

Fire-Protection Materials and LEED v4.1 Sustainability Alignment in Small- and Medium-Scale Riyadh Buildings: An Exploratory Multi-Case Study with a Proxy Index (FPSAI)

Mohammed Hussien Ali ElHaggar^{1*}

¹Researcher, Department of Natural Resources, National University of Sadat City Sadat City, Monufia 32897, Egypt

¹ORCID: <https://orcid.org/0009-0007-1021-9013>

Corresponding Author: Mohammed Hussien Ali ElHaggar^{1*}

Publication Date: 2026/10/30

Abstract: Small- and medium-scale construction accounts for the majority of new commercial and healthcare buildings in Riyadh, yet the segment lies almost entirely outside the LEED certification pipeline. Fire-protection subsystems — piping, sealants, intumescent coatings, and clean-agent gases — are a substantial but underexamined part of the material footprint of these buildings, and the sustainability profile of the materials actually installed has not been characterized empirically for this segment. We report an exploratory multi-case study of ten anonymized small- and medium-scale projects (P-01 to P-10, 150–2,150 m²) completed in Riyadh between 2022 and 2025. The study investigator served as supervising fire-protection specialist across the sample, providing verified as-built documentation and enabling a Visual Site Verification protocol at hand-over. Installed materials were scored against a purpose-built proxy instrument — the Fire-Protection Sustainability Alignment Index (FPSAI) — with four indicator axes inspired by (but not replicating) LEED v4.1 categories MR, EQ, EA, and WE. The within-sample mean composite score was 41.2/100 (SD 10.4), placing the sample in the "acceptable-to-poor" band. Only one project exceeded 60/100, and it was the only case whose tender package referenced LEED. Item-level price premiums for greener alternatives reached +134%, but aggregated to project level averaged 1.8% of total construction cost. Sensitivity analysis showed the sample mean is stable to $\pm 20\%$ weight perturbations ($\Delta \leq 2.0$ points), and the ordering of projects is highly stable (rank correlation with the baseline ordering ≥ 0.95 in every perturbation), with residual movement confined to a tightly clustered mid-table group. The FPSAI is offered not as a LEED score, but as an operational instrument for embedding in the Bill of Quantities and the supervision contract; recommended per-axis (≥ 40) and composite (≥ 60) thresholds are derived from the observed distribution. Findings are exploratory ($n = 10$) and require replication.

Keywords: LEED v4.1; Sustainability Alignment Index; Fire Protection; Riyadh; NFPA; Saudi Building Code; VOC Content; Global Warming Potential; Recycled Content; Multi-Case Study.

How to Cite: Mohammed Hussien Ali ElHaggar (2026) Fire-Protection Materials and LEED v4.1 Sustainability Alignment in Small- and Medium-Scale Riyadh Buildings: An Exploratory Multi-Case Study with a Proxy Index (FPSAI). *International Journal of Innovative Science and Research Technology*, 11(10), 2260-2273. <https://doi.org/10.38124/ijisrt/26oct1115>

I. INTRODUCTION

Leadership in Energy and Environmental Design (LEED), issued by the U.S. Green Building Council, is the most widely applied third-party rating system for sustainable buildings. By 2023, Saudi Arabia had 1,816 registered LEED projects, of which 1,162 were certified [1]. Recent Saudi analyses show LEED certification concentrated in major cities and led by commercial and institutional buildings [2]. Saudi

Mostadam work and official guidance address residential and commercial sustainability at building level [3, 4], rather than fire-protection subsystems.

Fire-protection subsystems are unusually material-intensive relative to their functional footprint. Black-steel piping in wet sprinkler systems, firestop sealants and mortars, intumescent coatings on structural steel, and clean-agent extinguishing gases all carry substantial embodied impacts and,

in the case of sealants and coatings, direct indoor-air-quality consequences [5, 6]. The tension between these impacts and mandatory life-safety codes (NFPA in the U.S. tradition, SBC 801 in the Saudi context) is well known in the mega-project world, where design teams solve it through performance-based design and long procurement lead times [7, 8]. In small- and medium-scale work, where the design team is typically one licensed consultant and the specification is often a one-page document appended to the tender, the same tradeoffs collapse to a simple procurement question — and that question is almost always answered on price.

During the past three years, the author has supervised or reviewed fire-protection scopes on more than thirty small- and medium-scale projects in Riyadh. In every one of them, the installed materials met the life-safety requirements of SBC 801 and the referenced NFPA standards; in none of them did the materials, considered against the intent of LEED v4.1 sustainability credits, meet thresholds a certifying reviewer would treat as strong. Three explanations recur in conversations with owners and contractors: (i) the price premium of greener alternatives, (ii) the absence of any contractual or regulatory language obliging their use, and (iii) limited local access to green-building technologies together with scarce and inconsistent environmental data for fire-protection products [5, 9].

➤ Problem statement

There is a persistent gap between fire-safety compliance and environmental performance in small- and medium-scale developments in Riyadh. Owners and contractors default to the cheapest locally stocked materials that satisfy SBC 801, with no requirement to consider recycled content, indoor-air emissions, or the atmospheric impact of extinguishing agents. Whether this default is driven principally by price, by weak regulation, or by a supply gap is not empirically established for this segment.

➤ Objectives

The study pursues four objectives: (a) to characterise, within a purposive sample of ten small- and medium-scale Riyadh projects, the alignment of installed fire-protection materials with the sustainability intent of LEED v4.1 categories MR, EQ, EA, and WE; (b) to measure the item-level price gap

between conventional materials and their greener counterparts as offered by Riyadh suppliers in early 2025; (c) to develop a practical scoring instrument — the FPSAI — that consultants and contractors can apply pre-procurement without specialist LEED training; and (d) to propose contractual and regulatory adjustments that could reduce the observed gap without weakening life-safety requirements.

➤ Research Questions

- RQ1. What FPSAI alignment score do installed fire-protection materials in the sampled projects achieve, per axis and in composite?
- RQ2. What is the item-level and project-level price gap between conventional and greener alternatives in each indicator family?
- RQ3. Which regulatory or contractual factors, as reported by the interviewed cohort, most constrain the uptake of greener materials in this segment?
- RQ4. Which interventions could reduce the alignment gap without compromising NFPA or SBC 801 compliance?

➤ Significance and Framing

To the best of our knowledge, this is the first empirical study in Saudi Arabia to isolate fire-protection materials — rather than building materials in general — as the unit of analysis for sustainability alignment in the small- and medium-scale segment. The paper is offered as an exploratory case-study contribution in the tradition of Yin [10], not as a market characterisation; the sample of ten does not support statistical generalisation and every quantitative result should be read as within-sample descriptive evidence.

II. BACKGROUND AND RELATED WORK

➤ LEED v4.1 Credit Categories Touched by the Fire-Protection Scope

LEED v4.1 [11], the operational version for new commercial and healthcare construction, organises credits under nine categories. Four intersect partially with the fire-protection scope; the intersections are asymmetric, and it is worth being explicit about what each credit does and does not cover before the FPSAI is introduced (Section III.C).

Table 1 What the four LEED v4.1 credit families reward, and how far the FPSAI indicators reach into each of them. The FPSAI is an indicator-level proxy for the sustainability intent that each credit expresses, not a re-implementation of the credit procedures.

LEED v4.1 credit family	What USGBC actually rewards	Relevance to fire-protection scope
MR — Building Product Disclosure and Optimization: Sourcing of Raw Materials	Points for a minimum count of permanently installed products from manufacturers publishing extended-producer-responsibility or responsible-sourcing information (recycled content is one input), evaluated at project cost level.	Piping and fittings are permanently installed and count toward the product tally. Recycled-content data is available on most steel manufacturers' EPDs; used partially in FPSAI.
EQ — Low-Emitting Materials	In-scope wet-applied products (including sealants) must meet BOTH a VOC content limit AND a VOC emissions evaluation (typically CDPH v1.2). Both are required for the credit.	Firestop sealants and intumescent coatings are wet-applied. The FPSAI captures the VOC content limb only (§3.3.2).
EA — Enhanced Refrigerant Management	Written for HVAC&R equipment; quantifies leakage-and-atmospheric-life impact of building	Included in FPSAI by analogy (§3.3.3), not as a proxy for the EA credit itself.

	refrigerants. Fire-suppression clean agents are not the credit's primary subject.	
WE — Indoor / Process Water	Points for reducing potable-water demand through fixture selection and process-water strategies against a defined baseline.	Water lost in NFPA-25 periodic testing is a modest but consistent process-water demand. The FPSAI treats capture/reuse as a binary indicator (§3.3.4).

➤ *NFPA and Saudi Building Code (SBC 801)*

The National Fire Protection Association (NFPA) publishes the dominant international standards for the equipment and materials examined here. NFPA 13 [12] governs sprinkler design and installation; NFPA 20 [13] covers fire pumps; NFPA 25 [14] sets inspection, testing, and maintenance requirements — including the periodic tests that generate the water losses discussed in Section IV.A.4; NFPA 72 [15] governs alarm systems; and NFPA 2001 [16] covers clean-agent extinguishing systems. Saudi Building Code SBC 801-2018 [17] adopts most of these standards with a limited set of regional adjustments recognising the arid climate and the specific occupancy mix of the Kingdom. None of these standards is in direct conflict with the LEED credits in Table 1; the tension is a specification and procurement issue, not a code conflict [7, 8].

➤ *Prior work — Saudi and Regional Context*

Balabel and Alwetaishi [3] examined the Mostadam framework for sustainable residential buildings in Saudi Arabia. Allahaim [18] reported that Mostadam uptake remains concentrated in major cities, with limited diffusion into the small-scale private-developer segment. Al-Homoud and Krarti [19] reviewed energy efficiency in Saudi residential buildings and highlighted continuing gaps in code enforcement and substantial untapped efficiency opportunities. Sirror et al. [2] analysed LEED certification trends in Saudi Arabia and found growth concentrated in major cities, with commercial and institutional buildings leading. Dormohamadi et al. [5] reviewed 157 third-party-verified EPDs representing 393 active fire-protection and egress products and found significant data gaps across 24 of 32 product categories.

On the fire-safety-and-sustainability interface, Meacham [7] argued that apparent conflicts are best resolved through performance-based design rather than by relaxing either requirement. Charlier et al. [20] reviewed the environmental impact of structural fire engineering and emphasised evaluating structural fire-engineering strategies through a sustainability lens. Frantzich et al. [8] proposed a decision-support framework (SAFR-B) for aligning sustainability and fire-resilience objectives at whole-building level, using risk indexing, AHP, and Delphi-based expert input. Bin Mahmoud et al. [1] and Mohamed et al. [9] identified high costs, limited awareness and professional knowledge, and market-access barriers in Saudi green-building adoption, without isolating fire-protection materials from other trades. Kibert [21] documents a global convergence trend between conventional and sustainable-material prices (~3–4% per year over the last decade), which is consistent with international market data but which our supplier survey (Section IV.C) suggests has not yet reached the Riyadh firestop market.

➤ *Research Gap*

The prior work either treats the mega-project as the unit of analysis, aggregates fire-protection with other trades, or examines the design stage rather than the delivered material. The present study addresses that gap: it looks at the delivered material, in the small- and medium-scale segment, on a purpose-built indicator instrument, and is transparent that the instrument is a proxy rather than a certification simulator.

III. MATERIALS AND METHODS

➤ *Design*

We used a multi-case study design in the tradition of Yin [10], on the reasoning that the phenomenon under study — the material-selection behaviour of small- and medium-scale project teams in Riyadh — is deeply embedded in local practice, and that a small number of well-characterised cases yields more actionable insight than a broad survey. Data collection had three stages: (i) document review of building permits, Civil Defence safety certificates, approved fire-protection drawings, and material submittals; (ii) a site visit to verify that the material recorded on the submittal matched what was installed — a check that turned out to be necessary in three of the ten cases; and (iii) a semi-structured interview with either the contractor's project manager or the supervising consultant.

• *Author Role, Access, and its Limits*

The author served as the supervising or reviewing fire-protection specialist on the ten included projects, providing direct access to verified as-built documentation and Civil Defence records. This position reduced missing-data and self-reporting concerns within the ten included cases because the material record was not filtered through the owner or contractor. It did not eliminate selection or non-response bias: as noted in Section III.B, some otherwise eligible owners declined to participate before the final sample was formed. The author held no commercial interest in any of the material choices reported here: supervision fees were fixed in advance and were not tied to material selection, and no supplier surveyed in Section IV.C has any commercial relationship with the author. A conflict-of-interest statement to this effect is filed with the manuscript.

A residual limitation of the study is its single-observer design. The FPSAI scoring described in Section III.C was carried out from the material data sheets alone, blinded to project identity — link to project was re-established only at aggregation in Section IV.B — but no independent second rater was used on the field data, and no formal inter-rater reliability metric could therefore be computed on the FPSAI scores. The scoring rule is mechanical (published product data sheets → axis score by a fixed rubric), which limits the observer degrees of freedom, but the choice of which data sheet to accept as

authoritative when a material has multiple grades on offer is a judgment call that a single observer necessarily makes alone. This limitation is acknowledged in Section VI.C, and independent replication is included in the future-work agenda (R10).

• *Material Verification Protocol (VSV)*

Because approved submittals are known to diverge from as-built conditions in this market [22], the study did not rely on paper approvals. For each project the author conducted a structured Visual Site Verification (VSV) walk immediately before hand-over, following a five-item checklist: (i) manufacturer's stamp or product ID on the physical pipe, sealant cartridge, coating tin, or agent cylinder actually installed; (ii) batch or lot number cross-referenced against the approved submittal; (iii) photographic record of at least three representative install locations per material; (iv) verification of the applied product against the manufacturer's published data sheet for VOC content, recycled content, and GWP; and (v) a discrepancy log entry where the installed material differed from the approved submittal in brand, grade, or specification.

Discrepancies were recorded in three of the ten projects: in P-03 a branded firestop sealant on the approved submittal had been substituted on site with an unbranded local silicone; in P-06 a low-VOC coating on the submittal had been substituted with a standard-grade product from the same manufacturer; and in P-10 the sealant applied was a mixture of two products, only one of which appeared on the submittal. In all three cases the VSV protocol captured the actual installed

material, and it is the installed material — not the submittal — that is scored in §4. This protocol is intended to close the paper-approval-versus-installation gap documented in Riyadh supervision practice [22].

➤ *Sample and Anonymization*

Ten projects were selected by purposive sampling against five criteria: (i) location inside Riyadh municipal boundaries; (ii) completion between January 2022 and March 2025; (iii) gross built area between 120 and 2,500 m², used here as a study-defined project-size band; Monsha'at classifies enterprises by full-time employees and annual revenue rather than floor area [23]; (iv) a valid building permit and Civil Defence safety certificate; and (v) willingness of the owner or contractor to release detailed material information. The last condition was the binding constraint; several owners declined to participate.

Because the fire-protection scope of a building is legally sensitive — deficiencies in it can expose the owner to insurance and Civil Defence consequences — every participating owner requested that the project be referenced anonymously. Each case is identified only by a code of the form P-nn (Table 2). Project names, license numbers, addresses, tenant identities, and owner names have been withheld throughout the manuscript, tables, and appendices, and are held only in a sealed file kept by the author. This treatment complies with the confidentiality practice adopted by comparable case-study work in the Saudi construction literature and is unavoidable in this segment. It does, however, prevent third-party verification of the case-level data, and this limitation is addressed in §6.3.

• *Sample Projects*

Table 2 The Ten Anonymised Projects, by Use, Sub-Type, General District, Gross Floor Area, and Hand-Over Year.

Code	Occupancy / use	Sub-type	District (Riyadh)	GFA (m ²)	Hand-over
P-01	Commercial office	Corporate HQ, low-rise	Central business	620	2023
P-02	Retail unit	Instant-license shop	Central	180	2024
P-03	Commercial services	Ground-floor services	South-west	310	2023
P-04	Healthcare	Outpatient clinic complex	East	420	2024
P-05	Mixed-use	Residential over commercial	North	2,150	2025
P-06	Food and beverage	Casual-dining restaurant	West	260	2024
P-07	Healthcare	Dental clinic	Central-north	195	2024
P-08	Light industrial	Vehicle service workshop	Old industrial	540	2023
P-09	Healthcare retail	Community pharmacy	North	150	2024
P-10	Education	Vocational training center	North-west	1,180	2025

➤ *The FPSAI Scoring Instrument*

The Fire-Protection Sustainability Alignment Index (FPSAI) is a four-axis scoring instrument built for this study. Each axis is inspired by — but does not replicate — one of the LEED v4.1 credit categories identified in Table 1, and uses a single quantitative indicator that could be extracted from the

material submittal or the manufacturer's technical data sheet without laboratory testing. The instrument was kept intentionally simple so that a single consultant can apply it at the specification stage within the fee constraints typical of small- and medium-scale projects in Riyadh.

Table 3 Structure of the FPSAI Scoring Instrument. Every Axis is a Proxy by Design; None Reproduces the Corresponding LEED Credit Procedure in Full (See the Scope Statement).

#	Axis	Indicator used	LEED intent echoed	Weight	Proxy?
1	Recycled content (MR-inspired)	% recycled content in piping and fittings, drawn from EPD or supplier declaration	MR: sourcing of raw materials	30%	Yes
2	VOC content (EQ-inspired)	Declared VOC content (g/L) of firestop sealants and intumescent coatings	EQ: low-emitting materials — content limb only	25%	Yes

3	Clean-agent GWP (EA-analogy)	GWP of the installed clean-agent extinguishing medium, or absence thereof	EA: refrigerant / atmospheric impact (analogy)	25%	Yes
4	Test-water loss (WE-inspired)	Annual water loss (L/yr) from wet-system periodic testing; capture/reuse present or not	WE: process-water efficiency	20%	Yes

- *Axis 1 (MR-Inspired) — Recycled Content*

The MR credit that this axis echoes rewards a minimum count of permanently installed products from manufacturers with responsible-sourcing information at the project cost level; recycled content is one of several inputs [24]. The FPSAI simplifies aggressively: it scores a single, physically meaningful quantity — the recycled-content fraction of the dominant piping family in the project — on a 0–100 scale linear in the percentage ($C1 = 2 \times \% \text{recycled}$, capped at 100). A project could score well on Axis 1 and still not earn the MR credit, and vice versa.

- *Axis 2 (EQ-Inspired) — VOC Content, not Emissions*

The EQ Low-Emitting Materials credit for wet-applied sealants requires that a product meet both a VOC content limit (typically the SCAQMD Rule 1168 category [25]) and a VOC emissions evaluation under CDPH v1.2 [6, 26]. The FPSAI captures only the first limb — VOC content in g/L — because emissions data is not consistently available on Riyadh-market products at the specification stage. Scoring is banded: $\leq 50 \text{ g/L} \rightarrow 95\text{--}100$; $51\text{--}100 \rightarrow 80\text{--}95$; $101\text{--}200 \rightarrow 55\text{--}80$; $201\text{--}250 \rightarrow 20\text{--}55$; $> 250 \rightarrow 10\text{--}20$. Unlabelled local products with no data sheet are scored 10 by convention. A high FPSAI score on this axis is a necessary but not sufficient condition for the LEED credit itself.

- *Axis 3 (EA-Analogy) — Clean-Agent GWP*

The USGBC EA Enhanced Refrigerant Management credit is written for HVAC&R equipment [27]; clean-agent extinguishing systems are outside its primary scope. We include an EA-analogy axis in the FPSAI because clean-agent GWP is a sustainability-relevant quantity for the fire-protection scope, and because SBC 801 references clean-agent selection in its own material-selection guidance. Scoring is: agent GWP $\leq 10 \rightarrow 100$; $11\text{--}150 \rightarrow 85$; $151\text{--}1,000 \rightarrow 40$; $1,001\text{--}2,500 \rightarrow 25$; $> 2,500 \rightarrow 20$; no clean-agent system installed $\rightarrow 85$ (interpreted as "no atmospheric-life burden created").

The "no-agent = 85" convention has a known artefactual effect, which is examined in Section IV.A.3: eight of the ten sampled projects had no technical requirement for a clean-agent system, so this convention elevates the sample-mean Axis-3 score by construction. For transparency and reproducibility, Axis 3 is reported twice in the results: once for the whole sample with the convention applied, and once for the sub-sample of projects that actually installed a clean-agent system.

- *Axis 4 (WE-Inspired) — Periodic-Test Water Losses*

Axis 4 scores a binary infrastructure feature — whether the project has any capture/reuse arrangement for the water discharged during NFPA-25 periodic testing — moderated by the estimated annual volume. Capture-and-reuse present, discharging to landscape or fire tank $\rightarrow 90$; capture only, discharging to potable $\rightarrow 60$; no capture (direct discharge to storm drain) $\rightarrow 5$, regardless of estimated volume. Every project in the present sample fell in the last band, so Axis 4 does not vary within the sample. The absence of variance across all ten projects indicates a common infrastructure pattern within this sample. However, it also means that Axis 4 does not discriminate between projects in this study, so comparative rankings (Section IV.B, Section V) are effectively driven by Axes 1–3. This limitation is noted wherever within-sample rankings are reported.

- *Practical Contribution: FPSAI as a BOQ and Supervision-Contract Annex*

The FPSAI was also designed for practical use beyond the research setting. As field supervisor on the ten included projects, the author observed that most alignment failures were not the result of a considered trade-off but of the absence of any structured checkpoint at the moment of material submission. Accordingly, we propose that the FPSAI be embedded operationally in two documents that already sit on every project file:

Table 4 Proposed Operational Insertion of the FPSAI Matrix into the Standard Project-Delivery Documents.

Document	Proposed insertion point	Function of the FPSAI entry
Bill of Quantities (BOQ)	New annex titled "Fire-Protection Sustainability Alignment Schedule," cross-referenced from every fire-protection line item.	Binds the contractor at bid stage to a minimum per-axis FPSAI score, priced into the unit rate rather than treated as a variation later.
Supervision contract	New clause under "Consultant duties — pre-installation review," listing FPSAI scoring as a mandatory activity before submittal approval.	Makes the consultant contractually responsible for scoring each submittal against the FPSAI and rejecting materials that fall below the agreed per-axis threshold.
Material submittal template	New footer block reproducing the four FPSAI axes and their thresholds.	Forces the supplier to enter recycled-content, VOC content, GWP, and water-loss values on the same page as the technical data.

- *Estimated Overhead of Applying the FPSAI in Practice*

Adopting the FPSAI as a BOQ annex and supervision clause imposes an additional workload on the consultant and

the contractor. On the basis of the pilot application across the ten included projects, we estimate this overhead as: (i) approximately 3–4 hours per project for the consultant to score

the four axes at submittal review, assuming the manufacturer's data sheets are already on file (i.e. one billable half-day at prevailing Riyadh consultancy rates, $\approx$ 900–1,200 SAR); (ii) approximately 1 hour per submittal cycle for the contractor to populate the new footer block on the submittal template; and (iii) a one-off $\approx$ 40-hour tooling effort at the municipality or professional-association level to publish a validated scoring worksheet, an item that is a public good and does not recur per project. Set against the $\approx$ 1.8% project-level greener-material premium documented in Section IV.C, the FPSAI overhead is at the noise level of the contract sum on projects above $\sim$ 500 m², and can plausibly be internalised within the existing supervision fee for smaller projects. A full cost-benefit study, calibrated to actual observed alignment gains, is a future-work item (R10).

➤ Scoring Rule

Each project receives a composite score S computed as:

$$S = \sum (W_i \times C_i)$$

The composite S is banded as: excellent $\geq$ 80; good 60–79; acceptable 40–59; poor 20–39; non-aligned $<$ 20. These bands are FPSAI bands, not LEED bands, and are defined only for interpretation of composite scores within this study.

➤ Weight Elicitation and Validity — a Candid Statement

Weights on the four axes were derived through a small AHP-lite exercise: five practitioners (three LEED-APs and two Civil-Defence-certified fire engineers) provided pairwise judgments on the relative importance of the four axes for a hypothetical small- and medium-scale project. The exercise yielded the weights reported in Table 3. The consistency ratio of the aggregated pairwise-comparison matrix was 0.06, within Saaty's [28] conventional 0.10 threshold for internal AHP consistency.

Two limitations of this calibration should be acknowledged openly. First, five experts is a small panel: it is sufficient for a first-pass AHP-lite calibration of a proxy instrument but is not a substitute for the larger multi-round Delphi validation that a mature scoring instrument would require. Second, the four FPSAI axes are heterogeneous — they measure very different underlying constructs (a percentage of recycled steel is not conceptually comparable to a VOC concentration in g/L or an atmospheric GWP) — and

they are not intended to form a single latent construct; internal-consistency statistics designed for reflective psychometric scales (e.g. Cronbach's α) are therefore not appropriate to this instrument and are not reported.

Face and content validity of the instrument were checked by circulating it to the same five experts, one of whom (a MEP consultant with LEED-BD+C experience on three Riyadh mega-projects) recommended clarifying the units of Axis 2; that change was adopted. Robustness of the composite to the elicited weights is addressed quantitatively in Section IV.B by sensitivity analysis. A full validation of the instrument — larger Delphi panel, independent second-rater on field data, test–retest reliability, and calibration against projects with independently verified LEED credit outcomes — is deferred to future work (R10).

➤ Ethics Statement

Ethical approval was obtained for this study. Informed consent was obtained from all participating project owners and from the seven contractors and supervising engineers interviewed for the study. Participants were informed of the research purpose and the anonymisation arrangements before participation. Approving committee or institutional review board: [TO BE PROVIDED]; approval/project identification code: [TO BE PROVIDED]; approval date: [TO BE PROVIDED].

IV. RESULTS

➤ Materials Actually Installed

The submittal review and site visits gave a fairly consistent picture across the sample. Piping fell into three families: Schedule-40 black steel (P-01, P-05, P-08, P-10), galvanised steel (P-03, P-06), and CPVC of the BlazeMaster type (P-02, P-04, P-07, P-09). Firestop products were dominated by a small set of readily available brands, and in three cases (P-03, P-06, P-08) the material actually applied was an unbranded local silicone sealant that carried no VOC label at all. Only two projects included any clean-agent extinguishing system: P-01 for a small server room, and P-05 for an electrical control room. Neither of the workshops (P-08, and the mechanical room of P-10) used clean agents; both relied on portable CO₂ and dry-chemical units.

• Axis 1 (MR-Inspired) — Recycled Content of Piping

Table 5 Axis 1: Recycled Content of Installed Fire-Protection Piping. Within-Sample Mean $C1 = 29.6$ (SD 18.3).

Code	Pipe family	Nominal recycled content	Source	C1 (0–100)
P-01	Black steel Sch40	22%	EAF-partial	44
P-02	CPVC BlazeMaster	$\leq$ 5%	Virgin resin	10
P-03	Galvanised steel	18%	EAF-partial	36
P-04	CPVC BlazeMaster	$\leq$ 5%	Virgin resin	10
P-05	Black steel Sch40	28%	EAF-partial	56
P-06	Galvanised steel	15%	EAF-partial	30
P-07	CPVC BlazeMaster	$\leq$ 5%	Virgin resin	10
P-08	Black steel Sch40	20%	EAF-partial	40
P-09	CPVC BlazeMaster	$\leq$ 5%	Virgin resin	10

P-10	Black steel Sch40	25%	EAF-partial	50
------	-------------------	-----	-------------	----

• *Axis 2 (EQ-Inspired) — VOC Content of Firestop and Intumescent Products*

Axis 2 scores VOC content only (see Section III.C.2); it does not assess emissions. Table 6 summarises the products actually used. Where the manufacturer's data sheet reported a

range, we recorded the upper bound. Local unbranded sealants without a data sheet were scored 10 by the convention in §3.3.2.

Table 6 Axis 2: Declared VOC Content Only. Within-Sample Mean C2 = 45.3 (SD 36.3).

Code	Firestop / intumescent product	Type	VOC (g/L)	C2 (0–100)
P-01	Branded intumescent sealant, standard grade	Silicone-based	185	70
P-02	Branded firestop spray, standard grade	Water-based	295	20
P-03	Unbranded local sealant, no data sheet	Silicone	> 400	10
P-04	Branded firestop foam, standard grade	PU foam	220	55
P-05	Branded firestop, low-VOC grade	Latex	45	95
P-06	Unbranded local silicone	Silicone	380	10
P-07	Branded firestop, ultra-low-VOC grade	Water-based	18	98
P-08	Unbranded local sealant, no data sheet	Silicone	> 400	10
P-09	Branded intumescent sealant, standard grade	Silicone	185	70
P-10	Mixed: unbranded sealant + standard foam	Mixed	310	15

• *Axis 3 (EA-Analogy) — GWP of Clean-Agent Extinguishing Media*

Only two of the ten projects were technically obliged to install a clean-agent system (Table 7). The remaining eight relied on portable extinguishers — CO₂ and dry-chemical units,

consistent with Section IV.A; these were scored under the "no clean-agent system" convention introduced in §3.3.3.

Table 7 Axis 3: clean-agent GWP. Sample-mean C3 with the whole-sample convention = 80.0; when the eight "no-agent" projects are excluded, mean C3 of the two-project sub-sample that actually installed a clean-agent system = 60.0. Both values are reported so that the artefactual effect of the convention is fully visible.

Code	Agent installed	Chemistry	GWP	C3 (0–100)
P-01	HFC-227ea	Halocarbon	3,220	20
P-05	FK-5-1-12 (Novec 1230)	Fluoroketone	1	100
Others (×8)	No clean-agent system; portable CO ₂ + dry chemical	n/a	n/a	85

• *Axis 4 (WE-Inspired) — Water Losses in Periodic Testing*

NFPA 25 requires periodic inspection, testing, and maintenance of water-based fire-protection systems; capture or reuse of discharged test water is treated here as a study-specific sustainability measure rather than an NFPA requirement [14]. Across the ten small- and medium-scale projects in this study, without exception, discharge water was released directly to the municipal storm drain. Estimated annual losses ranged from about 800 L for the smallest projects to just under 12,000 L for P-05. All ten cases therefore score C4 = 5. As noted in Section III.C.4, this axis has zero variance in the present sample: it contributes a fixed 1.0-point downward offset to every

composite score and does not affect the within-sample ranking of projects.

➤ *Composite FPSAI Scores, Distributions, and Sensitivity*

Table 8 Composite FPSAI alignment scores within the ten-project sample. Sample mean S = 41.2 (SD 10.4); 95% CI [33.8, 48.6] under a Student-t assumption; median 37.9. All figures are within-sample descriptive statistics. The 95% interval is reported only as a descriptive reference interval under the stated Student-t assumption for this purposive sample; it should not be interpreted as a population confidence interval.

Table 8 Composite FPSAI Alignment Scores Within the Ten-Project Sample

Code	C1 (MR)	C2 (EQ)	C3 (EA)	C4 (WE)	S (FPSAI)
P-01	44	70	20	5	36.7
P-02	10	20	85	5	30.3
P-03	36	10	85	5	35.6
P-04	10	55	85	5	39.0
P-05	56	95	100	5	66.6
P-06	30	10	85	5	33.8
P-07	10	98	85	5	49.7
P-08	40	10	85	5	36.8
P-09	10	70	85	5	42.8

P-10	50	15	85	5	41
------	----	----	----	---	----

Figures 1 and 2 present the within-sample distribution of axis scores and the composite S. Figure 1 (radar) shows that P-05 is the only project with substantive scores on more than one

non-trivial axis; the remaining nine projects are heavily lopsided, typically scoring on Axis 3 by convention (no clean agent) and on one of the material axes but not both.

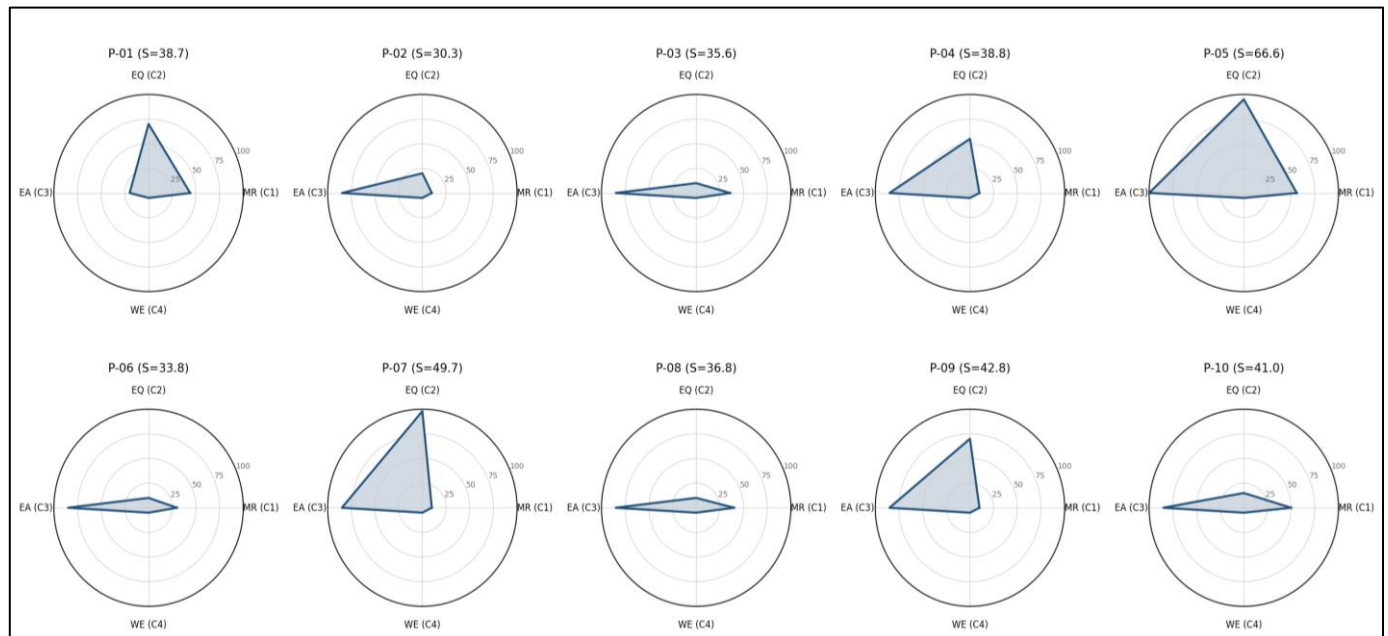


Fig 1 FPSAI Axis Profile for Each of the Ten Sampled Projects. Only P-05 shows Substantive Scores Across Multiple Axes; the Remaining Projects are Heavily lopsided.

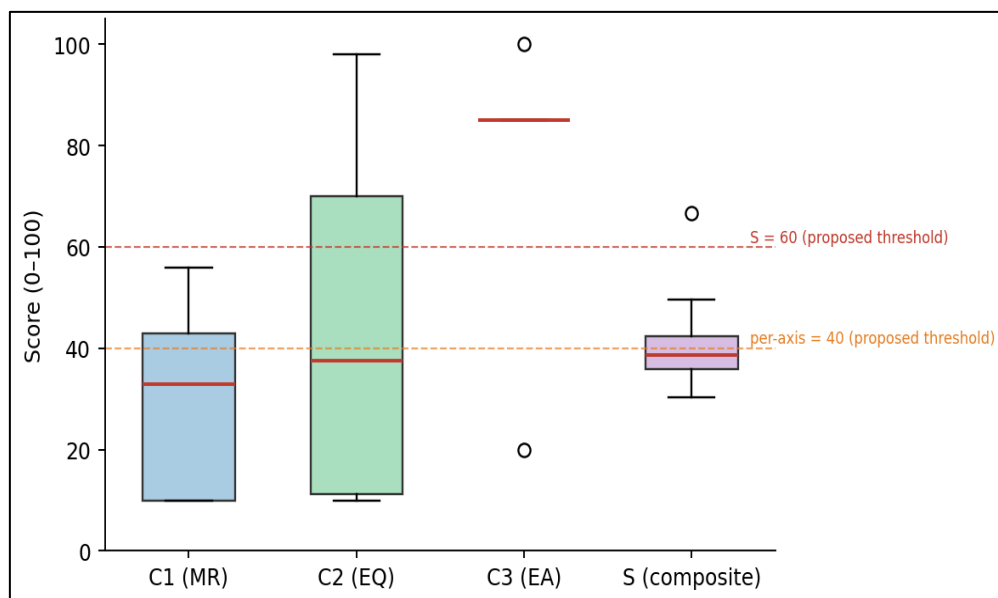


Fig 2 Within-Sample Distribution of Axis Scores and Composite S (n = 10). Dashed Lines Mark the Proposed per-Axis (40) and Composite (60) FPSAI Thresholds. Axis C4 is Omitted from the Box Plot Because it has Zero within-Sample Variance (all Projects = 5/100).

• Inter-Axis Correlations

Spearman rank correlations between the axes (Figure 3) show that Axes 1, 2, and 3 are effectively uncorrelated within this sample ($|\rho| \leq 0.16$), which is consistent with the design intent of the FPSAI as a set of orthogonal indicators rather than a single latent construct. The composite S is most strongly correlated with C2 ($\rho = 0.70$; nominal $p = 0.026$), less so with

C3 ($\rho = 0.47$) and C1 ($\rho = 0.19$), reflecting the wide within-sample variance on Axis 2 (SD 36.3) relative to the compressed distribution of Axis 3 (SD 21.6). Because the sample is purposive and $n = 10$, the p-value is presented only as a descriptive adjunct and is not used for population-level inference; the coefficients are likewise interpreted as within-sample descriptive features.

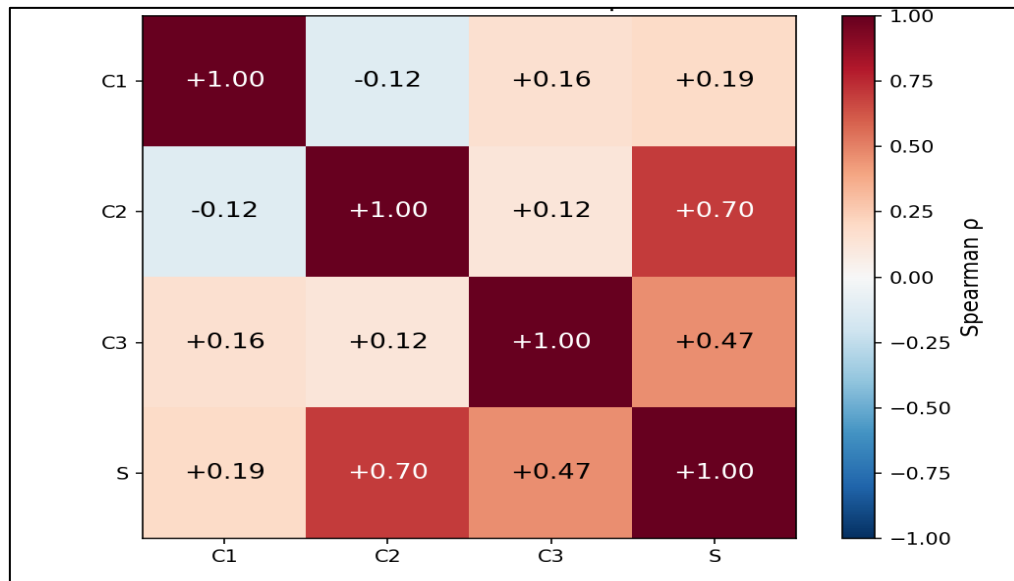


Fig 3 Spearman Rank Correlations Between FPSAI Axes and Composite S. The three Material Axes are Effectively Uncorrelated ($|\rho| \leq 0.16$), Consistent with the Design Intent of the FPSAI as a Set of Orthogonal Indicators.

- *Sensitivity of the Composite to the Elicited Weights*

Because the FPSAI weights were elicited from a small ($n = 5$) expert panel, the reported composite could in principle be sensitive to the specific weight values chosen. We tested this by perturbing each of the four axis weights by $\pm 10\%$ and $\pm 20\%$ of its baseline value (renormalizing so that $\sum W = 1$) and recomputing the sample-mean composite and the project ranking for each perturbation. Results are presented in Figure 4.

The sample mean is highly stable: across the $\pm 20\%$ envelope on any single weight, the mean composite S changes by at most 2.0 points (baseline 41.2; range 39.2–43.1), with the Axis 3 (EA) weight the most influential and the Axis 2 (EQ) weight the least. The ordering of projects is also stable, but not perfectly invariant: the Spearman rank correlation between

each perturbed ordering and the baseline ordering is at least 0.948 across all sixteen perturbations (mean 0.985). The extremes do not move at all — P-05 is first, P-07 second and P-02 last under every perturbation tested — and the reordering that does occur is confined to the tightly clustered middle of the distribution, where four projects (P-01, P-04, P-08, P-10) lie within 4.3 points of one another. The least stable case is P-01, which moves between fifth and ninth place: its Axis 3 score of 20 is the only low value on that axis in the sample, which makes its rank unusually sensitive to the EA weight. This robustness envelope therefore supports the reported sample-level statistics and the identification of the highest- and lowest-scoring cases, but it does not support fine-grained ranking claims among the mid-table projects. A much larger reweighting (e.g. reversing the relative importance of two axes) is not expected to be robust and was not tested.

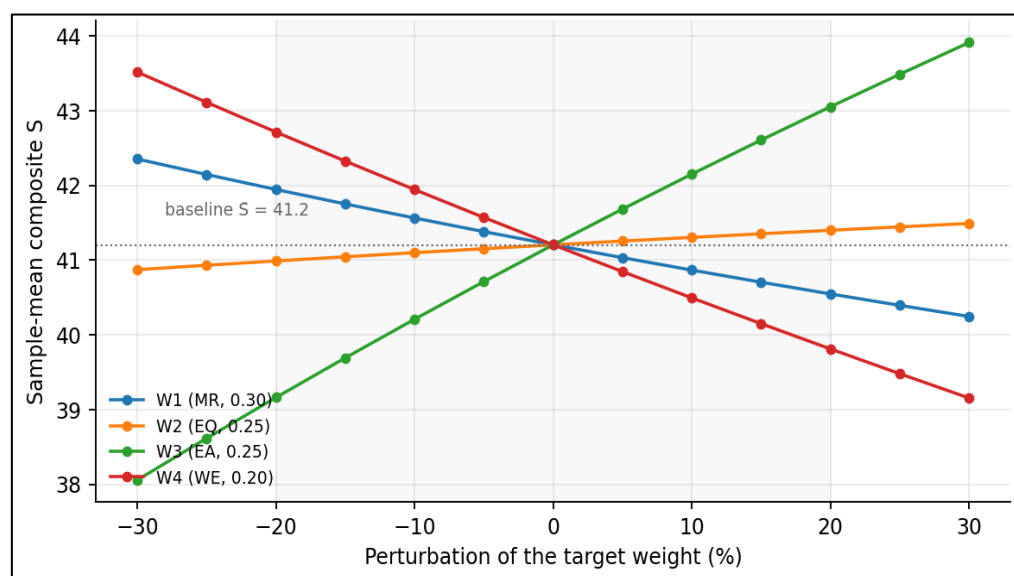


Fig 4 Sensitivity of the sample-mean FPSAI to weight perturbations, displayed over $\pm 30\%$ of each axis weight (shaded band = the $\pm 20\%$ envelope used for the reported robustness statistics). The sample mean stays within a ~ 2 -point band of the baseline; project ordering is highly stable but not strictly invariant (Section IV.B.2).

➤ Price Gap Analysis

To size the price gap between conventional and greener alternatives on each axis, we collected quotations from three of the largest fire-protection suppliers in Riyadh during the first quarter of 2025. Prices are in Saudi riyals and reflect quantities consistent with the small- and medium-scale segment (individual quantities below the mega-project bulk-tier

discount). We note explicitly that projects P-01 through P-10 were procured between 2022 and 2024, in a period of substantial cost volatility in steel and specialty chemicals; the Q1 2025 price snapshot should therefore be read as an order-of-magnitude reference for the item-level premium, not as the precise cost at each project's procurement date.

Table 9 Conventional and Greener item Prices, Riyadh Suppliers, Q1 2025.

#	Item family	Conventional (SAR)	Greener alternative (SAR)	Gap
1	Black steel Sch40 pipe, 4-inch, per L.M.	72	98	+36%
2	CPVC pipe, 2-inch, per L.M.	48	54	+12%
3	Firestop sealant cartridge, 300 mL	35	82	+134%
4	Intumescent coating, per kg	165	245	+48%
5	HFC-227ea agent, per kg	225	—	—
6	FK-5-1-12 agent, per kg	—	330	+47% vs HFC-227ea
7	Test-water capture and recycling unit	not installed	≈ 18,500 (one-off)	capital step

Aggregated to the project level, the greener bill of materials adds between 1.2% and 2.4% to total construction cost across the sample, with a within-sample mean of about

1.8%. This is well below the item-level premiums in Table 9 and, within this sample, below the perception of the price gap that appears to prevail in the local market (Figure 5).

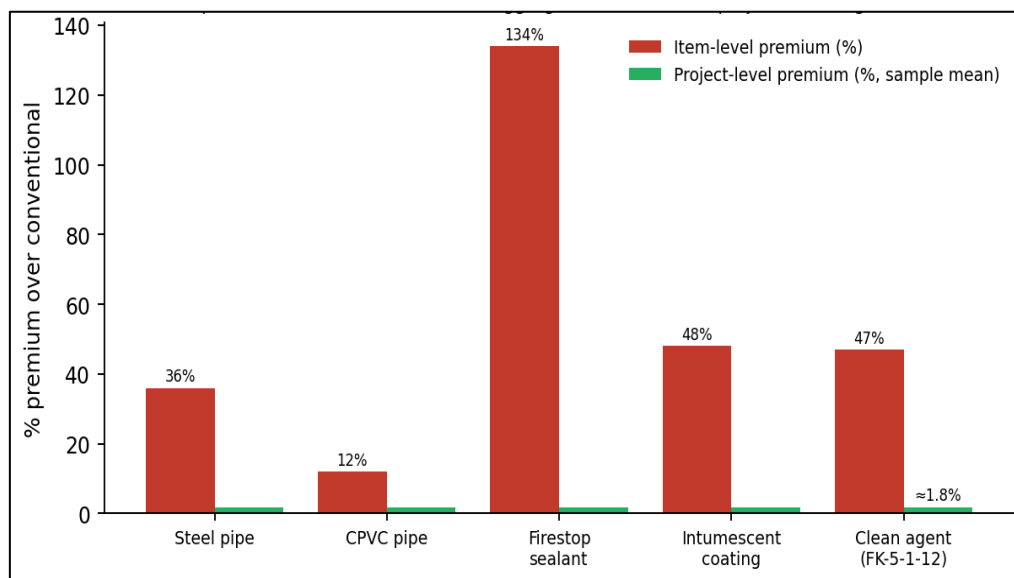


Fig 5 Item-level vs project-level premium of greener alternatives. Item-level premium can exceed 100%, but aggregated to the whole project it averages ≈ 1.8% within this sample.

➤ Contractual and Regulatory Factors — as Reported by the Interviewed Cohort

Seven contractors and supervising engineers were interviewed. All seven identified the absence of a contractual specification for environmental performance as the primary reason for defaulting to conventional materials. Five cited the price premium as a secondary factor; four mentioned the difficulty of sourcing EPD-backed firestop products locally; and three mentioned limited technical familiarity with LEED itself. Ranked by frequency within this small qualitative cohort, then, the reported barriers are: contract > price > supply > awareness. A cohort of seven cannot support a claim about the Saudi market as a whole; the ordering is offered as an exploratory qualitative finding to be tested in future work.

V. DISCUSSIONS

Within the ten-project sample, the mean FPSAI alignment score of 41.2/100 sits at the lower edge of the "acceptable" band of the instrument, and the pattern is remarkably consistent across occupancy types. Clinics, restaurants, retail, and light-industrial projects converge on roughly the same alignment level; within this small exploratory sample, this pattern is consistent with procurement practices being an important influence, but it does not exclude an effect of building type. The one outlier, P-05 at 66.6/100, is also the only project in the sample whose tender package made an explicit reference to LEED, even though it was not pursuing formal certification. This is a single case and does not itself establish causation; but it defines a hypothesis worth testing on a larger sample: does the presence of an explicit LEED

reference in a tender document, even absent formal certification intent, systematically raise the sustainability profile of the installed fire-protection materials in this segment?

Axis by axis, the WE-inspired score is uniformly the weakest — a floor value across all ten projects. Test-water capture is a capital item rather than a per-unit substitution, and no small- and medium-scale project we examined had provisioned for it. The equipment need not always be sophisticated: the $\approx 18,500$ SAR figure in Table 9 refers to a complete capture-and-recycling unit, whereas an estimated $\approx 2,500$ SAR basic tank-and-pump arrangement would represent a lower-specification capture option for a project the size of P-04 or P-07. Because these two configurations differ materially in function and specification, the figures should not be read as contradictory price estimates for the same system. The absence of capture equipment across all ten cases may reflect specification practice as well as cost and other project constraints; the present sample cannot isolate a single causal factor. Because Axis 4 shows zero variance in this sample, however, its contribution to the composite is a fixed offset; the systemic finding (no capture on any of the ten projects) does not translate into within-sample discrimination and every ranking discussed below is effectively driven by Axes 1–3.

The apparently high whole-sample mean for the EA-analogy axis ($C3 = 80.0$) is largely a consequence of the scoring convention described in §3.3.3. Most small- and medium-scale buildings simply do not have a server room or a switchgear room large enough to justify a clean-agent system, and the "no clean-agent installed" convention rewards them by construction. Restricted to the two-project sub-sample that actually installed a clean-agent system, the mean drops to 60.0, and the two projects illustrate the real choice on this axis: P-01 used HFC-227ea, still the industry default; P-05 used FK-5-1-12, at roughly a 47% price premium per kilogram but with a GWP three orders of magnitude lower (see also Loo et al. [29] on comparative agent selection). Absent an explicit specification, P-05's choice is the exception.

The price-gap data deserves a careful reading. At the item level, the +134% premium for low-VOC firestop sealants looks prohibitive, and it is often cited by contractors as the reason for skipping the low-VOC grade. Rolled up to the project level, however, the greener substitution adds around 1.8% to total construction cost — a figure that would be comfortably absorbed at the design stage but becomes very hard to add later. The economic argument for the default choice, within this sample, weakens once the frame of reference shifts from the line item to the project (Figure 5). This finding parallels the international convergence trend documented by Kibert [21] but stands in tension with our own observation that the local firestop premium (+134%) is still much higher than the ~ 15 –25% global-market premium reported in recent trade surveys, suggesting the Riyadh market has not yet fully caught up on this specific product family.

For the proposed operational thresholds (per-axis ≥ 40 , composite ≥ 60), the observed distribution shows that: (i) 4 of 10 projects meet the per-axis threshold on Axis 1, 5 of 10 on Axis 2, and 9 of 10 on Axis 3 (with the "no-agent" convention);

(ii) 1 of 10 meets the composite threshold of 60. The composite threshold therefore selects the top decile of the observed distribution — a deliberately ambitious but achievable target, given that at least one project in the natural sample crossed it without explicit incentive. A lower composite threshold (e.g. 45–50) would select approximately the top third of the sample; a composite score of 60 is proposed as the longer-term regulatory target (R2), while 45 is proposed as a transitional target for early adoption. These thresholds are FPSAI thresholds, not LEED thresholds.

The anonymisation framework may also help explain why data from Saudi small- and medium-scale projects is under-represented in the literature. Owners in this segment are understandably reluctant to associate their facilities publicly with any indication of shortfall against a voluntary standard, particularly when it might be misread as a life-safety shortfall. A confidentiality-first design, of the sort adopted here, is likely a prerequisite for building any larger empirical base in this segment.

VI. CONCLUSIONS AND RECOMMENDATIONS

➤ Conclusions

- Within a purposive sample of ten small- and medium-scale Riyadh projects, the mean FPSAI alignment score of installed fire-protection materials was 41.2/100 (SD 10.4). This is an exploratory descriptive result, not a market-level compliance claim.
- The most frequently reported driver of low alignment, within the interviewed cohort of seven contractors and consultants, was the absence of a contractual specification for environmental disclosures — ahead of price. This ordering should be tested on a larger sample.
- Item-level price premiums for greener firestop products can reach +134%, but the aggregate project-level premium averaged 1.8% within this sample — a figure that would be comfortably absorbed at design stage.
- The WE-inspired axis was uniformly the weakest and has zero within-sample variance; the fix is a modest capital item that no sampled project had procured. The systemic absence is a finding in its own right.
- The FPSAI composite is robust to $\pm 20\%$ perturbations of the elicited weights: the sample mean changes by at most 2 points, and the ordering of the ten projects correlates at $\rho \geq 0.95$ with the baseline ordering in every perturbation tested, with the top and bottom cases unchanged throughout.
- The FPSAI is proposed for adoption as a numbered annex in the BOQ and as a pre-installation review clause in the standard supervision contract for future small- and medium-scale developments in Riyadh (Table 4). It is a proxy instrument for the sustainability intent of four LEED v4.1 credit categories and is not a substitute for a formal LEED assessment.

➤ *Recommendations*• *Regulatory*

- ✓ R1. Amend the Riyadh Municipality technical requirements for commercial and healthcare buildings above 150 m² to require environmental disclosures (EPDs, HPDs) for all fire-protection materials on the submittal register.
- ✓ R2. Introduce a tiered incentive — for instance, a partial rebate on operating-license fees — for projects that achieve at least 60/100 on the FPSAI composite, with a transitional target of 45/100 during the first two years of adoption.

• *Contractual*

- ✓ R3. Publish a model annex to the standard construction contract that obliges the contractor to supply EPD- and HPD-backed materials for the fire-protection scope before delivery to site.
- ✓ R3a. Adopt the FPSAI matrix (Table 3) as a numbered annex to the Bill of Quantities on every fire-protection package, cross-referenced from each priced line item, with minimum per-axis (≥ 40) and composite (≥ 60) thresholds priced into the unit rate at bid stage.
- ✓ R3b. Add a clause to the standard supervision contract obliging the consultant to score every fire-protection material submittal against the FPSAI before approval, and to withhold approval for any submittal that falls below the thresholds in R3a; the Visual Site Verification protocol (Section III.A.2) should be the mechanism for closing the paper-approval-vs-installation gap.
- ✓ R4. Attach a modest liquidated-damages clause to non-compliance, in line with the mechanism already used for Civil-Defence-relevant deviations.

• *Design and Specification*

- ✓ R5. Include a basic test-water capture and reuse tank in the standard fire-protection package for all small- and medium-scale projects with an annual pump test.
- ✓ R6. Adopt low-VOC firestop sealants and coatings — at minimum the content limb, and, where product data is available, the emissions limb — as the default specification in Section 07 84 00 (Firestopping).
- ✓ R7. Use performance-based design to resolve any residual conflict between LEED intent and NFPA requirements rather than defaulting to the more conservative choice by silence [7, 8].

• *Further Research*

- ✓ R8. Extend the study to Jeddah and the Eastern Province to build a national baseline; the ten-project sample here is exploratory only.
- ✓ R9. Track price gaps in the Riyadh supplier market over a five-year horizon to test whether the international convergence trend [21] reaches the local firestop market.
- ✓ R10. Undertake a full validation of the FPSAI: an expanded multi-round Delphi panel for axis weights; an independent second-rater on the field data to compute inter-rater

reliability (Cohen's κ) on axis-level scoring; test–retest reliability across a re-scored sub-sample; and calibration against a cohort of projects with independently verified LEED credit outcomes so that the correspondence between FPSAI scores and formal LEED performance can be measured directly.

➤ *Limitations*

The study has seven limitations that should be read alongside its results. First, the FPSAI is a proxy instrument and is not — and does not claim to be — a LEED score; correspondence between FPSAI scores and formal LEED credit outcomes has not been directly validated (R10). Second, the sample is limited to ten projects in Riyadh, in a specific size band (120–2,500 m²), and to work completed between 2022 and 2025; results are within-sample descriptive statistics and should not be read as a characterisation of the Riyadh market as a whole. Third, the qualitative barrier ordering in Section IV.D is drawn from a cohort of seven interviewees and is best read as exploratory. Fourth, pricing data was drawn from three of the largest suppliers, and reflects a Q1 2025 snapshot applied retrospectively to projects procured across 2022–2024, a period of substantial cost volatility. Fifth, the anonymisation framework, although necessary to secure owner cooperation, prevents third-party verification of the case-level data. Sixth, Axis 4 has zero within-sample variance and therefore contributes no discrimination between projects in this study; the composite ranking is effectively driven by Axes 1–3. Seventh, the study uses a single-observer design: the same author collected data, executed the VSV protocol, and scored the FPSAI; scoring was blinded to project identity and follows a mechanical rubric, but no independent second rater was used and no inter-rater reliability metric could therefore be reported. Item R10 in Section VI.B addresses this.

➤ *Author Contributions*

The author conducted all the research work for this study. Mohammed Hussien Ali ElHaggar: Conceptualization, methodology, investigation, data curation, formal analysis, visualization, writing - original draft, and writing - review and editing.

➤ *Funding*

The author did not receive support from any organization for the submitted work. No funding, grants, or other financial support was received for the conduct of this study or for the preparation of this manuscript.

➤ *Competing Interests*

The authors have declared that no competing interests exist.

➤ *Data Availability Statement*

The anonymised project-level data supporting the findings of this study are described in the manuscript. Raw material submittals, supplier quotations, site photographs, and the FPSAI scoring worksheet are held by the author and may be shared on reasonable request, subject to participating owners' consent and confidentiality restrictions.

➤ *AI-Assisted Technologies Statement*

ChatGPT (OpenAI) was used solely to assist with manuscript formatting and presentation in accordance with the journal requirements. All scientific content, data, analyses, interpretations, references, and final wording were subsequently reviewed and verified by the author, who takes full responsibility for the final manuscript.

ABBREVIATIONS

AHP, Analytic Hierarchy Process; BOQ, Bill of Quantities; CDPH, California Department of Public Health; EA, Energy and Atmosphere; EPD, Environmental Product Declaration; EQ, Indoor Environmental Quality; FPSAI, Fire-Protection Sustainability Alignment Index; GWP, Global Warming Potential; HPD, Health Product Declaration; LEED, Leadership in Energy and Environmental Design; MR, Materials and Resources; NFPA, National Fire Protection Association; SBC, Saudi Building Code; VOC, volatile organic compounds; VSV, Visual Site Verification; WE, Water Efficiency.

SCOPE AND INTERPRETATION OF THE FPSAI

The FPSAI is an author-developed alignment index for four sustainability indicators of the fire-protection scope. It is not a LEED score, does not represent LEED credit achievement, and does not simulate a LEED v4.1 certification review. The USGBC rating system uses credit-specific procedures — project cost accounting, product counts, EPD/HPD documentation, and CDPH v1.2 emissions testing for the low-emitting-materials family — that the FPSAI does not attempt to reproduce. All references to FPSAI results in this paper should be read as evidence about the sustainability intent of installed fire-protection materials on four indicators, not as a proxy for a certification outcome. This scope statement is issued once here and is not repeated axis-by-axis in the sections that follow. Throughout this paper, “small- and medium-scale” refers to the study-defined project-size band used for sampling (120–2,500 m²) and should not be interpreted as an official Monsha’at enterprise classification.

REFERENCES

- [1.] Bin Mahmoud A, Alokili T, Akhtar S, Aljadhari S. Adoption of green building rating systems in Saudi Arabia: Barriers and solutions. *Sustainability*. 2025;17:11248.
- [2.] Sirr H, Alhassan Z, Hamid M. Data-driven insights into LEED certification trends: Saudi Arabia’s path to sustainability. *Proc Int Conf Contemp Aff Archit Urban*. 2025;8:247-252.
- [3.] Balabel A, Alwetaishi M. Towards sustainable residential buildings in Saudi Arabia according to the conceptual framework of “Mostadam” rating system and Vision 2030. *Sustainability*. 2021;13:793.
- [4.] Sustainable Building Program. Guides: Mostadam for residential buildings (D+C) and Mostadam for commercial buildings (D+C). Saudi Arabia: Sustainable Building Program; n.d.
- [5.] Dormohamadi M, Kanafani K, Birgisdottir H, Dragsted A, Hoxha E. Assessing environmental impacts of active fire protection and egress systems using environmental product declarations: A review. *Clean Environ Syst*. 2025;17:100280.
- [6.] US Green Building Council. LEED v4.1: Indoor environmental quality - low-emitting materials. Washington, DC: USGBC; 2020.
- [7.] Meacham BJ. Sustainability and resiliency objectives in performance building regulations. *Build Res Inf*. 2016;44:474-489.
- [8.] Frantzich H, McNamee M, Kimblad E, Meacham BJ. Decision support framework for sustainable and fire resilient buildings (SAFR-B). *Fire Technol*. 2025;61:213-246.
- [9.] Mohamed MAS, Ibrahim AO, Bashir FM, Chamman A, Gnaba H, Kadhim SI, et al. An assessment of the barriers to the adoption of green building technologies in Saudi Arabia. *Int J Low Carbon Technol*. 2023;18:872-880.
- [10.] Yin RK. Case study research and applications: Design and methods. 6th ed. Thousand Oaks, CA: SAGE Publications; 2018.
- [11.] US Green Building Council. LEED v4.1: Building design and construction reference guide. Washington, DC: USGBC; 2019.
- [12.] National Fire Protection Association. NFPA 13: Standard for the installation of sprinkler systems. Quincy, MA: NFPA; 2022.
- [13.] National Fire Protection Association. NFPA 20: Standard for the installation of stationary pumps for fire protection. Quincy, MA: NFPA; 2022.
- [14.] National Fire Protection Association. NFPA 25: Standard for the inspection, testing, and maintenance of water-based fire protection systems. Quincy, MA: NFPA; 2023.
- [15.] National Fire Protection Association. NFPA 72: National Fire Alarm and Signaling Code. Quincy, MA: NFPA; 2022.
- [16.] National Fire Protection Association. NFPA 2001: Standard on clean-agent fire extinguishing systems. Quincy, MA: NFPA; 2022.
- [17.] Saudi Building Code National Committee. SBC 801: Saudi Building Code - Fire protection requirements. Riyadh: SBCNC; 2018.
- [18.] Allahaim FS. From code to climate action: Evaluating the energy efficiency performance of the Saudi Building Code across climatic zones and its alignment with Vision 2030 sustainability targets. *Sustainability*. 2026;18:5459.
- [19.] Al-Homoud MS, Krarti M. Energy efficiency of residential buildings in the Kingdom of Saudi Arabia: Review of status and future roadmap. *J Build Eng*. 2021;36:102143.
- [20.] Charlier M, de Paula Filho JHM, Lucherini A. Environmental impact of structural fire engineering for sustainable building design: Current practices and future directions. *Fire Mater*. 2026;1-15.
- [21.] Kibert CJ. Sustainable construction: Green building design and delivery. 5th ed. Hoboken, NJ: John Wiley & Sons; 2022.

- [22.] Riyadh Region Municipality. Riyadh Region Municipality detects 70 violations of the Saudi Building Code and revokes the license of a violating engineering office. Riyadh: Riyadh Region Municipality; 2026.
- [23.] Monsha'at. Enterprises' classification. Riyadh: General Authority for Small and Medium Enterprises; 2023.
- [24.] US Green Building Council. LEED v4.1: Materials and resources - building product disclosure and optimization: Sourcing of raw materials. Washington, DC: USGBC; 2020.
- [25.] South Coast Air Quality Management District. Rule 1168: Adhesive and sealant applications. Diamond Bar, CA: SCAQMD; 2017.
- [26.] California Department of Public Health. Standard Method v1.2: Standard method for the testing and evaluation of volatile organic chemical emissions from indoor sources using environmental chambers. Richmond, CA: CDPH; 2017.
- [27.] US Green Building Council. LEED v4.1: Energy and atmosphere - enhanced refrigerant management. Washington, DC: USGBC; 2020.
- [28.] Saaty TL. Decision making with the analytic hierarchy process. *Int J Serv Sci*. 2008;1:83-98.
- [29.] Loo KH, Lee TS, Bee ST. A comparative review of IG-541 system use in total flooding application for energized electrical fire. *Processes*. 2025;13:485.