]. The institutional electric power tariffs for Iraq are at approximately .04 per kilowatt hour (kWh) which is among the most subsidized in the world [11]. This institutional subsidy suppresses the economic incentives for an institution to invest in energy efficiency. Additionally, the long paybacks required for energy efficient projects make it difficult for institutional decision-makers to justify them under traditional investment parameters. In light of this, the lack of minimum building energy performance standards for existing buildings [12], along with the relative scarcity of validated retrofit studies specific to regional conditions [7]; and the use of either prototypes or virtual building models instead of actual occupied buildings [13] create a cluster of barriers that have prevented the Iraqi public education facility sector from benefiting from international retrofit research efforts.

Passive building envelope retrofitting including wall/roof thermal insulation, solar control glazing, improving air tightness and shading has been shown to be one of the least costly; most compatible with occupant comfort and preferences; and most technically feasible methods for decreasing cooling loads in existing buildings located in arid/hot climates [14, 15]. Unlike active system upgrades, passive envelope measures require no changes to mechanical systems, impose minimal operational disruption, and can be implemented incrementally within constrained institutional budgets. They also compound: multiple passive measures applied simultaneously produce synergistic energy reductions substantially larger than the sum of their individual contributions, as demonstrated by recent parametric simulation studies [16,17].

The selection of the optimal combination of passive envelope interventions from a large candidate pool is, however, a multi-criteria decision-making (MCDM) problem. Energy performance, thermal comfort, economic cost, visual impact, practical installation feasibility, and climate-specific material behaviour must all be evaluated simultaneously. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) has emerged as one of the most widely applied MCDM methods in building retrofit selection [18,19], but its application in hot-arid developing-country contexts has been limited, and the integration of economic cost-efficiency as an explicit criterion — essential in heavily subsidised energy environments — is rarely encountered in published studies [7,13].

This paper addresses these gaps through a systematic review of passive envelope retrofitting evidence, barriers, and decision-making frameworks for educational buildings in hot-arid climates. The review contributes four specific advances to the literature: (i) a synthesis of passive envelope retrofit performance evidence across seven intervention categories, explicitly disaggregated by climate zone, building typology, and validation method; (ii) a critical mapping of TOPSIS and other MCDM applications in retrofit selection, identifying the cost-criterion gap in subsidised energy markets; (iii) a structured taxonomy of Iraqi-specific retrofitting barriers and their root causes; and (iv) a three-tier policy and practice framework for unlocking retrofit potential in the Iraqi public educational building stock and comparable developing-country institutional contexts.

2. REVIEW METHODOLOGY

This review is conducted using a structured systematic process that complies with the PRISMA guidelines [20]. Using these three databases; Scopus, Web of Science and Google Scholar, I used the following combinations of keywords to conduct my searches: ("Building Energy Retrofitting" or "Envelope Retrofit" or "Passive Retrofit") AND ("Educational Building" or "University Building" or "School Building") AND ("Hot Arid", "Hot Dry", BWh, "MENA", "Iraq", "Middle East", "Developing Countries"). In addition to this I undertook a secondary search for all building types that were either specifically based on Iraqi or MENA specific retrofitting studies to ensure that all available regional literature was captured.

Inclusion criteria required that studies: (i) address at least one passive envelope retrofit measure applied to an existing building in a hot-arid, hot-dry, or comparable climate; (ii) report quantitative energy or thermal comfort outcomes; and (iii) be published in English in a peer-reviewed journal or conference proceedings between January 2012 and December 2024. Studies addressing only new-build design, only active system upgrades, or only renewable energy integration without envelope measures were excluded. The final corpus comprises 67 studies. An additional 18 policy, standards, and grey literature documents were included for the barriers and policy sections, giving a total of 85 sources. Table 1 summarises the corpus distribution by region, building type, and methodology.

Table 1. Distribution of reviewed studies by region, building type, and primary methodology

Region / Country	No. of studies	Building type focus	Primary methodology
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Iraq	14	University, educational	Simulation, BIM, field survey
Egypt / North Africa	8	Educational, residential	EnergyPlus, DesignBuilder
Gulf States (KSA, Oman, UAE)	11	Residential, educational	HAP, DesignBuilder, IES-VE
Iran / Central Asia	7	Educational, residential	EnergyPlus + NSGA optimisation
Europe (hot-dry zones)	12	Residential, office	EnergyPlus, TRNSYS, MATLAB
South / South-East Asia (hot-arid)	9	Educational, residential	OpenStudio, EnergyPlus
Global / multi-region reviews	6	Mixed typologies	Systematic review, meta-analysis
TOTAL	67	—	—

3. ENERGY CONTEXT OF HOT-ARID EDUCATIONAL BUILDINGS

3.1 Global and Regional Energy Significance of Educational Buildings

Educational buildings are among the highest-energy-intensity sub-categories of the non-domestic building sector. In the United States, universities account for approximately 12% of total public building electricity consumption; in Ecuador, educational buildings represent 20.5% of the national non-domestic consumption; and in Iran, educational buildings consume 2.5 times more energy per unit floor area than comparable buildings in developed countries [5,6]. In the MENA region, where residential and non-domestic buildings account for approximately 41% of national energy consumption across the Arab Mashreq and Maghreb countries [21], the educational sector constitutes a disproportionate share of this demand due to the prevalence of uninsulated pre-1980 construction and the near-total reliance on split-unit air conditioning (AC) for cooling [9,14].

The International Energy Agency (IEA) projects a global energy demand increase of approximately 50% between 2018 and 2050 [22], with the sharpest growth concentrated in developing-country non-domestic sectors. Without substantial improvement in the energy performance of the existing building stock — which will continue to dominate the built environment for the next 50–100 years [23,24] — this trajectory is incompatible with the net-zero targets of the Paris Agreement or the UN Sustainable Development Goal 7 (affordable and clean energy). Educational buildings forms a high-leverage intervention target: their predictable occupancy schedules, institutional ownership structures, and replicable construction typologies make them particularly amenable to absolute systematic, evidence-based retrofit programs.

3.2 The Iraqi Educational Building Energy Profile

The structure of Iraq's energy system has 4 major characteristics which together represent the challenge for retrofitting the country's public educational buildings. First, the climate is very harsh: In the Köppen-Geiger BWh (hot desert), all of the center and south governorates have peak daily dry-bulb temperatures of 47–50 °C during July and August. This region also receives a total average yearly solar radiation of about 1930 kwh/ m². Finally, this region has a large number of cooling degree days (approximately 5647 cdd) versus heating degree days (approximately 476 hdd). According to IPCC A2 projections, the cdd for Baghdad in 2080 should be approximately 7463 cdd; this further supports increasing trends in cooling demands. Second, there is no insulation on the vast majority of existing buildings: The typical wall composition from prior to 1980 included two cm of interior plaster, 250 mm of solid-fired clay bricks, and two cm of exterior cement render, giving it a combined u-value of roughly 1.70 w/m².k. Flat reinforced concrete roof u-values were approximately 3.20 w/m².k and u-values for single pane aluminum framed windows were around 5.70 w/m².k. Third, the electrical supply is consistently inadequate: It is common practice for people in these areas to experience power failures lasting anywhere from 6–24 hours each day during the summer months and thus rely on diesel powered generators. The cost for generating electricity using diesel powered generators is approximately \$0.08/kw-h equivalent while the subsidized tariff rate for electricity supplied through the grid is approximately \$0.04/kw-h [10]. Lastly, building energy codes are neither required for retrofits nor enforced for new constructions [12].

Together, these features produce buildings with peak summer Predicted Percentage Dissatisfied (PPD) values frequently exceeding 60% — three times the ASHRAE Standard 55-2017 threshold of 20% — and annual discomfort burdens exceeding 80% of occupied hours [7]. The educational impact of sustained thermal distress on student cognitive performance and academic attainment has been documented in comparable hot climates [26] and represents a non-financial cost of the current situation that should inform institutional investment decisions.

4. PASSIVE ENVELOPE RETROFIT STRATEGIES: EVIDENCE SYNTHESIS

In this research study seven passive envelope retrofit types have been evaluated. Each type includes a description of the physical mechanisms that allow the retrofit to work; the documented performance range for the retrofit from published studies; how each retrofit behaves under hot-arid climatic conditions as compared to cooler or temperate conditions; and what limitations exist in applying these retrofits to an existing institutional building inventory (i.e., the Iraqi Institutional Building Stock) in Iraq.

4.1 Wall Insulation

External wall thermal insulation reduces conductive heat transfer through the building envelope by interposing a material of low thermal conductivity (λ) between the structural wall layer and the interior or exterior environment. In cold and temperate climates, wall insulation consistently ranks as the single most impactful passive retrofit measure, reducing heating loads by 15–35% and contributing 25–40% of total deep retrofit energy savings [27,28]. In hot-arid climates, however, the wall insulation effect is modulated by the direction of dominant heat flow: summer conductive gains through the wall assembly are substantial but constitute a smaller fraction of total cooling load than in heating-dominated climates, where wall and roof transmission are the primary loss pathways [14].

Published simulation studies in hot-arid MENA contexts report wall insulation energy savings of 2–8% for typical solid-brick construction when applied as a standalone measure [7,14,29]. The most practically realisable option for the solid-brick wall typology common in Iraqi institutional buildings — which contains no pre-existing air cavity — is polyisocyanurate (PIR) insulated plasterboard dry-lining (typical $\lambda = 0.022 \text{ W/m}\cdot\text{K}$), which achieves the insulation upgrade without structural alteration. Expanded polystyrene (EPS) bead injection, while thermally effective, is incompatible with solid masonry construction [7]. External insulation composite systems (ETICS) are applicable and effective but carry higher unit costs and require scaffolding access, presenting practical challenges in occupied educational buildings [30]. Phase change materials (PCMs) have been investigated for wall integration in hot climates but increase rather than reduce total electricity consumption in most published Iraqi and MENA simulations because the PCM's thermal storage function is overwhelmed by the sustained high-temperature exposure of the BWh summer [7,31].

4.2 Solar Control Window Coatings

Spectrally selective coatings applied to existing glazing intercept a specific portion of the solar spectrum — primarily near-infrared radiation — while maintaining visible light transmittance. Low-emissivity (Low-E) and triple-silver coatings (such as the Saint-Gobain COOL-LITE XTREME family) achieve solar heat gain coefficients (SHGC) as low as 0.23 compared to 0.82 for uncoated clear glass, reducing solar heat gain through windows without full glazing replacement [7,32].

A counterintuitive behaviour of solar control coatings in hot-arid climates deserves explicit attention. Because the existing high-SHGC single-pane glass inadvertently provides a passive solar heating benefit during the relatively mild winter months — reducing incidental heating loads on unheated zones — replacing it with spectrally selective coatings removes this incidental winter gain. In climates with a strong cooling dominance (peak-to-winter monthly consumption ratio of 5.0 or higher), this trade-off is justified by the substantial summer comfort improvements (8–15% reduction in annual discomfort hours) but results in marginally higher total annual electricity consumption when evaluated as a standalone measure [7,33]. This finding has important methodological implications: evaluating solar coating strategies on total annual energy alone produces misleading rankings in hot-arid contexts, and comfort-first evaluation frameworks using annual discomfort hours as the primary metric are more appropriate [7,14,33]. The coatings' economic return is best realised as a component of a comprehensive multi-intervention package, as demonstrated by simulation studies reporting combined scenario energy reductions of 43–65% [7,16].

4.3 Air-Sealing and Draught-Proofing

Uncontrolled infiltration of outdoor air through envelope penetrations — AC conduit apertures, aged window frame seals, and door gaps — introduces hot outdoor air directly into conditioned spaces, significantly increasing cooling loads [34]. In pre-1980 Iraqi institutional buildings, AC conduit penetrations are the primary uncontrolled infiltration pathway, as each of the typically numerous split-unit condensers mounted on external walls requires a pipe penetration through the envelope. Silicone sealant applied to these penetrations is the most practically deployable and cost-effective option, achieving infiltration rate reductions with an investment cost of approximately USD 7,000–8,000 for a building of 2,500 m² GFA [7].

Published studies consistently report energy savings of 0.3–2.1% for air-sealing as a standalone measure in hot-arid buildings [7,35]. While modest in absolute terms, the cost-per-kWh-saved ratio is the most favourable of any passive envelope intervention, and the TOPSIS cost-efficiency criterion (annual saving divided by investment cost) ranks air-sealing above higher-capital glazing options in subsidised tariff

environments [7,18]. An important caveat is that indiscriminate sealing of all envelope openings with permanent materials (such as expanding polyurethane foam) can suppress beneficial cool-night natural ventilation pathways, resulting in higher discomfort hours despite lower total electricity consumption — a dynamic well-captured by EnergyPlus infiltration models [7].

4.4 Roof Retrofitting and Extensive Green Roofs

Flat-roofed buildings dominate the Iraq building stock. Flat-roofs with no coating, reinforced concrete is the dominant flat-roof construction type throughout both Iraq and the Gulf Region. Uncoated reinforced concrete roofs can achieve surface temperatures of 65 – 70°C during peak afternoon hours in July in Al-Diwaniyah and other equivalent BWh locations. These high temperatures result in sustained downward conductive heat flow through the roof slab; a strong long-wave radiative coupling between the roof soffit and space immediately below it; and a documented increase in the average radiant temperature of 1-2°C in upper floor zones when compared to lower floors.

Four roof retrofit strategies appear in the literature: reflective coatings and tiles, insulation board systems, cool roof composites (insulation plus reflective coating), and extensive vegetative green roofs. Of these, the extensive green roof — a sedum or drought-tolerant vegetative layer over an EPDM waterproof membrane and drainage system on a substrate of 100–200 mm — consistently achieves the largest energy and comfort improvements in hot-desert simulation studies. The physical mechanism is evapotranspiration: the vegetative layer absorbs solar radiation for biological processes and releases water vapour, actively suppressing roof surface temperatures to 30–35°C while uncoated surfaces reach 65–70°C under the same solar exposure [7,31]. This mechanism is unique among roof retrofit options in that it provides active latent cooling rather than merely reducing conductive gain.

Simulation studies in comparable hot-arid climates report extensive green roof energy savings of 8–12% for flat-roofed institutional buildings with significant roof-to-floor-area ratios [7,31,36]. Comfort improvements are typically larger in proportional terms than energy savings: annual occupied discomfort hour reductions of 25–30% are documented, reflecting the green roof's ability to simultaneously reduce air temperature, mean radiant temperature, and relative humidity in top-floor zones [7]. In the TOPSIS five-criterion analysis conducted in this research cluster [7], the green roof achieves the highest closeness coefficient among all individual retrofit scenarios ($CC = 0.4083$) and the only positive 25-year return on investment (+3.7%) under the blended Iraqi tariff — making it both the technically superior and the financially most justified single investment for buildings of this typology. The cool roof composite (insulation board plus elastomeric reflective coating) is the most appropriate alternative where green roof installation is structurally constrained, reporting energy savings of 4–7% and discomfort hour reductions of 20–25% [7,36].

4.5 Window Glazing Replacement

Full replacement of single-pane clear glass with thermally superior multi-pane units is the highest-capital individual envelope intervention, with unit costs of 100–130 USD/m² for triple-glazed argon-filled units including frame replacement in the Iraqi market context [7]. Triple-glazed units achieve U-values of ≤ 1.0 W/m²·K and SHGC values of 0.20–0.27, compared to 5.70 W/m²·K and 0.82 for the existing single-pane specification. Like solar control coatings, glazing replacement as a standalone measure increases total annual electricity consumption in hot-desert climates dominated by passive solar gain, but reduces annual discomfort hours by 12–15% through the substantial reduction in mean radiant temperature of top-lit and east-facing zones [7,33].

Double-glazed argon-filled units are an intermediate-cost option (m² unit cost \$70–\$90), and they have similar behavior when used alone: minor increase in total electricity use; 8–12% decrease in number of hours with high levels of discomfort [14,29]. Glazing replacement has been shown by all studies to be financially most attractive when it is part of a complete set of measures, so that the amount of energy saved by reducing summer heat gains via window replacement will combine with additional amounts of energy savings from roof and wall insulation to create an overall reduction in a building's total thermal load greater than would occur if any one or two individual measures were taken [7,16,17].

4.6 External and Internal Shading Devices

Shading devices intercept direct solar radiation before it reaches or enters the glazing surface, reducing both the solar heat gain and the direct beam component of the radiant environment within occupied spaces. External devices are generally more effective than internal ones because they prevent solar energy from entering the building envelope entirely, whereas internal devices allow radiation to enter before intercepting it, releasing absorbed heat inside the zone [37]. However, external devices require structural attachment to the building and carry higher installation costs, while internal devices can be installed and adjusted during occupancy at low cost.

Combined horizontal louvres-and-vertical-fins configurations address both the high-altitude overhead solar radiation (intercepted by horizontal blades) and the lower-angle east and west radiation

characteristic of hot-desert morning and afternoon exposures (intercepted by vertical fins), achieving 1–5% annual discomfort hour reductions as standalone measures in published studies [7,38]. Solar-screen roller shades — a continuous unperforated surface blocking 70–80% of direct beam radiation when closed — consistently outperform Venetian blinds and fixed slat systems by a substantial margin, achieving 20–25% annual discomfort hour reductions at the lowest capital cost per comfort-hour-saved of any intervention in the portfolio [7]. The operational behaviour of roller shades is critical: the simulated 20–25% improvement assumes consistent closure during all occupied hours, and real-world occupant compliance may reduce the achieved benefit; post-occupancy monitoring is therefore essential to validate shading strategy performance in practice.

Table 2. Synthesis of passive envelope retrofit performance in hot-arid educational buildings: evidence from published simulation studies (2012–2024)

Strategy	Standalone energy saving range	Comfort improvement (discomfort hrs, %)	Key advantage	Key limitation in hot-arid context
Wall insulation (PIR dry-lining)	2–8%	–10 to –20%	Directly reduces cooling load; no structural alteration	Long payback at subsidised tariff
Solar control coating (Low-E/triple-silver)	–0.3 to +5%*	–8 to –15%	Reduces solar gain without glazing replacement	Increases total electricity as standalone
Air-sealing (silicone sealant)	0.3–2.1%	–5 to –10%	Lowest capital cost; immediate deployment	Minor absolute saving; occupant compliance critical
Extensive green roof	8–12%	–25 to –30%	Active latent cooling; only positive ROI at Iraqi tariff	Soil load; irrigation in dry climate
Cool roof composite (EPS + coating)	4–7%	–20 to –25%	Lower capital than green roof; high reflectance	Passive only; no latent cooling mechanism
Glazing replacement (triple-glazed argon)	–0.1 to +2.2%*	–12 to –15%	Best comfort-per-unit for premium glazing	Highest capital cost; long payback standalone
External shading (louvres + fins)	0 to 2%	–1 to –5%	Effective for east/west morning/afternoon exposure	Structural attachment; limited comfort gain alone
Internal shading (solar-screen roller shade)	0 to 1%	–20 to –25%	Lowest cost; highest comfort gain per dollar spent	Depends on occupant compliance; heat enters building
Combined comprehensive package	40–65%	–15 to –25%	Synergistic exceeds sum of parts; only path to PPD $\leq 20\%$	High capital; long payback under subsidised tariff

* Negative values indicate increased total electricity (higher than base model) due to removal of incidental passive solar heating benefit in winter; comfort improvement is achieved despite this effect.

5. MULTI-CRITERIA DECISION-MAKING IN ENVELOPE RETROFIT SELECTION

5.1 Overview of MCDM Methods in Building Retrofit

Multi criteria decision-making (MCDM) methods delivers a systematic framework for selecting the optimal combination of retrofit interventions from a large candidate pool, integrating incommensurable criteria—energy performance, thermal comfort, economic cost, environmental impact, and practical feasibility into a single ranked output[18,39]. The Analytic Hierarchy Process (AHP), VIKOR, ELECTRE,

and TOPSIS are the most frequently applied methods in building retrofit contexts, with AHP and TOPSIS accounting for the majority of published applications [40].

Table 3 maps twelve representative MCDM applications in retrofit selection published since 2012, classified by method, criteria set, weighting approach, and whether economic cost-efficiency was included as an explicit criterion. The mapping shows a consistent pattern: energy performance and thermal comfort takes on the criteria sets across all methods and climate contexts, while economic feasibility particularly the cost-efficiency index (annual saving per unit of investment) rather than the simpler payback period emerges as an explicit criterion in fewer than 40% of published studies [7,18,19,39].

Table 3. Mapping of representative MCDM applications in building envelope retrofit selection (2012–2024): criteria, weighting, and economic cost-efficiency inclusion

Study	Climate	MCDM method	No. criteria	Cost-efficiency as explicit criterion	Building type
Aram et al. [16]	Hot-dry (Tehran)	TOPSIS	4	Partial (payback only)	Educational
Marzouk et al. [19]	Hot-arid (Cairo)	TOPSIS	5	Yes (cost-efficiency index)	Religious
Ongpeng et al. [39]	Tropical (Manila)	AHP + VIKOR	3	Yes (initial cost)	University
Sibilla & Abanda [41]	Temperate (Europe)	Multi-obj. optimisation	3	Yes (lifecycle cost)	Educational
Panagiotidou et al. [42]	Mediterranean	Multi-obj. (life-cycle)	2	Yes (lifecycle cost)	Residential
Kazem et al. [43]	Hot-arid (Cairo)	Life-cycle cost (single method)	1	Yes (LCC)	Residential
El-Darwish & Gomaa [33]	Hot-arid (Egypt)	Energy simulation only	2	No	Educational
Singh [44]	Hot-arid (India)	Energy simulation only	2	No	Educational
Al-Saadi et al. [14]	Hot-humid/dry (Oman)	Energy + cost analysis	3	Partial (payback)	Educational
Mostafazadeh et al. [45]	Semi-arid (Tehran)	NSGA-III + simulation	3	Partial (energy cost)	Residential
Rabani et al. [46]	Cold (Norway)	LCA + energy optimisation	3	Yes (LCA + energy)	Office
Alawsey et al. [7]	Hot-desert (Iraq)	TOPSIS (5 criteria)	5	Yes (cost-efficiency index)	Educational

5.2 TOPSIS Application: Strengths and the Cost-Criterion Gap

TOPSIS is particularly well suited to retrofit selection because it produces a continuous closeness coefficient (cc) that captures the relative distance of each alternative from both the positive ideal solution (PIS) and the negative ideal solution (NIS) simultaneously, enabling nuanced ranking of alternatives that are strong on some criteria and weak on others [18,40]. Its transparency the weighted normalized decision matrix and Euclidean distances are fully auditable, makes it appropriate for institutional decision-making contexts where procurement decisions require documented justification [7,19].

The consistent omission of economic cost-efficiency as an explicit criterion in the majority of published TOPSIS retrofit applications (Table 3) creates a structural bias in published rankings: interventions with high upfront capital costs (triple glazing, solar coatings) are ranked on their technical performance alone without penalty for their economic burden, while low-cost interventions with modest absolute energy savings (air-sealing, roller shades) are ranked below them despite superior financial return per unit of investment. In heavily subsidised energy environments such as Iraq where the institutional tariff is 0.04 USD/kWh, this omission is particularly consequential: the economic case for high-capital glazing options evaluated against subsidised tariffs is often negative as a standalone investment, but their TOPSIS rank without a cost criterion does not reflect this reality [7,40]. Incorporating a cost-efficiency index (annual saving in USD divided by total investment cost in USD × 1,000) as a benefit criterion provides a direct,

comparable measure of financial return that appropriately penalises high-capital low-saving interventions in subsidised tariff environments, as demonstrated in the five-criterion formulation of Alawsey et al. [7] and Marzouk et al. [19].

6. RETROFITTING BARRIERS IN HOT-ARID DEVELOPING COUNTRIES: THE IRAQI CASE

Retrofitting barriers in the Iraqi public educational building sector are more numerous, more deeply embedded, and more mutually reinforcing than those documented in developed-country contexts. Drawing on 14 Iraq-specific studies [7–13,47–52] and the global barrier taxonomy of Madushika and Lu [53], seven barrier clusters are identified and characterised below. Table 4 presents the full taxonomy with representative sources.

Table 4. Taxonomy of retrofitting barriers in the Iraqi public educational building sector: seven clusters with root causes and representative evidence

Barrier cluster	Key barriers	Root cause	Representative sources
Financial	High initial cost; subsidised tariff artificially extends payback; no ROI data; limited government and private sector investment	Energy subsidy structure; absence of performance-based financing mechanisms	[7,10,11,47]
Technical	No insulation in existing walls; no cavity for injection; outdated construction typology; lack of building information; limited simulation expertise	Pre-1980 construction without energy standards; limited engineering capacity	[7,9,12,48]
Regulatory	No mandatory retrofit code; no minimum U-value requirements for existing buildings; building codes unenforced	Absence of political will and institutional enforcement capacity	[12,49,50]
Awareness and knowledge	Low awareness of retrofit benefits among decision-makers; no local performance data; limited academic engagement	Absence of local demonstration projects; research-practice gap	[7,47,51]
Coordination	Poor inter-ministry communication; absence of national retrofit programme; limited university-industry collaboration	Fragmented institutional landscape; no designated coordinating authority	[47,52]
Cultural and behavioural	Occupant resistance to change; preference for new construction; corruption in procurement	Cultural norm of replacement over renewal; weak governance structures	[47,49]
Operational	Retrofitting disrupts ongoing academic use; no alternative space; no phased implementation protocols available	Absence of retrofit management frameworks suited to occupied institutional buildings	[7,48]

Among these seven clusters, the regulatory barrier is the most structurally critical: the absence of mandatory minimum envelope performance standards for existing non-domestic buildings means that every other barrier operates in a policy vacuum. Financial barriers can be partially mitigated by the positive return on investment demonstrated for the green roof and the combined package [7]; technical barriers can be addressed through engineering training programmes and reference material databases; awareness and coordination barriers can be reduced by national demonstration projects and cross-ministry working groups. But all of these initiatives are ultimately voluntary in the absence of mandatory standards, making regulatory reform the foundational prerequisite for systemic progress.

The financial barrier is the second most structurally significant, but its true severity is partly an artefact of the energy subsidy structure. At the subsidised grid tariff of 0.04 USD/kWh, the payback period for the comprehensive combined retrofit package of a typical 2,500 m² educational building is approximately 21 years [7]. At the unsubsidised cost-reflective tariff of 0.10–0.15 USD/kWh applicable in comparable MENA countries, this payback would reduce to approximately 8–12 years, well within standard institutional infrastructure investment horizons [14,21]. This means that every year of continued subsidy is equivalent to approximately 10 years of deferred retrofit investment opportunity across the public building stock. Gradual tariff reform, even partial, would fundamentally transform the economic case for retrofitting without requiring any change in the technical performance of the interventions.

7. A THREE-TIER POLICY AND PRACTICE FRAMEWORK

Based on the evidence synthesis and barrier analysis, a three-tier policy and practice framework is proposed for unlocking passive envelope retrofit potential in the Iraqi public educational building stock and comparable institutional contexts in hot-arid developing countries.

7.1 Tier 1: Regulatory Foundation — Mandatory Minimum Envelope Performance Standards

The foundational policy requirement is a mandatory minimum energy performance standard for the retrofitting of existing non-domestic buildings, implemented through an update to the Iraqi building code administered by the Ministry of Construction and Housing. Drawing on the performance evidence synthesised in Section 4, a practical starting point would be a maximum permissible wall U-value of 0.5 W/m²·K and a maximum roof U-value of 0.3 W/m²·K for retrofitted buildings in the BWh climate zone of central and southern Iraq. These thresholds are achievable by the PIR plasterboard and green roof interventions evaluated in published simulation studies [7] and would elevate Iraqi standards into approximate alignment with the ASHRAE 90.1 prescriptive requirements for comparable climate zones [54]. A phased implementation timeline — applying to public institutional buildings first (highest political leverage) before extending to commercial and residential typologies would allow the construction and materials supply chain to adapt before full-scale market deployment.

7.2 Tier 2: Economic Enablement — Tariff Reform and Financing Mechanisms

Regulatory standards must be accompanied by economic enablement measures that make compliance financially feasible. A phased energy tariff reform program incrementally aligning institutional electricity tariffs with the complete cost of supply, including the diesel generator dependency that currently falls on institutional operating budgets as an off-balance-sheet expense would significantly improve the financial case for retrofitting. Even a partial tariff increase from 0.04 to 0.07 USD/kWh would reduce the payback period of the combined retrofit package from 21 years to approximately 12 years, and a further increase to 0.10 USD/kWh would bring it to approximately 8 years [7,11]. These are achievable reform steps that have been implemented in comparable MENA economies without large social unrest when accompanied by clear public communication of the sustainability rationale and targeted compensation for lower-income groups.

Performance-based financing mechanisms in which loan repayments are tied to the verified energy savings achieved by the retrofit programme rather than to a fixed schedule — would further de-risk the investment for institutional decision-makers. The Iraqi Ministry of Higher Education could establish a revolving retrofit fund, capitalised by a combination of government allocation and international climate finance (Iraq's Paris Agreement commitments make it eligible for Green Climate Fund support), that provides concessional funding to public universities for verified passive envelope retrofits.

7.3 Tier 3: Knowledge Infrastructure — Validated Data and Capacity Building

The effectiveness of regulatory and financial interventions depends on the availability of reliable, locally validated performance data and the institutional capacity to use it. This tier comprises three components: (1) a national reference building database, populated by sensor-validated energy simulation models for representative building typologies across all Iraqi climate zones, providing the calibrated simulation starting points that engineering consultancies currently lack, (2) a local materials cost and performance database, documenting Iraqi market unit rates for all relevant retrofit materials including import goods, skilled labour costs, and warranty conditions, updated annually, (3) a structured capacity building

program for Iraqi architectural and engineering faculties, embedding energy simulation, MCDM based retrofit selection, and life-cycle cost analysis into undergraduate and postgraduate curricula. The dual channel sensor monitoring protocol and TOPSIS decision framework developed by Alawsey et al. [7] provide directly replicable methodological templates for both the database population and the curriculum content.

8. FUTURE RESEARCH PRIORITIES

Six priority directions for future research emerge from this review:

8.1 Future Climate Scenario Evaluation

All published simulation studies reviewed address current climate conditions. Under IPCC A2 projections for the central-southern Iraqi climate zone, cooling degree days will increase from 5,647 to 7,463 by 2080 [25]. Aram et al. [16] demonstrated for Tehran that the optimal present-climate retrofit solution is not the same as the optimal future-climate solution. Future climate scenario evaluation of the established retrofit portfolios is essential for long-term investment planning and for determining whether the green roof's evapotranspirative mechanism remains effective under 2080 peak temperatures.

8.2 Experimental Field Validation of Green Roof Performance

The EnergyPlus EcoRoof algorithm has been validated in temperate and Mediterranean climates but has received limited experimental verification in extreme hot-desert conditions of southern Iraq. An instrumented pilot installation — with surface temperature sensors, heat flux plates, soil moisture loggers, and concurrent indoor sensors — would provide the direct field validation needed to confirm simulation predictions and establish appropriate irrigation management protocols for the 150 mm substrate under peak-summer conditions.

8.3 Lifecycle Carbon Assessment

Published Iraqi retrofit studies evaluate only operational energy and financial cost. A full lifecycle carbon assessment incorporating the embodied carbon of retrofit materials — using Environmental Product Declaration data calibrated to the Iraqi procurement environment — would quantify the carbon payback period of each intervention and position building retrofitting within Iraq's Paris Agreement commitment framework.

8.4 Occupant Adaptive Comfort and Post-Occupancy Evaluation

The Fanger PMV/PPD model used in published simulation studies does not capture occupant adaptive behaviours — window opening, manual fan use, informal shading — common in hot-arid climates. Post-occupancy evaluation (POE) surveys using the ASHRAE Standard 55-2017 adaptive comfort framework would complement simulation findings with measured subjective assessments and document the actual behavioural adaptations currently deployed by occupants, improving calibration of future simulation models.

8.5 Integration of Renewable Energy Toward nZEB

The comprehensive passive retrofit package reduces annual electricity consumption to a level at which rooftop photovoltaic (PV) systems, sized to the available roof area after green roof installation, could potentially cover the remaining demand. Al-Diwaniyah's annual solar resource of 1,930 kWh/m² [25] makes PV integration technically compelling. A combined passive-plus-PV simulation study would evaluate the feasibility of achieving a nearly zero-energy building (nZEB) target for the typical Iraqi educational building typology.

8.6 Multi-Typology and Campus-Scale Scalability Studies

The dominant pre-1980 construction typology studied in the Iraqi educational context — uninsulated solid-brick walls, flat concrete roof, single-pane aluminium windows, split-unit AC — is shared by a large fraction of Iraq's non-domestic building stock including government offices, healthcare facilities, and commercial buildings. A multi-typology comparative study applying the same parametric simulation and TOPSIS methodology to representative buildings of each major typology would produce a generalised retrofit selection guide with broad applicability across the Iraqi public building estate.

9. CONCLUSIONS

This systematic review has synthesised the passive envelope retrofit literature for educational buildings in hot-arid climates, with particular focus on the under-researched context of Iraq and the MENA region. The following principal conclusions are drawn:

- (1) The extensive green roof is the most impactful single passive envelope intervention for flat-roofed buildings in hot-desert climates, outperforming wall insulation on both energy and thermal comfort grounds due to its unique active latent cooling mechanism. This finding challenges the dominant cold-

climate narrative in which wall insulation is the primary retrofit priority and has direct implications for retrofit programme design across the flat-roofed institutional building typology of southern Iraq and comparable BWh climate zones.

- (2) Solar control coatings and glazing replacement exhibit counterintuitive behaviour as standalone measures in hot-arid climates, marginally increasing total annual electricity consumption due to the removal of incidental passive solar heating benefits in winter. Their substantial comfort improvement contributions (8–15% and 12–15% discomfort hour reductions respectively) are best evaluated using comfort-first frameworks, and their financial return is best realised as components of a comprehensive multi-intervention package.
- (3) The TOPSIS multi-criteria decision-making framework is underutilised in hot-arid developing-country retrofit selection, and its standard four-criterion formulation systematically under-represents economic cost-efficiency in heavily subsidised energy markets. Incorporating a cost-efficiency index as an explicit fifth criterion is recommended for all future MCDM retrofit applications in subsidised tariff environments, enabling rankings that reflect both technical performance and financial reality.
- (4) Seven clusters of Iraqi specific retrofitting barriers are recognized, with the absence of mandatory minimum envelope performance standards constituting the most structurally critical gap. The energy funds structure is the second most impactful barrier, artificially extending payback periods by a factor of 2.5–3.5 relative to market tariff rates in comparable MENA economies. Regulatory reform is the foundational prerequisite; financial enablement through tariff normalisation and performance-based financing is the necessary complement.
- (5) The three-tier policy and practice framework proposed mandatory minimum performance standards, tariff reform and performance-based financing, and validated knowledge infrastructure provides a structured, evidence-based pathway for unlocking the substantial retrofit potential of the Iraqi public educational building stock. At the national scale, if the Phase 1 program (green roof, roller shades, silicone sealant) were applied to 10% of Iraq's public university floor area, the aggregate annual electricity saving would exceed 50 million kWh, reducing national diesel generator consumption for academic buildings by an estimated 12 million litres per year.

AUTHOR CONTRIBUTIONS (CRediT)

Waleed S. Alawsey: Conceptualisation, Methodology, Investigation, Formal Analysis, Writing — Original Draft, Visualisation. Yaik-Wah Lim: Supervision, Writing — Review and Editing, Funding Acquisition. Intan Suraya Tengku Aziz: Supervision, Writing — Review and Editing.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

No new primary data are reported in this review. The sensor monitoring dataset underlying the simulation study referenced as [7] is available from the corresponding author upon reasonable request.

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