Empirical Evaluation of Owner-Focused Education for Portfolio-Scale Building Decarbonization

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Abstract. Decarbonizing the building sector is essential for climate mitigation, yet progress is frequently constrained by technical, financial, informational, and cultural barriers among building owners. This study empirically evaluates a targeted, owner-focused capacity-building intervention based on the Inform-Educate-Train-Support framework and the Stanford Building Decarbonization Learning Accelerator platform, aimed at enabling informed retrofit and energy transition decisions at the building portfolio scale. A 90-minute pilot seminar was delivered to a large institutional building owner and its administrators and facility managers (n = 180), with a purposive evaluation sample of 27 decision-makers. The seminar integrated climate science fundamentals with operational and embodied carbon concepts and practical decarbonization strategies for existing buildings, including electrification of HVAC systems, renewable energy integration, energy efficiency measures, and life-cycle-based decision metrics. A structured post-seminar assessment showed high short-term knowledge retention, with a mean accuracy of 95.2%. Follow-up actions – including energy contract reviews and requests for technical support – indicate early translation of knowledge into operational decarbonization processes. These results provide initial early empirical evidence that structured, owner-focused education can activate institutional decision-making and initiate portfolio-level building decarbonization pathways.

1 Introduction

In the European Union (EU), the existing building stock requires substantial retrofitting to meet climate targets and achieve Nearly Zero-Energy Building (NZEB) and Zero-Emission Building (ZEB) standards [1]. However, the transition of these buildings is constrained not only by technical limitations and financial barriers, but also by cultural resistance and significant informational deficiencies [2]. Despite the central role of building owners, administrators and facility managers in initiating and approving retrofit decisions, their

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educational and capacity-building needs remain largely underexamined within the Architecture, Engineering, Construction and Operations (AECO) fields. Addressing this gap is critical for overcoming persistent non-technical barriers and enabling more effective decarbonization actions.

Sunikka-Blank and Galvin show that building owners frequently lack adequate support from industry actors and policy frameworks, making it difficult for them to navigate competing priorities and identify appropriate decarbonization solutions [3]. Consequently, many owners rely on a "learning by doing" approach, which is empirically less effective than strategies informed by higher levels of education [4]. Additional studies highlights both limited awareness of innovative retrofit strategies among building owners and a misalignment with AECO industry priorities [5], alongside persistent misconceptions – for example, scepticism about heat pump performance in cold climates [6]. Research also documents a persistent gap between owners' willingness to decarbonize and their actual implementation, driven by unawareness, weak motivations, and limited access to trusted information [7]. Moreover, retrofit decisions tend to be guided more by architectural reconfiguration and functional repurposing needs than by environmental goals [8].

Taken together, these findings reveal a persistent educational deficit that constrains building owners' ability to identify, evaluate, and adopt effective decarbonization measures. However, no empirical studies have evaluated whether targeted educational interventions can effectively improve building owners' decarbonization knowledge, shift behavioural intentions, or stimulate early implementation actions. This gap limits our understanding of how educational and capacity-building strategies might support more informed decision-making and accelerate transition toward NZEB and ZEB targets.

This paper contributes to the literature by empirically assessing the effectiveness of a targeted educational intervention for building owners, administrators, and facility managers, focusing on knowledge retention and follow-up actions. To begin addressing the identified gap, the study examines a pilot initiative grounded in the I-E-T-S framework. The analysis evaluates the impact of the intervention using post-seminar knowledge-assessment data and documented follow-up actions. The findings offer initial evidence of how structured educational programs can strengthen decision-making capacities and support decarbonization efforts among building owners.

2 Method

2.1 The I-E-T-S framework

The educational initiative for building owners is conceptualized and developed using the I-E-T-S Capability-Building Matrix, a learning and capacity-development framework originally developed by Strategic Project Solution, Inc. Although not formally published in peer-reviewed literature, the framework has been applied in training pro-grams at Stanford University and has supported collaboration across the AECO industry.

The I-E-T-S framework comprises four sequential stages – Inform, Educate, Train, and Support – representing a progressive pathway from initial unawareness to active engagement and sustained implementation. Grounded in capacity development theory [9, 10] and adult learning principles [11, 12], this structure ensures that educational interventions move beyond information transmission to foster lasting behavioural and operational change. To strengthen the communicative and motivational dimensions of the model, elements of Sinek's Golden Circle (Why-What-How) are integrated into the framework [13]. Specifically, the Inform phase addresses the Why, articulating the purpose and relevance of the topic; the Educate phase focuses on the What, presenting core concepts and early

evidence of successful applications to build understanding and motivation; and the Train and Sup-port phases emphasize the How, providing stakeholders with the methods, tools, and organizational structures required for practical implementation and sustained progress.

2.2 Point of departure

2.2.1 The Stanford Building Decarbonization Learning Accelerator

Stanford University established the Building Decarbonization Learning Accelerator (BDLA) to promote the integration of decarbonization strategies into academic curricula [14]. The BDLA website provides free, open-access educational materials – including case studies, slide decks, and other teaching resources – designed to support the creation of university-level courses and seminars. All educational materials and methodological references developed by Stanford University's Center for Integrated Facility Engineering (CIFE) and the Building Decarbonization Learning Accelerator (BDLA) are used as supporting resources with-in the broader educational framework. These materials are adapted for academic and re-search purposes with appropriate attribution.

2.2.2 The Prevention of GHG Emissions from Buildings project

The Prevention of GHG Emissions from Buildings Project was launched in 2022 at CIFE with the aim of accelerating portfolio-scale building decarbonization. The project developed a Prototype Decarbonization Protocol (PDP) for the retrofit of existing buildings, articulated into five main steps (see Fig. 1): (i) identification and analysis of off-site carbon-free energy sources; (ii) identification and analysis of on-site carbon-free energy sources; (iii) assessment of energy-efficiency measures to reduce building energy demand; (iv) evaluation of alternatives to replace fossil fuel–based systems and equipment; and (v) minimization of the embodied carbon of all new materials and products installed during the retrofit process.

In addition, the project produced a set of representative case studies demonstrating the outcomes of applying the protocol in real contexts, thereby providing practical evidence of viable pathways for reducing greenhouse gas (GHG) emissions from existing buildings. The protocol framework and the associated case studies form the core educational content of the training courses developed for building owners involved in the initiative.

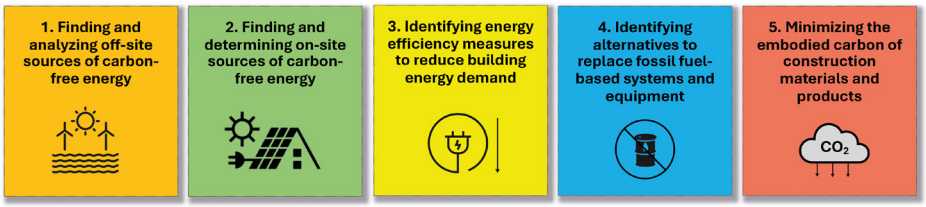

Fig. 1. The five main steps of the Prototype Protocol for decarbonizing existing buildings.

2.3 Educational intervention for building owners, administrators and facility managers

2.3.1 Objective

The educational intervention targets portfolio owners responsible for the management of multiple buildings. The intended audience includes building administrators and facility

managers, many of whom do not possess a formal background in building de-carbonization. In line with the first two stages of the I-E-T-S framework, the primary objective of the intervention is to establish a set of clearly defined learning outcomes, enabling participants to (i) correctly identify the main sources of GHG emissions in buildings, (ii) classify and interpret the principal building decarbonization strategies, and (iii) distinguish between major technological and operational solutions for emission re-duction. The intervention is designed to support participants' progression from a condition of limited awareness to an initial, structured conceptual understanding of building decarbonization.

2.3.2 Content

The educational intervention was designed in accordance with the Inform–Educate–Train–Support (I-E-T-S) framework and specifically targeted the "Why" and "What" dimensions of building decarbonization. It is structured in two modules. The first module addressed the rationale for decarbonization by presenting the consolidated scientific foundations of anthropogenic climate change. It reviewed key observed and projected impacts, including the rise in global mean surface temperature, the growing frequency of extreme weather events, climate-induced internal displacement, long-term population growth trajectories, premature mortality associated with ambient air pollution, and the growing number and economic magnitude of climate-related damage claims. The module then introduced the physical science mechanisms governing climate change, followed by a structured treatment of the concepts of climate mitigation and climate adaptation, with explicit reference to their implications for the built environment.

The second module focused on actionable technical pathways for decarbonizing existing buildings. It began by contextualizing the contribution of the AECO sector to global GHG emissions and disaggregated sectoral emissions into operational and embodied components. The module subsequently introduced the Prototype Decarbonization Protocol developed at Stanford University as a reference framework for portfolio-scale intervention planning. Energy supply strategies were examined through the combined use of off-site carbon-free electricity procurement and on-site renewable energy generation. Demand-side and energy-efficiency measures were then addressed, including building envelope retrofits, improvements in HVAC system efficiency and operational control, and upgrades of lighting technologies. These strategies were supported by case studies illustrating the synergistic effects of technological interventions and occupant behavioural change. Finally, the module examined the progressive phase-out of fossil fuels in buildings through full system electrification, with a specific focus on heat pump technologies, and introduced the economic implications of electricity–gas substitution using basic cost–benefit analysis and life-cycle–based decision metrics to support strategic investment.

2.3.3 Delivery

The educational intervention was delivered as a two-module pilot seminar to a large institutional portfolio owner with properties in Italy, Malta, Albania, and Romania. The portfolio includes several dozen buildings across multiple countries, with an aggregate annual energy consumption on the order of tens of GWh. A total of 180 professionals participated, including chief financial officers, financial staff, directors, building administrators, facility managers, architects, and engineers involved in renovation and asset management. The seminar was delivered in four sessions (Milan, Rome, Palermo, and Valletta) between April and May 2025. Each session had a total duration of 90 minutes, consisting of 60 minutes of structured instruction followed by a 30-minute moderated

question-and-answer session designed to promote clarification, discussion, and consolidation of key concepts.

2.3.4 Evaluation

The effectiveness of the seminar was evaluated through a structured post-intervention survey administered one week after the session to assess short-term knowledge retention and conceptual understanding. A purposive sample of 27 professionals was selected by the portfolio owner from among the seminar participants, specifically targeting individuals engaged in ownership, asset management, and investment decision-making processes.

The survey instrument consisted of a questionnaire with dichotomous (true/false) items directly aligned with the seminar's core learning objectives and designed to capture key domains of knowledge related to climate change and building decarbonization. The instrument served both as a knowledge-reinforcement tool for participants and as a first-order metric for the evaluation of immediate educational outcomes. Given the non-technical background of many participants, a dichotomous (true/false) format was select-ed to minimize cognitive load and maximize response reliability. This approach is consistent with rapid diagnostic assessment methods commonly adopted in executive and professional training contexts. The survey was therefore designed as a first-order screening tool rather than an instrument for fine-grained knowledge differentiation.

The questionnaire covered the content of both parts of the seminar. The first set of items addressed the "Why," focusing on foundational scientific principles of anthropo-genic climate change, the contribution of the AECO sector to global GHG emissions, and the importance of a life-cycle perspective on emissions mitigation, encompassing both operational and embodied carbon. The second set of items addressed the "What," evaluating participants' understanding of the principal technical and operational decarbonization levers, including the procurement of carbon-free electricity, the determinants of photovoltaic system performance (e.g., orientation and shading), and the energy and economic benefits of LED lighting. Finally, the survey assessed awareness of the influence of occupant and operational behaviours on building energy performance and the resulting GHG emissions.

3 Results

3.1 Post-seminar knowledge retention assessment

The post-seminar assessment indicates high short-term knowledge retention across all evaluated topics, with a mean accuracy of 95.2% (range: 88.9–100%). As shown in Fig. 2, full accuracy (100%) was achieved for items related to life cycle GHG emissions mitigation and the energy benefits of LED lighting, indicating a high level of conceptual assimilation. Slightly lower scores were observed for items addressing the building sec-tor's share of global GHG emissions and the effect of behavioural change on energy performance (88.9%), identifying specific domains where further instructional reinforcement may be beneficial. Overall, the results confirm the effectiveness of the educational intervention in consolidating core knowledge on climate change, building decarbonization strategies, and related operational action.

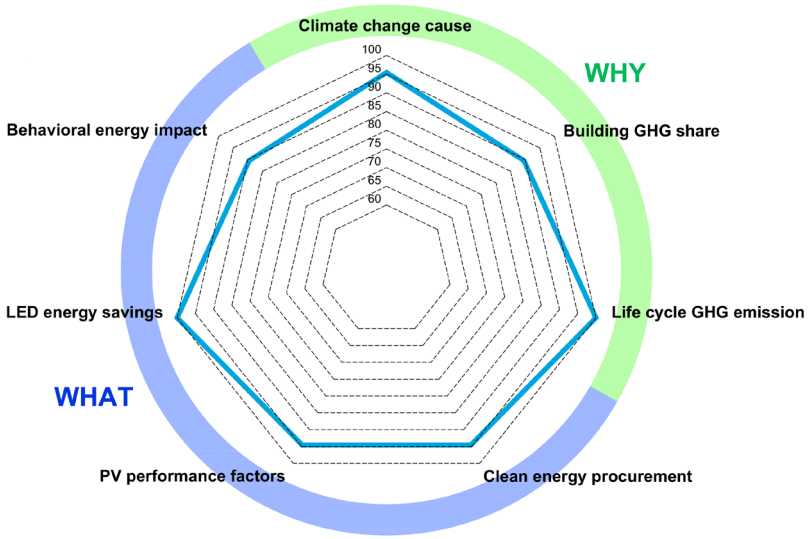

Fig. 2. Accuracy rates from the post-seminar knowledge survey (n = 27), illustrating participant retention of key seminar concepts. Scores range from 0–100%, with 0% representing no correct answers and 100% full accuracy.

3.2 Institutional follow-up actions

Within six months following the seminar, the portfolio owner formally initiated a series of follow-up actions that can be classified within the "Train" and "Support" stages of the Inform-Educate-Train-Support (I-E-T-S) framework, corresponding to the "How" dimension of the capacity-building process, i.e., the operationalization of decarbonization strategies. These actions spanned multiple operational and strategic domains:

- Energy procurement and contract optimization: senior management initiated a review of existing energy supply agreements to identify economically viable providers of off-site carbon-free electricity. To operationalize this effort, the chief financial officer's office launched a portfolio-wide project to map utility expenditures across all properties and to screen locally available renewable electricity suppliers based on cost, contractual terms, and long-term price stability.
- Design and performance standards for deep renovation: the owner requested specialized technical training for both internal management and associated design teams to enable systematic integration of the NZEB standard into ongoing and future renovation projects. In parallel, direct technical assistance was sought for the preliminary design of a new NZEB-compliant facility.
- Techno-economic decision support: additional guidance was requested to strengthen cost-benefit and life-cycle-based assessments for evaluating photovoltaic (PV) system deployment in combination with the electrification of existing fossil-fuel-based heating systems.
- Project delivery and governance models: the seminar also prompted recognition that effective decarbonization requires a shift from a conventional design-bid-build process toward an integrated design approach, with earlier and more coordinated stakeholder involvement across the project life cycle [15].
- Financial training and policy literacy: finally, the owner requested continuous professional training for the chief financial officer and finance staff on evolving

energy and climate legislation, project financing mechanisms, state incentives, Energy Service Companies (ESCOs), and Power Purchase Agreements (PPAs), as well as a follow-up seminar for the full cohort of 180 professionals on these topics, scheduled for April 2026.

Together, these quantitative outcomes and qualitative institutional responses pro-vide complementary evidence of short-term learning effects and early organizational activation following the educational intervention.

4 Discussion

These results provide early empirical indications that targeted education for building owners, administrators, and facility managers can directly reduce key non-technical barriers to decarbonization by increasing institutional awareness and technical literacy, while simultaneously catalysing governance-level decision-making processes. In contrast to much of the existing literature documenting persistent knowledge-action gaps and decision inertia among building owners, this study indicates that a structured, theory-grounded educational intervention can activate early institutional responses beyond individual behavioural intentions.

The emergence of requests related to energy procurement, project financing, and integrated delivery models is scientifically significant because it signals a transition from technical awareness toward strategic, portfolio-scale decarbonization governance. At the same time, follow-up interactions confirmed that financial risk perception, incentive uncertainty, and long investment payback horizons remain dominant constraints on the timing and scale of implementation. In this context, the I-E-T-S capability-building matrix appears to function as an effective operational framework for activating the progression from knowledge acquisition to actionable decarbonization strategies in a real-world organizational setting. This empirical observation of the Inform-Educate-Train-Support sequence within an institutional portfolio represents an initial validation of the framework in the context of building decarbonization.

Several limitations must be acknowledged. The post-seminar evaluation relied on a relatively small purposive sample (n = 27) and assessed only short-term knowledge retention one week after the intervention. The study was intentionally configured as an exploratory pilot aimed at testing feasibility and detecting early institutional responses, rather than establishing causal attribution through controlled experimental design. It did not directly measure changes in building energy use or GHG emissions, and the institutional context represents a specific organizational and governance setting. Consequently, the observed follow-up actions should be interpreted only as early indicators of organizational activation. Future research should extend the temporal horizon of evaluation, incorporate direct performance metrics, and test the scalability of the I-E-T-S-based educational approach across different ownership structures.

5 Conclusions

This study provides empirical indications that targeted, owner-focused educational interventions can effectively reduce key non-technical barriers to building decarbonization by strengthening institutional awareness, technical literacy, and early governance activation. Implemented through the Inform–Educate–Train–Support (I-E-T-S) framework, the pilot seminar successfully engaged a large institutional portfolio owner and its administrators and facility managers, enabling a structured transition from limited awareness to informed, organization-wide consideration of decarbonization strategies.

The post-seminar evaluation showed very high short-term knowledge retention (mean accuracy 95.2%), confirming the effectiveness of the educational design in consolidating core climate and decarbonization concepts. More importantly, the emergence of concrete follow-up actions – including portfolio-wide energy contract reviews, photovoltaic feasibility assessments, electrification planning, and requests for financial and policy-literacy training – indicates an early but tangible translation of knowledge into operational and governance-level processes.

These findings suggest that education may act as a structural enabling condition for portfolio-scale decarbonization, capable of activating decision-making dynamics that technical solutions and policy instruments alone often fail to trigger. By positioning building owners as informed and proactive agents of change, owner-focused education complements regulatory and technological approaches and, despite reflecting only short-term learning effects, may represent a crucial lever for accelerating the transition to a low-carbon building sector.

Nomenclature

AECO	Architecture, Engineering, Construction and Operations
BDLA	Building Decarbonization Learning Accelerator
CIFE	Center for Integrated Facility Engineering
ESCo	Energy Service Company
GHG	Greenhouse gas
HVAC	Heating, Ventilation, and Air conditioning
I-E-T-S	Inform-Educate-Train-Support framework
LED	Light Emitting Diode
PDP	Protype Decarbonization Protocol
PPA	Power Purchased Agreement
NZEB	Nearly Zero-Energy Buildings
ZEB	Zero Emission Buildings

Artificial intelligence tools were used to support language refinement, grammar correction, and stylistic clarity of the manuscript. All scientific content, data analysis, interpretations, and conclusions were developed exclusively by the authors, who take full responsibility for the integrity and originality of the work.

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