Rethinking Eco-Feedback: Expanding Interaction Design through the Human–Building Interaction Perspective

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Abstract

The original conceptualization of eco-feedback was broad, encompassing also concepts such as signifiers and feedforward. Over the decades that followed, research on eco-feedback became increasingly narrow, focusing predominantly on providing users with feedback on energy consumption. In light of recent developments in Human-Building Interaction, it is timely to revisit and broaden current research on eco-feedback. This first requires refining its vocabulary by distinguishing between eco-signifiers, eco-feedforward, and eco-feedback. Secondly, the scope of "eco-interaction" should be expanded through the HBI perspective—one that situates interaction within the spatial and temporal scales of the home and building environment rather than at isolated interfaces, and foregrounds the role of multiple sensory experiences in shaping how occupants perceive, interpret, and respond to interaction within intelligent built environments.

CCS Concepts

• **Human-centered computing → Interaction design theory, concepts and paradigms**.

Keywords

Eco-Feedback, Human-Building-Interaction, Energy consumption

1 Introduction

Energy consumption in the building sector is a major source of overall energy use and carbon emissions [10, 11], with the residential sector contributing a significant share [10, 11]. Consequently, reducing household energy use has become a central focus across multiple research fields, including HCI [1, 6, 7, 9, 13, 15, 18–20]. Eco-feedback was one of the earliest HCI approaches to support conservation through interaction design [13, 18, 19]. Yet this broad conceptualisation introduced in [18] is rarely maintained in later work [13, 19], which often focuses narrowly on feedback about consumption consequences [12, 16, 19].

In light of more recent developments in Human-Building Interaction (HBI), which offer new perspectives on how user behaviour is shaped not only by interfaces but also by the responsive dynamics of entire living environments [4, 8], we argue that the terminology used to describe eco-feedback research requires refinement. Specifically, past and future work could be categorised as eco-signifier, eco-feedforward, and eco-feedback studies based on which specific stages of Norman's interaction model they target, so that: (1). eco-feedback can be re-extended to its original conceptualisation as "eco-interaction", encompassing broader aspects of interaction beyond post-action feedback; and (2). "eco-interaction" techniques can be incorporated at different stages of interaction, serving as connective mechanisms—"glue"—between the feedback and control processes distributed across multiple layers of HBI systems. Such a reframing could promote the design of intelligent environments that enable and reinforce sustainable behaviour in a more integrated and systemic manner.

2 Eco-feedback

McCalley and Midden introduced eco-feedback in 1998 as a design strategy to promote conservation behaviour [18], highlighting the role of interaction design in encouraging sustainable actions. Although coined "eco-feedback," their concept extends beyond post-action feedback to include signifiers and feedforward that guide users before an action, aligning with Norman's interaction model. They also argued that eco-feedback systems should be grounded in robust psychological models of behaviour.

More than a decade later, Froehlich et al. surveyed eco-feedback technologies, noting that although environmental psychology and HCI both aim to understand and influence conservation behaviours, they differ substantially in focus and methodology [13]. Environmental psychology emphasises behavioural theory and controlled experiments, whereas HCI prioritises design, user experience, and situated use. This divergence reflects disciplinary orientations yet also highlights the value of integrating both perspectives to improve eco-feedback systems. Review studies [1, 13, 15, 16, 19, 20] further show that research in both fields—especially on energy and resource consumption—has centred on feedback about consumption consequences. However, such systems often fail to convey clear causal links between user actions and resulting consumption, leaving users with limited contextual understanding and reducing the potential for sustained behaviour change.

3 Human-Building Interaction

More recently, Human-Building Interaction (HBI) has emerged as an interdisciplinary field drawing on HCI, architecture, environmental psychology, and building sciences [2–5, 8]. Like eco-feedback research, HBI emphasises sustainability, examining how interactive building systems, interfaces, and feedback mechanisms can support energy efficiency, occupant comfort, and sustainable behaviour [2, 4, 5].

HBI provides a broader framing of interaction by extending the interface from a single point of interaction to the entire building environment [2, 4]. From this perspective, a building is a complex system of interconnected components, and users engage with it holistically through distributed interfaces rather than isolated devices or systems [2, 4].

Day et al.'s conceptual model of HBI frames the built environment as a layered system composed of interconnected sub-layers linked through control and feedback mechanisms [8]. This model offers a new perspective for understanding occupant behaviour and for applying interaction design principles to promote energy-conserving actions. Day et al. also highlight the multi-sensory nature of HBI and its influence on shaping user behaviour. For instance, [14] builds on these two perspectives to analyse and redesign the thermostat UI. By incorporating immediate thermal feedback, [14]'s "Feel-heat, Feel-it" thermostat helps bridge feedback across different layers of the building environment, enabling users to better anticipate and manage the behaviour their heating system.

4 Blending perspectives

Within sustainable HCI, complementary approaches such as Sustainable Interaction Design (SID) and Sustainable User Interaction (SUI) have emerged. SUI reframes unsustainable behaviour as a consequence of interactive system design rather than user shortcomings [9]. From this perspective, design choices shape behaviour and consumption, shifting the goal from changing individual attitudes to redesigning interaction environments that enable and reinforce sustainable practices.

HBI accommodates both the design-oriented perspective and the eco-feedback approach that targets behaviour directly. It also provides a broader framework that allows the extension of eco-feedback beyond its current scope and back to its initial scope as defined by McCalley and Midden by incorporating design elements such as signifiers and feedforwards [17, 21]. Within this framing, "eco-interaction" techniques can be integrated across all stages of HBI to more holistically support sustainable practices. These techniques should also address gaps between building system layers, as misaligned feedback or control has been shown to cause usability and performance issues [14].

To advance this research direction, it is essential to refine the terminology used in the literature—to differentiate eco-feedback studies according to the stage of Norman's action model they address, and to identify appropriate psychological theories that can provide a robust theoretical grounding for designs targeting one or multiple stages of the interaction loop. Such refinement will also help situate eco-interaction more clearly within the broader HBI context, supporting the development of design strategies that account for the temporal, spatial, and systemic complexities of intelligent and sustainable buildings.

5 Conclusion

In this paper, we discussed the initial conceptualization of eco-feedback and its influence on subsequent decades of research, which often diverged from the original definition and adopted a narrower scope. The emerging field of HBI offers a broader perspective for understanding how the building environment, together with building interfaces, shapes user behavior. By integrating this systems-level view, we can leverage HBI insights to develop new "eco-interaction" designs that remain true to the original vision of eco-feedback proposed by McCalley and Midden[18] and enables and reinforces sustainable behaviour in a more systematic way.

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