Post-Occupancy Evaluation Framework for Smarthomes: A Techno–Human–Social Perspective

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***Abstract*—This paper proposes a new conceptual framework for evaluating smarthome environments from a Techno–Human–Societal perspective. As Artificial Intelligence technologies become increasingly embedded in residential settings, existing Post-Occupancy Evaluation approaches remain predominantly focused on energy savings and technical efficiency, limiting their ability to capture AI-based services that continuously interact with residents. To address this gap, this study introduces the Techno–Human–Societal Post-Occupancy Evaluation framework, organizing evaluation into three core dimensions: technological performance, human experience, and societal acceptance and sustainability. The proposed framework provides a conceptual foundation for future empirical validation and indicator refinement across diverse smarthome contexts, contributing to the broader agenda of human-centered smart city evaluation.**

Keywords- Smarthome; Post-Occupancy Evaluation; Energy Efficiency; Residential Comfort; Sustainability.

I. INTRODUCTION

Advancements in Artificial Intelligence (AI) technologies are rapidly spreading across residential environments. Smarthome systems aim to optimize energy use through automated control, predictive algorithms, and real-time feedback, while enhancing user convenience. However, empirical evidence on how residents perceive and experience these services remains limited, as performance evaluations have largely focused on energy savings and technical efficiency, often overlooking human and social dimensions [1].

Post-Occupancy Evaluation (POE) has been widely used to assess building performance after occupancy, integrating technical criteria and user experience [2]. Nevertheless, existing POE frameworks are limited in evaluating AI-based services that actively interact with residents and influence everyday energy behaviors. To address this gap, this study proposes a smarthome-specific POE framework grounded in a techno–human–societal perspective. The framework was developed through a two-step process involving a comprehensive review of POE and smarthome-related studies, followed by the analysis and restructuring of existing evaluation items, with particular attention to users' understanding of AI systems, perceived control, trust, and social impacts.

The remainder of this paper is organized as follows. Section II reviews the limitations of conventional POE. Section III presents the proposed THS-POE framework. Section IV discusses its characteristics and implications. Section V concludes with directions for future work.

II. LIMITATIONS OF CONVENTIONAL POE AND THE NEED FOR INTEGRATED EVALUATION FRAMEWORKS

POE has developed as a methodology for assessing building performance during actual use, with traditional studies focusing primarily on physical environmental performance—such as thermal comfort, acoustics, and energy consumption—and user satisfaction in residential, office, and public buildings [3]. POE typically employs mixed methods, combining surveys, interviews, on-site observations, and measurements of indoor environmental quality and resource use [1]. However, many POE studies remain one-off assessments, characterized by limited comparability across cases due to non-standardized indicators, unclear cost responsibilities, and weak integration with construction and operational processes [4]. Consequently, prior research has consistently highlighted the need for standardized indicators, data sharing, and stronger links between research and practice [5].

As smart technologies become increasingly embedded in buildings, POE faces new challenges related to user learning and acceptance, data ethics, and platform interoperability [6]. Recent studies have begun to expand evaluation scopes by incorporating usability, user behavior, and operational feasibility alongside conventional performance indicators, while also emphasizing the importance of institutional and regulatory perspectives [7]. These developments indicate that future POE research must move beyond physical performance and user satisfaction toward integrated assessments that account for technological performance, human–service interaction, and broader societal impacts.

III. TECHNO-HUMAN-SOCIETAL POST-OCCUPANCY EVALUATION (THS-POE) FRAMEWORK

The THS-POE framework is designed to integratively assess technological, human, and societal dimensions in smarthome residential environments. Moving beyond the conventional POE focus on physical performance and user satisfaction, it reflects key characteristics of AI-based systems, including autonomy, interactivity, learning capacity, and social implications.

As illustrated in Figure 1, the THS-POE framework is structured around three interrelated domains—Technology, Human, and Society—each capturing a distinct yet complementary dimension of smarthome performance.

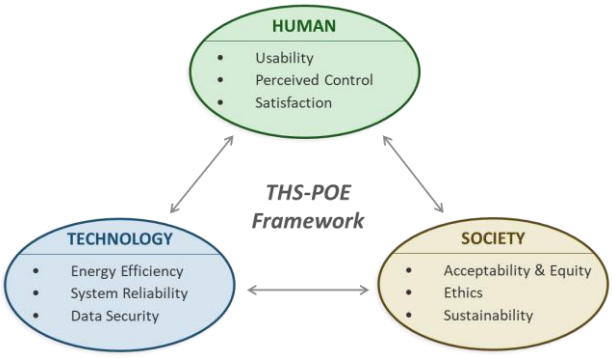

Figure 1. Conceptual Structure of the THS-POE Framework.

The specific indicators and measurement methods for each domain are summarized in Table I. The Technology domain evaluates functional and operational performance, such as energy efficiency, system reliability, and data security, combining measured indicators with users' perceived performance and trust; data are collected through system logs, expert assessments, and user evaluations. The Human domain focuses on user experience and behavior, addressing usability, emotional satisfaction, perceived control, and intention to continue use in recognition of AI systems' ongoing influence on everyday energy-related decisions; measurement relies primarily on user surveys and semi-structured interviews. The Society domain examines social acceptability and sustainability, incorporating equity, accessibility, ethical considerations, CO_2 reduction effects, and institutional support to assess long-term societal implications, drawing on quantitative data and expert assessments.

The THS-POE adopts a technology-neutral and flexible structure, allowing indicator selection and weighting to be adjusted according to research objectives, housing contexts, and policy settings. This openness supports both contextual adaptability and cross-case comparability. Importantly, the framework is not intended as a one-time diagnostic tool, but as a longitudinal evaluation instrument capable of tracking how smarthome systems and their users co-evolve over time. By incorporating both objective performance metrics and subjective user assessments, THS-POE bridges the gap between technical system evaluation and the lived experience of residents, offering a more holistic basis for evidence-based housing policy and smart city planning.

IV. Discussion : Characteristics and Implications of the THS-POE Framework

The THS-POE framework is proposed as a flexible and extensible POE tool for smarthomes, rather than as a fixed or prescriptive evaluation protocol. It aims to enable systematic and comparable assessments across diverse housing types, technological configurations, and institutional or policy contexts, while remaining responsive to rapid technological change. Central to this framework is the recognition that the success of AI-based smarthome services cannot be measured by technical performance alone, but must also account for how residents understand, trust, and appropriate these systems in their daily lives.

Each of the three domains is designed to serve a distinct set of stakeholders within a single evaluative logic. The Technology domain provides performance-oriented indicators—such as energy efficiency, system reliability, and data security—that are directly relevant to designers, system developers, and facility managers. The Human domain, by focusing on actual user experience, usability, perceived control, and emotional response, serves housing operators, service providers, and user-centered design processes. The Society domain addresses broader concerns such as equity, accessibility, ethics, and sustainability, offering critical insights for policymakers, local governments, and public housing authorities. This three-domain structure allows differentiated interpretation by each stakeholder group while maintaining a coherent and integrated evaluative logic.

In terms of application timing, the framework is intended to be used repeatedly across the full housing life cycle. Unlike conventional POE, which is often conducted as a one-time assessment at a fixed point after completion, it can be applied at different stages—initial operation, stabilization, and long-term use. This enables the capture of not only short-term outcomes such as energy efficiency, but also the evolution of user perception, learning processes, and social acceptance over time.

TABLE I. Structure and Indicators of the Techno–Human–Societal Post-Occupancy Evaluation Framework

Domain	Primary Indicator	Secondary Indicators	Measurement Methods
Technology	Energy efficiency	Energy consumption, reduction rate	Data analysis, User and expert evaluation
	System reliability	Error rate, response time, data privacy	System logs, expert assessment
Human	Usability	Ease of learning, ease of operation	User surveys, interviews
	Satisfaction	Emotional satisfaction, intention of continued use	User surveys
Society	Acceptability	Equity, accessibility, ethics	User and expert evaluation
	Sustainability	CO_2 emission reduction, maintenance systems, policy support	Quantitative data, expert assessment

In AI-based system environments where performance and user interaction continuously change, such temporal flexibility becomes a critical evaluation feature.

Structurally, the framework adopts a technology-neutral design that is not tied to any specific technology or platform. Rather than being tailored to particular buildings, algorithms, or system types, it defines evaluation domains at a conceptual level, allowing individual indicators and measurement methods to be adjusted according to technical conditions and data availability. For instance, energy performance can be assessed through smart meter data or building management system logs, while user experience can be measured via surveys or interviews. This modular design enables comparative analysis across heterogeneous smarthome systems.

V. Conclusion and Future work

This study examined the limitations of conventional Post-Occupancy Evaluation (POE) in the context of the rapid diffusion of AI-based smarthome technologies and proposed a Techno–Human–Societal (THS) POE framework. By treating technological performance, user experience, and social acceptability and sustainability as equally important dimensions, THS-POE enables a comprehensive evaluation of AI-based smarthome services beyond energy savings alone.

While this study focuses on conceptual framework development rather than empirical validation, it provides a foundation for future research. Subsequent studies may refine indicators, apply expert-based weighting, and empirically test the framework across diverse residential contexts, positioning THS-POE as a basis for cumulative and comparative evaluation within smart city research.

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