RINNO

Determinants of Energy Saving Technology Adoption by Architecture and Construction Firms

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1 Introduction

Buildings are responsible for over one-third of global final energy consumption and a comparable share of energy-related CO_2 emissions, making the sector pivotal to climate and energy-security goals. Even with improving energy intensity, absolute building emissions have not fallen fast enough because expanding floor area keeps outpacing efficiency gains. Deep renovation, therefore, sits at the heart of credible decarbonisation pathways.

The EU's recast Energy Performance of Buildings Directive (EPBD, Directive (EU) 2024/1275) sets a new trajectory: all new public buildings must be zero-emission from 1 January 2028, and all other new buildings from 1 January 2030, complemented by minimum energy performance standards (MEPS) for the worst-performing non-residential stock (bottom 16% by 2030 and 26% by 2033) and member-state renovation plans. The recast also introduces Renovation Passports, tailored, staged roadmaps to deep-renovate individual buildings. Together, these policies elevate deep renovation from "nice-to-have" to a market norm.

At the same time, the European Bank for Reconstruction and Development (EBRD) has updated its Environmental & Social Policy (2024) and Energy Sector Strategy (2024–2028) to align finance with Paris goals and accelerate green building investments via Green Economy Transition (GET) targets, risk-sharing instruments, and mainstreamed policy support in client countries. These frameworks increasingly rely on intermediated finance, guarantees and technology eligibility lists (the Green Technology Selector) to mobilise private capital for high-impact, replicable renovations.

Despite these initiatives, adoption of energy-saving technologies (ESTs) remains uneven. Prior studies highlight capital intensity, information failures, capability gaps, and organisational factors as binding constraints; conversely, cost savings, market pull, and policy support act as key drivers. However, evidence from decision-makers who actually sponsor and sign off on deep-renovation projects remains limited, particularly across roles (architects vs contractors), geographies (UK/US), and firm sizes. This preliminary study addresses these gaps.

We survey 155 decision-makers in the US and UK construction ecosystems (equal split by country and by profession). We quantify 20 barriers (5-point scale) built from prior validated instruments, and 16 drivers adapted from the industrial energy-efficiency literature; reliability is high ($\alpha = 0.887$ and 0.895). We also capture adoption stage and evaluation stage (3-item measure) to observe where organisations are on their journey.

Descriptively, respondents point to upfront capital, funds/material constraints, skills, technology maturity, information access, and system/data security as the most salient barriers; and to cost savings, market demand, rising energy prices, and access to information as leading drivers. Inferentially, barriers and drivers both correlate positively with adoption and evaluation, consistent with an "exposure effect" in which organisations further along in the process perceive more (not fewer) barriers. Profession, location, and firm size systematically moderate these relationships. These findings motivate a policy package that is segment-specific, finance-led, and information-rich, while guarding against digital/cyber risks that may grow as renovation technologies digitise.

2 Methodology and Sample

2.1. Methodology

A survey was developed with the aim of examining the barriers and drivers of EST adoption among key decision makers. The survey included items related to the respondent's personal characteristics, the organisation, and their personal perceptions regarding the barriers and drivers of EST implementation. The survey was developed by adapting validated scales for suitability to the research context. The survey was distributed to decision makers in organisations in the United States and the UK. While we acknowledge there are many stakeholders engaged in this context, we follow the approach of Du et al. (2014) and focus on two groups of stakeholders namely architects and construction contractors as they represent the groups most likely to be involved in the decision to implement energy saving technologies in the construction sector. Respondents were sourced and invited using Qualtrics panel services. Two attention traps were added to filter out unengaged responses. Incomplete responses were also filtered out by Qualtrics.

2.2. Sample

The data consisted of a total of 155 full responses from decision makers in organisations of varying sizes. In terms of the location of respondents, there was close to an equal split with slightly more respondents residing in the US (n=78/ 50.3%) compared to 75 respondents in the UK (49.7%). The sample was predominately male, with female respondents representing a mere 23.9% of the sample. Recent statistics report 10.9% of workers in the construction industry are female in the US (US Bureau of Labor statistics, 2022) and 15% are female in the UK (BBC, 2023). Thus, our sample is close to the current gender split of the industry. In terms of education, the sample was highly educated with 79.9% possessing a college degree. Respondents were broken into three age groups respondents aged 25-39 representing 52.3% of the sample (n=81), 40–49-year-olds accounting for 29.7% of the sample (n=46), and respondents aged 50+ accounting for the remaining 18.1% of the sample (n=28).

Of the sample, there was close to an equal split between architects (50.3%) and construction contractors (49.7%). Tenure in the organisation varied from 1-2 years (n=12 / 7.27%), 3-5 years (n= 62/ 40.0%), 6-9 years (n=37 / 23.9%), and 10+ years (n=44 / 28.4%). The large majority of respondents were experienced with 45.8% (n=71) stating they had over 10 years' work experience, a further 32.9% (n=51) had 6-9 years' work experience, 20.6% (n=32) had 3-5 years' work experience and only 0.6% or 1 respondent had 1 years' work experience. The majority of respondents were upper management (n=122 / 78.7%) or middle management (n=29 18.7%). This is important given the emphasis of our study on decision makers. Respondents represented organisations of varying size including micro-enterprises (less than 10 employees) which represented 16.8% of the sample, small enterprises (10-49 employees) accounting for 14.8% of the sample, medium enterprises (50-249 employees) representing 47.1% of the sample and large enterprises (over 250 employees) 21.3% of the sample. The characteristics of the sample are summarised in Table 6 below.

Table 1. Sample Characteristics

Characteristics	Category	N	%
Gender	Female	37	23.9%
	Male	118	76.1%
Age	25-39	81	52.3%
	40-49	46	29.7%
	50+	28	18.1%
Education	Primary School	3	1.9%
	Secondary School	28	18.1%
	Undergraduate degree	34	21.9%
	Postgraduate degree	83	53.5%
	PhD	7	4.5%
Location	UK	77	49.7%
	US	78	50.3%
Profession	Architect	78	50.3%
	Contractor	77	49.7%
Tenure	1-2 years	12	7.27%
	3-5 years	62	40.0%
	6-9 years	37	23.9%
	10+ years	44	28.4%
Rank	Non-management	2	1.3%
	Lower management	2	1.3%
	Middle management	29	18.7%
	Upper management	122	78.7%
Work Experience	1-2 years	1	0.6%
	3-5 years	32	20.6%
	6-9 years	51	32.9%
	Over 10 years	71	45.8%
Organization Size	Less than 10 employees	26	16.8%
	10-49 employees	23	14.8%
	50-249 employees	73	47.1%
	250+ employees	33	21.3%

3 Preliminary Analysis

3.1. Barriers to EST Adoption: Overall Sample

Barriers to EST implementation were measured using 20 items using a 5-point Likert scale ranging from 1 (“Definitely not a concern”) to 5 (“Definitely a concern”) based on Du et al. (2014), Arayici et al. (2018), and D'Oca et al. (2018). The mean and standard deviation for each barrier is illustrated below in Table 2. As shown, limited funds and material resources, high initial investment, and systems and data security represent the highest issues of concern among our respondents.

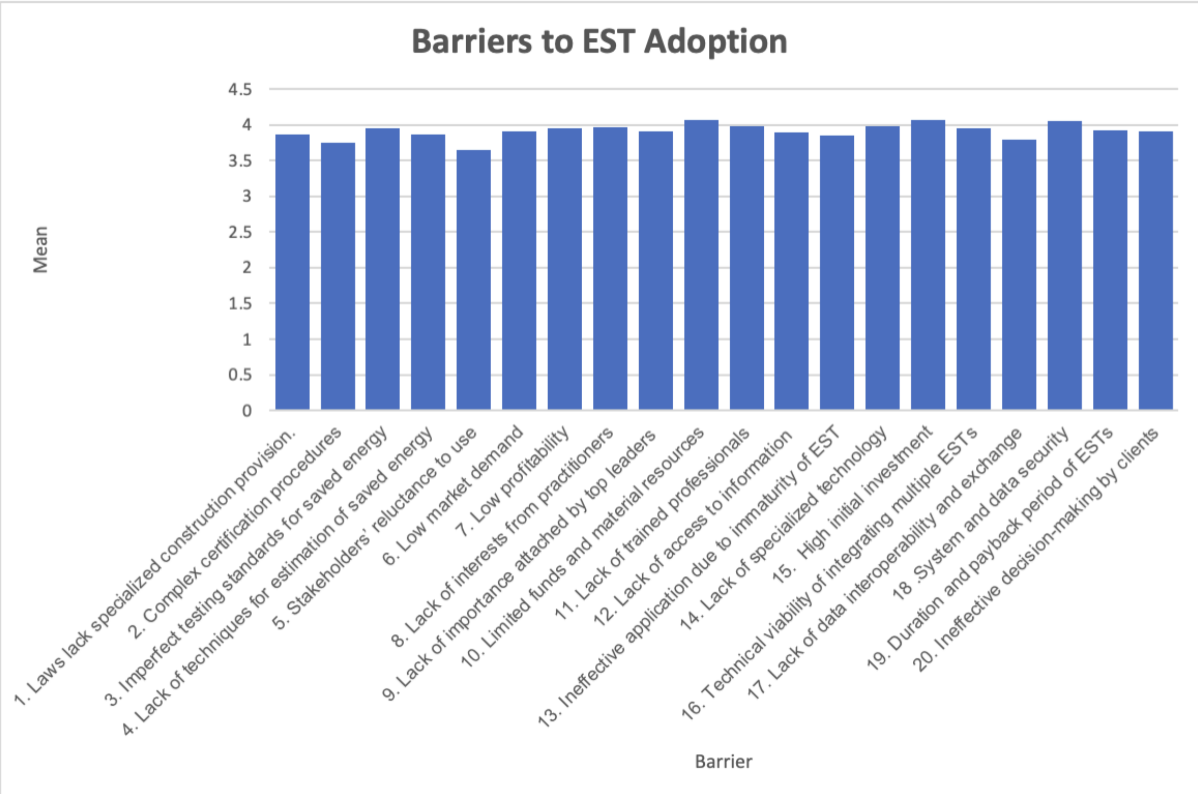

Figure 1 Barriers to EST Adoption

Table 2. Barriers to EST Adoption

Item	Mean	Std. Dev
B1. Some laws, regulations, policies and standards of energy-saving technologies lack specialized provisions for the building sector.	3.86	.841
B2. Complex certification procedures for subsidies and tax concessions	3.75	1.132
B3. Imperfect testing standards for saved energy	3.95	.900
B4. Lack of techniques and tools for estimation of saved energy	3.86	1.009
B5. Stakeholders' reluctance to use	3.65	1.102
B6. Low market demand	3.90	1.046
B7. Low profitability	3.95	.949
B8. Lack of interests from practitioners	3.97	.925
B9. Lack of importance attached by top leaders of enterprises	3.90	.924
B10. Limited funds and material resources	4.07	.927
B11. Lack of trained professionals	3.98	1.016
B12. Lack of access to information on costs and benefits of using energy-saving technologies	3.89	1.017
B13. Ineffective application due to immaturity of the technology	3.85	.854
B14. Lack of specialized technology for specific conditions	3.98	.963
B15. High initial investment	4.07	.954
B16. Technical viability of integrating multiple energy saving technologies	3.95	.931
B17. Lack of data interoperability and exchange	3.79	1.044
B18. System and data security	4.05	1.040
B19. Duration and payback period of energy saving technologies	3.92	.977
B20. Ineffective decision-making by clients	3.90	1.027

3.2. Drivers of EST Adoption: Overall Sample

Drivers of EST implementation were measured using 16 items using a 5-point Likert scale ranging from 1 (“Definitely not a driver”) to 5 (“Definitely not a driver”) based on Cagno et al. (2013). The mean and standard deviation for each barrier is illustrated below in Table 3. As shown, rising energy prices, cost savings, market demand, and access to information on long-term benefits represent the highest issues of concern among our respondents.

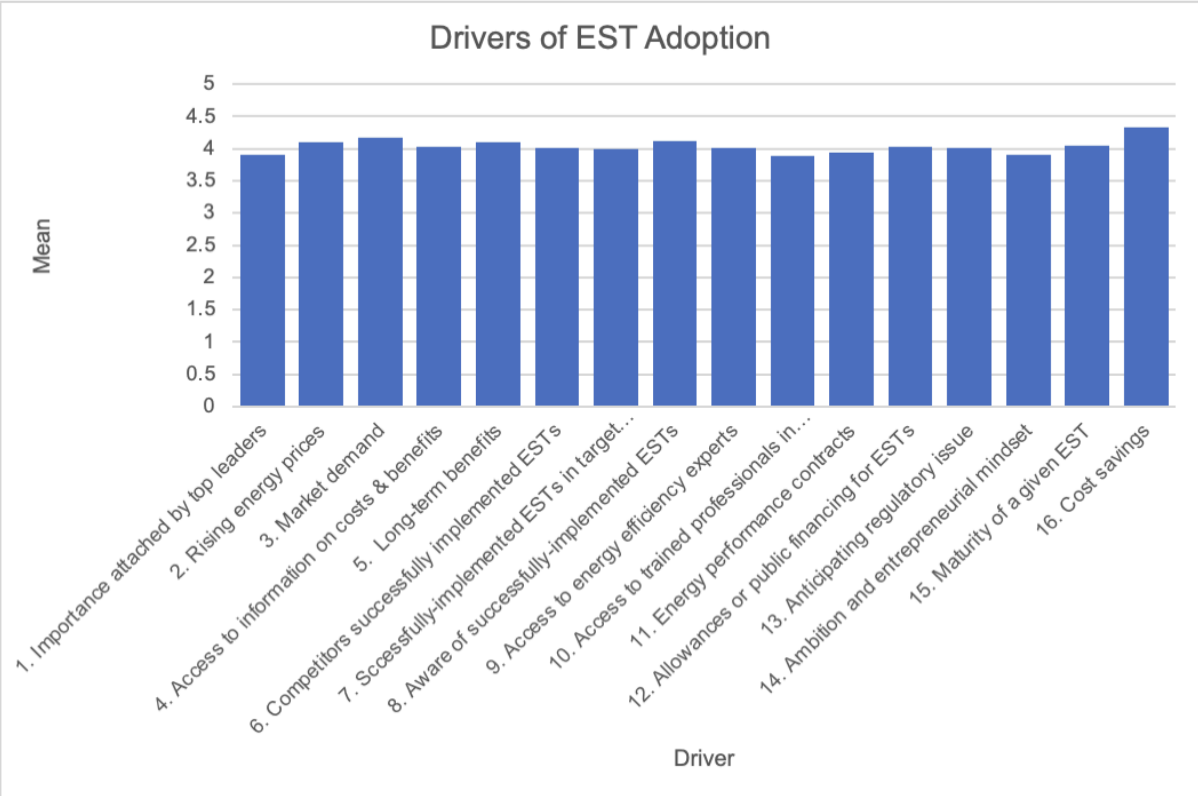

Figure 2 Drivers of EST Adoption

Table 3. Drivers of EST Adoption

Driver	Mean	Std. Deviation
D1. Importance attached by top leaders of enterprise	3.90	.874
D2. Rising energy prices	4.10	1.014
D3. Market demand	4.17	.903
D4. Access to information on the costs and benefits of using energy-saving technologies	4.03	.875
D5. Access to information on long-term benefits	4.10	.843
D6. Access to information on successfully implemented energy saving technologies by competitors	4.01	.883
D7. Access to information on successfully implemented energy saving technologies in target markets	3.99	.841
D8. Access to information on successfully implemented energy saving technologies	4.12	.797
D9. Access to energy efficiency experts	4.01	.912
D10. Access to trained professionals within your organisation	3.89	.991
D11. Energy performance contracts	3.95	.996
D12. Allowances or public financing for energy saving technologies	4.03	.946
D13. Anticipating regulatory issues and compliance with regulations	4.01	.993
D14. Ambition and entrepreneurial mindset	3.90	.945
D15. Maturity of a given energy saving technology	4.04	.904
D16. Cost savings	4.33	.838

3.3. Analysis by Profession

Following Du et al. (2014), we analysed the barriers to adoption based on the occupation of respondents. Respondents were divided into two groups based on occupation: architects and contractors. The differences among groups was explored for the drivers of EST adoption as shown below in Figure 3. In terms of the top drivers of EST adoption, there was strong overlap. The top 3 drivers for architects were market demand, allowances or public financing for ESTs, and cost savings. The top 3 drivers for contractors were market demand, awareness of successfully implemented ESTs, and cost savings.

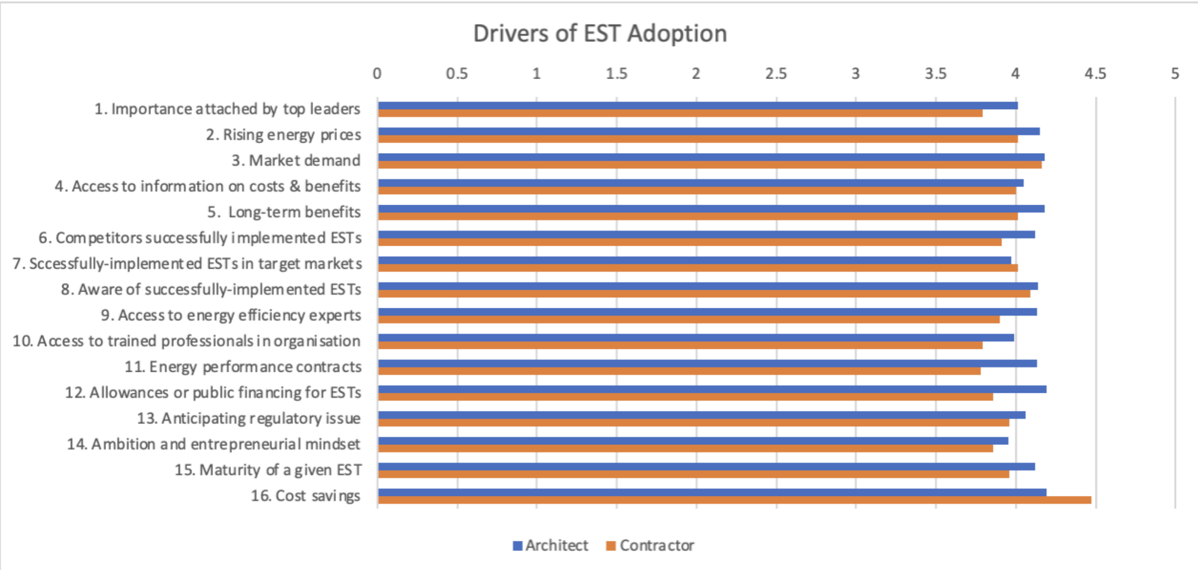

Figure 3 Mean scores for drivers based on occupation.

The top 3 barriers among architects were system and data security, lack of importance attached by top leaders, and limited funds and material resources. For contractors, the top 3 barriers were limited funds and material resources, lack of specialised technology, and high initial investment.

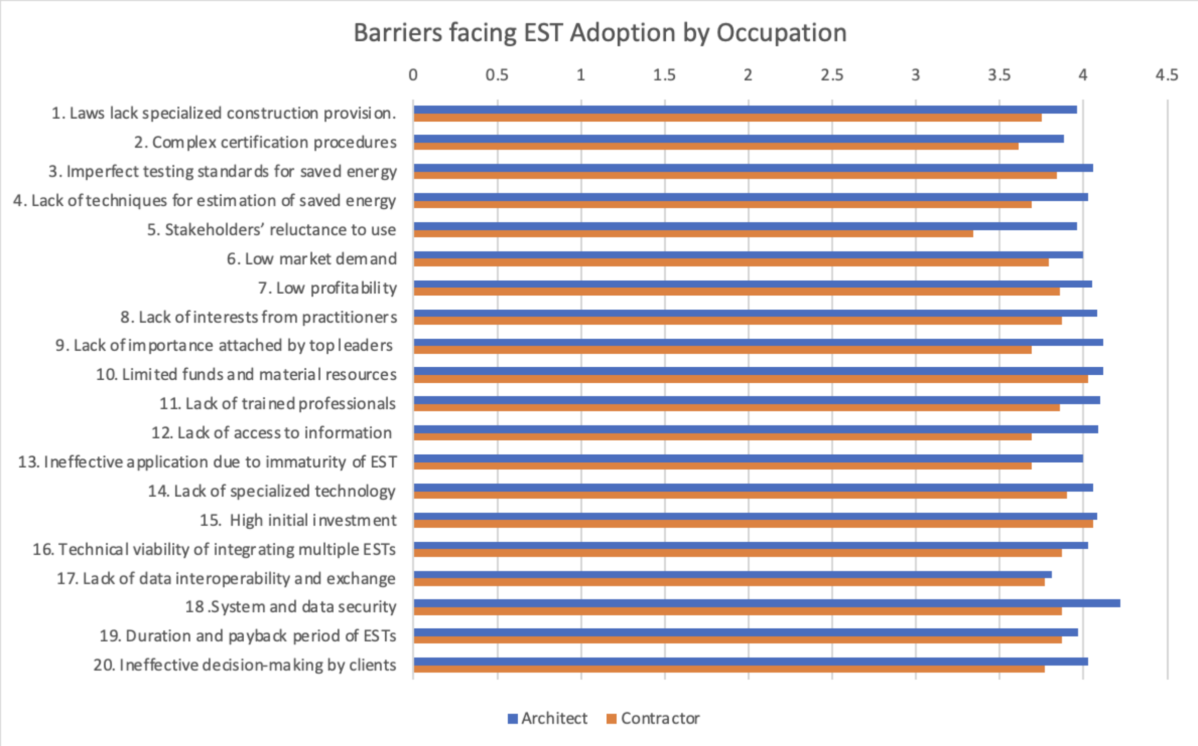

Figure 4 Mean Scores for barriers based on occupation

3.4. Analysis by Location

Analysis was also conducted to explore differences in the drivers and barriers based on the location of respondents. Again, respondents were divided into two groups; respondents located in the United Kingdom and respondents located in the United States. The top 3 drivers of EST adoption had some overlap. Among UK respondents, the top drivers were market demand, anticipating regulatory change, and cost savings, whereas in the US top drivers were market demand, awareness of successfully-implemented ESTs, and cost savings.

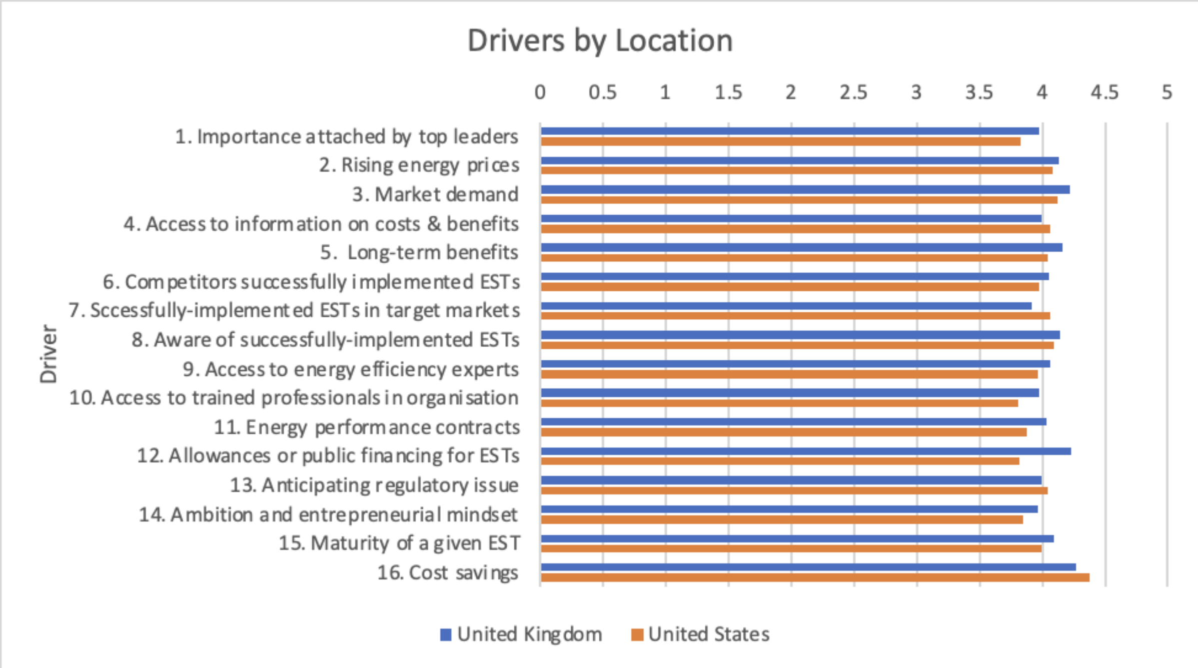

Figure 5 Mean scores for drivers based on location.

There were a number of differences in the barriers facing adoption based on the location of respondents. As can be seen from Figure 6 below, there were significant differences across most factors.

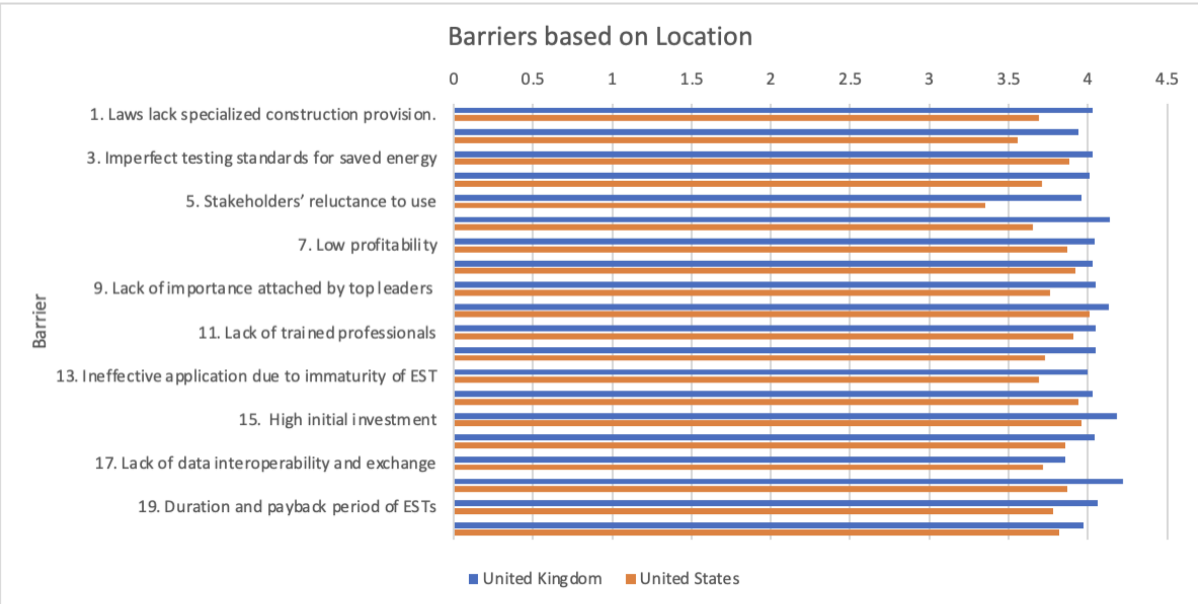

Figure 5 Mean scores for barriers based on location.

3.5. Analysis by Organisation Size

With respect to organisation size, there were some key differences among the drivers based on organisation size as outlined in Table 14 below. The top three barriers to EST adoption demonstrated some overlap and were as follows: micro-enterprises (D6, D7, D16), small enterprises (D16, D3, D8), medium enterprises (D2, D16, D3, D13, D15), and large enterprises (D3, D5, D16). Cost savings was a top 3 driver among organisations of all sizes.

Table 4. Mean scores for drivers based on organization size.

Driver	Micro-enterprises	Small enterprises	Medium Enterprise	Large Enterprise
1. Importance attached by top leaders	3.54	3.74	4.05	3.97
2. Rising energy prices	3.92	3.7	4.44	3.79
3. Market demand	3.92	4.17	4.26	4.15
4. Access to information on costs & benefits	3.81	3.78	4.16	4.06
5. Long-term benefits	3.88	3.91	4.22	4.12
6. Competitors successfully implemented ESTs	4	3.65	4.14	4
7. Successfully implemented ESTs in target markets	4.08	3.7	4.14	3.82
8. Aware of successfully implemented ESTs	3.96	4.13	4.21	4.03
9. Access to energy efficiency experts	3.77	3.74	4.22	3.94
10. Access to trained professionals in organisation	3.77	3.52	4.12	3.73
11. Energy performance contracts	3.65	3.61	4.15	4
12. Allowances or public financing for ESTs	3.96	3.78	4.15	3.97
13. Anticipating regulatory issue	3.77	3.74	4.26	3.85
14. Ambition and entrepreneurial mindset	3.77	3.78	3.92	4.06
15. Maturity of a given EST	3.73	3.83	4.26	3.94
16. Cost savings	4.46	4.43	4.33	4.15

There were some differences among the barriers based on organisation size. The top three barriers to EST adoption demonstrated some overlap and were as follows: micro-enterprises (B10, B16, B14), small enterprises (B10, B11, B18), medium enterprises (B10, B14, B19), and large enterprises (B3, B15, B18).

Table 5. Mean scores for barriers based on organization size.

Barrier	Micro-enterprises	Small enterprises	Medium Enterprises	Large Enterprises
1. Laws lack specialized construction provision.	3.38	3.52	4.1	3.94
2. Complex certification procedures	3.58	2.91	4.12	3.64
3. Imperfect testing standards for saved energy	3.77	3.39	4.11	4.15
4. Lack of techniques for estimation of saved energy	3.65	3.43	4.12	3.73
5. Stakeholders' reluctance to use	3.08	3.09	3.97	3.79
6. Low market demand	3.58	3.61	4.14	3.82
7. Low profitability	3.81	3.65	4.22	3.7
8. Lack of interests from practitioners	3.73	3.7	4.16	3.94
9. Lack of importance attached by top leaders	3.58	3.52	4.11	3.97
10. Limited funds and material resources	4.12	4.13	4.21	3.7
11. Lack of trained professionals	3.73	3.65	4.19	3.94
12. Lack of access to information	3.73	3.3	4.08	4
13. Ineffective application due to immaturity of EST	3.77	3.39	4.04	3.79
14. Lack of specialized technology	3.96	3.83	4.15	3.73
15. High initial investment	3.88	4.13	4.12	4.06
16. Technical viability of integrating multiple ESTs	4	3.74	3.97	4
17. Lack of data interoperability and exchange	3.5	3.65	3.93	3.79
18. System and data security	3.58	3.78	4.27	4.09
19. Duration and payback period of ESTs	3.54	3.83	4.1	3.91
20. Ineffective decision-making by clients	3.77	3.52	4.1	3.82

3.6. Regression Analysis

The regression analysis explored how barriers and drivers influence the adoption of energy-saving technologies (ESTs). Across the whole sample, both barriers and drivers significantly affected adoption and evaluation stages. Interestingly, barriers had a positive relationship with adoption, meaning organisations further along in adopting ESTs reported more concerns. This likely reflects increased awareness of challenges as companies progress in implementation. Drivers, such as cost savings and access to information, also had a positive influence, making organisations more likely to adopt and evaluate ESTs. Together, barriers and drivers explained around 25–27% of the variation in how far along companies were in their adoption and evaluation processes.

The influence of barriers and drivers varied by profession and country. Among architects, both barriers and drivers significantly affected adoption and evaluation, explaining over 60% of evaluation outcomes. In contrast, contractors were less influenced by these factors, except when evaluating ESTs, where both barriers and drivers played a smaller but still significant role. Location also mattered: in the UK, both barriers and drivers strongly shaped adoption and evaluation, explaining over 56–60% of the variation. Among US respondents, barriers and drivers were less predictive, explaining only around 11% of outcomes, suggesting that UK organisations may be more influenced by policy clarity, financing, and market signals.

Demographic factors and organisational characteristics further shaped EST adoption. Among architects, gender, age, and education negatively influenced evaluation progress, suggesting that younger, more experienced professionals drive adoption within this group. For contractors, organisation size mattered most, with larger firms adopting ESTs faster. Across locations, UK respondents who identified as more politically liberal tended to move more slowly, while in the US, larger organisations again progressed further. Overall, company size consistently emerged as a strong predictor, while awareness of drivers and barriers remained key to advancing both adoption and evaluation.

4 Policy recommendations

The findings of this research demonstrate that while there is growing recognition of the benefits of energy-saving technologies, significant barriers continue to inhibit widespread adoption across the construction sector. Among decision-makers in both the UK and US, concerns over high upfront costs, limited access to finance, data and system security, information gaps, and skills shortages consistently emerge as critical obstacles. At the same time, cost savings, market demand, and regulatory clarity are powerful drivers, especially where public financing and structured policy frameworks are available

These dynamics underline the importance of policy interventions that simultaneously remove frictions and amplify incentives. Deep renovation sits at the heart of Europe's and other regions' pathways to achieve climate neutrality and energy-security targets. The recast EU Energy Performance of Buildings Directive (EPBD, Directive (EU) 2024/1275) sets ambitious obligations for zero-emission buildings, minimum energy performance standards (MEPS), and Renovation Passports as practical tools to drive the transition. Similarly, the European Bank for Reconstruction and Development (EBRD), through its updated Environmental & Social Policy (2024), Energy Sector Strategy (2024–2028), and Green Economy Transition (GET) framework, provides dedicated mechanisms to unlock private capital, de-risk investments, and scale sustainable construction across its regions.

The positive relationship observed in this study between the perceived barriers and actual adoption of ESTs highlights an "exposure effect": organisations further along the adoption journey are more aware of technical, financial, and regulatory challenges. This suggests that policies should not only raise awareness but must actively de-risk and support implementation, through finance, skills, regulatory certainty, and data-security frameworks.

Building on the empirical results of this study and aligning with the EPBD and EBRD frameworks, the following policy recommendations propose a multi-layered strategy designed to:

- Lower capital and administrative hurdles,
- Strengthen information flows and technical capability,
- Safeguard digital security, and
- Scale market demand via public procurement and renovation pipelines.

This integrated approach addresses the structural, financial, and informational barriers identified in our data while leveraging drivers such as cost savings, regulatory clarity, and technological maturity to accelerate the transition toward high-performance, low-carbon buildings.

Recommendation 1: Set Clear and Practical Renovation Targets to Remove Uncertainty

Respondents in the UK rated unclear policies and complex certification among the highest barriers, particularly architects who also flagged lack of information and immature technologies. By giving organisations clear rules, step-by-step guides, and simplified certification, confusion can be reduced and administrative burdens lowered, making it easier to plan investments. By introduce minimum energy performance standards (MEPS) and step-by-step renovation roadmaps (e.g. Renovation Passports), companies will know exactly what is expected and by when. Similarly, digital logbooks provide easy tracking of building compliance.

Recommendation 2: Make Green Financing Easy and Affordable

Across our sample, high upfront investment and limited access to funds emerged as the top barriers, particularly for SMEs. However, cost savings and public financing ranked among the strongest drivers. Policies should provide low-cost loans, cash grants, tax incentives, and portfolio guarantees to reduce investment risks. Working with local banks and suppliers to create pre-approved "green-labelled" technologies will simplify funding access and give decision-makers confidence. These measures are especially important in the UK, where public financing was found to have a stronger influence on adoption than in the US.

Recommendation 3: Build Trust by Securing Data and Digital Systems

System and data security was one of the highest-rated concerns, particularly among architects who design and specify technologies. Without clear safeguards, organisations are hesitant to integrate energy-saving technologies that rely on connected systems. Introducing minimum cybersecurity standards, mandating secure-by-design principles, and certifying vendors who comply will build trust and reduce perceived risks. Clear data-handling guidelines for IoT-enabled energy-saving tools and building management systems will further encourage adoption.

Recommendation 4: Expand Training to Build Skills and Close Capability Gaps

The survey highlighted a lack of trained professionals as a significant barrier, especially among SMEs. Additionally, immature technologies and installation complexity add further uncertainty for decision-makers. Launching specialised training programmes for designers, installers, and building managers will help close these capability gaps. Fast-track certifications, hands-on workshops, and gender-inclusive initiatives will expand the skilled workforce, improve implementation quality, and make energy-saving technologies more accessible.

Recommendation 5: Drive Demand Through Public Building Renovation Pipelines

Respondents rated market demand and evidence of successful projects among the most powerful drivers of adoption. Contractors, in particular, are influenced when they see results in practice. Governments and municipalities should lead by example by renovating public buildings such as schools, hospitals, and offices. Aggregating projects through municipal energy agencies and using energy performance contracts (EPCs) will lower costs, stabilise demand, and stimulate private-sector participation. Visible success stories will encourage more organisations to follow.

Recommendation 6: Tailor Support to Company Size, Role, and Location

The data show distinct adoption patterns between architects, contractors, SMEs, and large firms, as well as between UK and US respondents.

- **For SMEs:** Provide small grants, simplified approvals, and curated technology lists to address funding and capability gaps.
- **For larger firms:** Link financing to portfolio-wide renovation plans and require structured energy management practices.
- **For architects:** Focus on improving information availability, providing design tools, and enforcing data security standards.
- **For contractors:** Prioritise practical demonstrations, bundled work packages, and targeted financial incentives.

Segmented support ensures policies address real-world differences in how organisations evaluate and adopt energy-saving technologies.

Recommendation 7: Prove What Works With Better Measurement and Verification

Respondents highlighted access to evidence of successful projects as one of the strongest drivers for adoption. Requiring pre- and post-renovation performance monitoring on publicly funded projects and sharing anonymised energy-savings data would help decision-makers understand what works in practice. Building an open evidence platform or integrating results into tools like the Green Technology Selector will enable organisations to make informed investment decisions and reduce the risks associated with new technologies.

ABOUT RINNO

RINNO is a four-year EU-funded research project that aspires to deliver greener, bio-based, less energy- intensive from a life cycle perspective and easily applicable building renovation elements and energy systems that will reduce the time and cost required for deep energy renovation, while improving the building energy performance. Its ultimate goal is to develop, validate and demonstrate an operational interface with augmented intelligence and an occupant-centered approach that will streamline and facilitate the whole lifecycle of building renovation.

For more information, please visit **https://rinno-h2020.eu/**

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