From Decision Trees to Program Design: Translating Household Context into HVAC Upgrade Pathways

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ABSTRACT

Residential upgrade programs often assume households can act on incentives once they are offered. In practice, households' decisions to repair or replace HVAC equipment are shaped by contextual constraints, such as tenure, perceived authority to make changes, access to contractors, and the feasibility of "enabling upgrades." This paper offers a program-facing translation of an interpretable decision-tree model that connects household context to upgrade actionability. Using survey-based evidence on HVAC modification behavior, we present a simplified tree that program administrators can use to identify key "decision gates," segment households into actionable groups, and match each group with appropriate delivery supports (e.g., contractor navigation, enabling-upgrade bundling, targeted financing, or landlord engagement strategies). We focus on actionable program insights rather than model benchmarking: the contribution is a practical segmentation and intervention mapping that can be adopted by program teams without requiring complex modeling capacity. The results illustrate how transparent decision rules can improve program design by aligning offerings with what households perceive as feasible in their lived context.

Introduction

Programs for residential energy upgrades typically prioritize technical potential and economic payback, then deploy incentives and messaging intended to close the gap between costs and benefits (Elliott et al. 2004; Farese et al. 2012; Langevin 2018; Hirst and Brown 1990; Schmidt and Stenger 2024). However, even well-designed incentives can underperform if they assume households are equally able to act on program offers (L. W. Davis 2024). Households make repair and replacement decisions within constraints that shape what feels possible, timely, and worth doing - constraints such as renting versus owning, the presence of enabling upgrades (e.g., electrical capacity), limited time and attention, uncertainty about contractors and quotes, or perceived hassle and risk (Li et al. 2021; Antonopoulos et al. 2024).

This paper argues that programs can benefit from a practical representation of actionability: a set of transparent, context-linked decision rules that helps program teams anticipate where households are likely to stall and what supports would unlock progress (Ajzen 1991; F. D. Davis 1989; Ball-Burack et al. 2025; Langevin 2018). We use an interpretable decision tree derived to translate household context into program-relevant segments

(Vijayshankar et al. 2026b). The paper's purpose is not to present a new adoption model or benchmark predictive performance. Rather, it offers a program design translation that turns model logic into implementable choices about targeting, sequencing of support, and delivery channels.

Methodology

Data

We draw on household survey data capturing HVAC modification behavior and household context, including tenure, dwelling characteristics, engagement with contractors and quotes, perceived barriers, and decision drivers (Fuentes et al. 2024). More specifically, the survey includes measures related to contextual constraints, market engagement, and household priorities and perceived benefits. Together, these variables provide a basis for examining not only whether households modify HVAC systems, but also how perceived feasibility and decision context shape those actions.

Modeling approach

We fit an interpretable decision tree to classify whether households reported HVAC modification behavior, using context and behavioral measures as predictors. Decision trees provide a transparent set of "if–then" rules that align with how programs operationalize eligibility and outreach (e.g., rules based on tenure, readiness, and engagement) (James et al. 2013; Kistinger et al. 2025; Dong et al. 2023). While more complex models may improve predictive performance, the decision tree is used here because its structure can be directly translated into program design: each split can be treated as a "decision gate," and each leaf can be treated as an actionable segment. Full descriptions of model selection, validation, and benchmarking extend beyond the scope of this manuscript (Vijayshankar et al. 2026b).

Translation approach

We translate the decision tree into a program segmentation framework by first identifying the most influential splits as actionability gates. We then interpret terminal nodes as action-oriented segments, or groups of households that face distinct combinations of constraints and motivations. Finally, we map each segment to program supports intended to address its likely binding constraint, such as enabling-upgrade bundling, contractor navigation, targeted financing, or landlord engagement.

Results

Overview: why a decision tree is useful for programs

Decision trees provide a compact set of "if–then" rules that resemble how program administrators operationalize eligibility, outreach, and service delivery. Rather than emphasizing model performance or comparing multiple algorithms (Vijayshankar et al. 2026a), this paper uses the decision tree as a translation artifact: each split is treated as a decision gate that indicates where a household's path toward HVAC modification is likely to diverge, and each leaf represents an actionable segment that can be matched to specific program supports. Figure 1 shows a decision tree for HVAC modification.

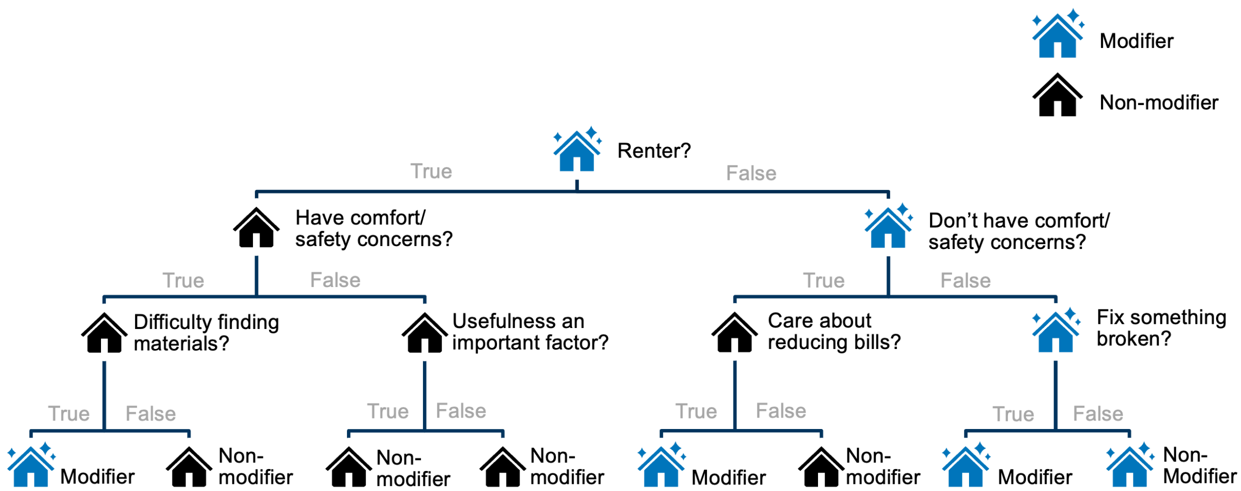

Figure 1. Interpretable decision-tree rules for HVAC modification outcomes. Each row shows a feature condition, illustrating how comfort, safety, cost considerations, and housing characteristics influence modification decisions.

Tenure as the first constraint

The first split in the decision tree is whether a household is a renter. This aligns with a well-known program reality: tenure shapes perceived authority, willingness to invest, and which delivery channels are feasible (e.g., tenant-facing outreach versus landlord/property-manager engagement) (L. W. Davis 2023; Souza 2018; Gillingham 2012). In practical terms, tenure is an early gate because it influences not only financial calculus but also who can approve work, who schedules it, and what types of upgrades are permissible. While this research focuses on the decision-making of residents, additional research is needed to understand property-owner decision-making for a more comprehensive view of changes in residential buildings.

From a program perspective, tenure should be treated as a front-end routing rule rather than simply another household characteristic. Programs that rely only on customer-facing rebate and choice architectures risk missing renter households, whose pathway to action may depend more heavily on landlord engagement, direct-install models, or whole-building approaches than on individual incentives alone.

Comfort and safety as a dominant decision driver – regardless of tenure

After tenure, the next split is comfort and safety concern, indicating that perceived urgency and well-being meaningfully structure pathways to HVAC modification (Fisk et al. 2020; Baniassadi et al. 2022; Antonopoulos et al. 2024). Comfort and safety concerns do not simply “increase motivation”; they differentiate the type of support households need.

Comfort and safety concerns operate differently across tenure groups. Among renters, these concerns do not automatically translate into HVAC modification; instead, they route households into a pathway where practical frictions such as access to materials or vendors become highly salient. Among owners, by contrast, comfort and safety concerns appear to move households into a more modification-dominant pathway, where repair or replacement is more likely regardless of whether equipment failure is the immediate trigger. For programs, this suggests that comfort and safety should be treated as a triage variable. Households experiencing immediate comfort or safety problems may benefit from fast-track service options and messaging centered on well-being and reliability, rather than standard bill-savings language alone.

Different binding constraints for renters and owners

At the third level of the tree, the binding constraints diverge more clearly between renters and owners. For renters, difficulty finding materials emerges as an important split conditional on comfort and safety concerns, suggesting that even households facing urgent needs may still be constrained by access barriers such as procurement, scheduling, vendor availability, or permissions. On the lower-urgency renter pathway, perceived usefulness becomes more salient, indicating that when comfort and safety are not pressing, renters may evaluate HVAC changes primarily in terms of whether the action seems worthwhile within a context of limited authority and shorter time horizons (F. D. Davis 1989; Venkatesh et al. 2003; Taherdoost 2022; Kakar and Kakar 2017).

For owners, different considerations dominate. Concern about reducing bills distinguishes a pathway where cost salience may support modification, while the importance of fixing something broken reflects a more classic repair-triggered route to action (Drehobl et al. 2024; EIA 2024; Nadel 2019). Taken together, these patterns suggest that the same program offering will underperform if it assumes that renters and owners face the same barriers. For renters, access and authority are often central, whereas for owners the key constraints are more likely to involve trigger events, salience, and transaction friction.

Actionable segments from the tree

To make the tree operational, we label a small set of leaf-level segments in program language. These are not "personas," but delivery-relevant groups defined by the tree's gates.

1. **Renter with comfort and safety concern face market access barrier** - These households have urgency but encounter procurement/scheduling barriers.
2. **Renter with comfort and safety concern facing lower market friction** - These households have urgency and fewer access frictions; landlord/property-manager alignment may be the key lever.
3. **Renter without comfort and safety concern** - These households are unlikely to modify absent a strong enabling condition (building owner action, bundled services, or a compelling co-benefit).
4. **Owner and bill-salient** - These households are receptive to cost framing and may respond to incentive design, audits, and clear total-cost pathways.
5. **Owner with comfort and safety concern or Owner that is repair-triggered** - These households face urgent needs; they benefit from rapid response, trusted contractors, and streamlined financing and approval.

Application from these delivery-relevant groups are more systematically analyzed in the following section and summarized in Table 1.

Program Design Implications: Targeting, Sequencing, and Delivery

Targeting: who to prioritize and why

The decision tree suggests that programs can improve uptake by routing households into different pathways early, rather than relying on uniform incentives and messaging. A practical starting point is tenure: renter households may be better served through landlord-facing tools, property-manager partnerships, or direct-install and whole-building approaches, while owner households can remain on more conventional customer-facing rebate and financing pathways (Gillingham 2012; L. W. Davis 2023; Souza 2018; Parag and Janda 2014).

A second routing step is urgency. Comfort and safety concerns identify households that may benefit from fast-track scheduling and reduced transaction approval time. In practice, a short intake or pre-screen that asks whether a household rents or owns and whether the issue is currently tied to comfort or safety could be sufficient to assign households to an appropriate service track.

Sequencing: what to offer first

The tree also suggests that sequencing matters because, for some segments, the primary constraint is not willingness to pay but ability to act (Hirst and Brown 1990; Cattaneo 2019; Hesselink and Chappin 2019). For renters with difficulty finding materials, the priority may be access and coordination, including procurement support, vendor availability, scheduling assistance, and landlord permission, rather than rebates alone. For repair-trigger owners, the most effective first step may be rapid response paired with a trusted contractor pathway and fast financing approval, rather than extensive informational materials. For bill-savers, by contrast, the sequence may reasonably begin with an assessment, a clear explanation of expected bill impacts, and simple total-cost framing, followed by incentives and financing options.

Delivery: aligning channels and constraints

A key implication of the decision tree is that program success depends not only on what support is offered, but also on how and through whom that support is delivered. Households facing different combinations of tenure, urgency, and practical friction are unlikely to respond equally well to the same delivery channel. As a result, delivery design should be treated as a central program decision rather than a secondary implementation detail.

For renter households, delivery often depends on actors beyond the occupant, including landlords, property managers, maintenance staff, and housing organizations. In these cases, customer-facing rebates alone may be insufficient because the household experiencing discomfort is not always the household able to authorize or coordinate the work. Delivery strategies for renters may therefore need to rely more heavily on landlord engagement, portfolio-based approaches, direct-install models, or trusted intermediary organizations that can help coordinate permissions and scheduling.

For owners, delivery can more often proceed through direct customer pathways, but the appropriate channel still depends on the nature of the decision context. Owners motivated by bill reduction may benefit from digital tools, audits, contractor bid comparison, and financing offers that make value and total cost easier to evaluate. By contrast, owners responding to broken equipment or immediate comfort and safety concerns may need rapid-response pathways that reduce hassle, shorten timelines, and connect them quickly to vetted contractors. In these cases, delivery speed and trust may matter more than extensive information provision.

Taken together, these findings suggest that delivery should be matched to the household's likely binding constraint. When the primary barrier is authority, delivery should focus on the actors who control the asset. When the barrier is market access or coordination, delivery should reduce procurement and scheduling burdens. When the barrier is uncertainty about value, delivery should emphasize clarity, comparison, and financing simplicity. Table 1 translates these delivery implications into segment-specific pathways that program administrators can use to align outreach, contractor networks, and support services with household context.

Table 1. Translating decision-tree segments into program supports

Decision-tree segment (rule path)	Binding constraint (what's likely "stuck")	Program supports that fit the constraint	Best-fit delivery channel	What to track (segment metrics)
Materials-friction renters *(Renter, comfort and safety concern, difficulty finding materials)*	Market access, coordination, and permissions	Approved vendor network; program-managed procurement; turnkey or direct-install option; landlord engagement templates; priority scheduling	Property managers, community partners, and direct-install contractors	Time-to-appointment; quote-to-install conversion; drop-off reasons
Supported-urgency renters *(Renter, comfort and safety concern, not reporting materials difficulty)*	Authority alignment and speed	Landlord consent fast-path; health and safety framing; rapid-response repair funds or service crews; escalation support when landlords stall	Landlord lists, housing orgs, and maintenance networks	Landlord participation; approval turnaround time; completion within # days; unresolved cases
Low-urgency renters *(Renter, no comfort and safety concern, usefulness salient)*	Low perceived payoff and low control over asset	Whole-building or portfolio approaches; landlord incentives; integrate with maintenance cycles; bundle comfort co-benefits only when paired with owner action	Building owners, portfolio retrofit programs, and housing providers	Owner opt-in rate; units upgraded per building; persistence or retention; tenant satisfaction
Bill-savers *(Owner, cares about reducing bills)*	Decision confidence and clarity of value	Simple savings or total-cost calculator; audit/assessment; bid comparison help; clear rebates and financing pathway; contractor matchmaking	Utility marketing, digital tools, and contractor partners	Assessment-to-install conversion; financing uptake; cost per completed upgrade
Repair-trigger owners *(Owner, comfort and safety concern, "fix something broken" pathway)*	Urgency, hassle, and perceived risk	Rapid response scheduling; pre-negotiated pricing; same-week install; point-of-sale or on-bill financing; trusted contractor matching	Call-center triage, contractor network, and emergency response partners	Days-to-restore service; completion within emergency window; customer satisfaction; complaint rate

Evaluation: measuring actionability, not just participation

Because the tree highlights where household pathways diverge, programs can strengthen evaluation by tracking gate-specific points of drop-off rather than participation totals alone (Elliott et al. 2004; Farese et al. 2012; Muehleisen et al. 2016). Useful measures include routing shares by tenure, volumes entering comfort- and safety-related triage tracks, quote and scheduling outcomes for households facing access barriers, and time-to-action from intake or assessment to installation. Programs may also benefit from calculating segment-specific cost-effectiveness, such as cost per completed upgrade, to understand where tailored delivery pathways improve both participation and resource allocation.

This conference paper intentionally focuses on operational translation: converting an interpretable tree into program segmentation, sequencing guidance, delivery supports, and practical metrics. It does not reproduce comprehensive model benchmarking, full interpretability analyses, or methodological contributions reserved for the journal manuscript under review.

Limitations

This paper should be interpreted as a program-facing translation of survey-based patterns rather than a causal analysis of HVAC adoption. The decision-tree splits reflect associations in the data, meaning that variables such as renter status or comfort and safety concern are best understood as practical routing indicators rather than causal levers. In addition, both the outcome and many predictors are self-reported, which introduces the possibility of recall error, interpretation differences, and social desirability bias. The tree is also derived from a single sample collected in a particular context, so the relative importance of gates and thresholds may vary across housing markets, climates, contractor conditions, and policy environments. More broadly, decision trees achieve transparency by simplifying relationships, which means they may miss interactions captured by more flexible models. Finally, key operational frictions such as contractor availability, permitting delays, quote turnaround times, and landlord responsiveness are not directly observed. For these reasons, the segments proposed here should be used as hypothesis-generating and routing tools, then refined through local pilots and operational validation.

Conclusion

Residential HVAC modification is often modeled as a function of economics and technical potential, yet the pathway from interest to action is frequently constrained by context; especially tenure, perceived authority, urgency tied to comfort and safety, and practical market frictions. This paper presented a program-facing translation of an interpretable decision tree that makes these constraints operational. Rather than emphasizing model benchmarking or methodological novelty, we used the tree to identify a small set of actionability gates and convert them into implementable program segments with matched supports for more strategic and pluralistic deployment (Schmidt and Stenger 2023, 2024).

The decision tree highlights a simple but consequential implication for program design: households do not face a single "adoption problem." Renters and owners diverge early, and subsequent pathways are shaped by whether households are responding to comfort and safety concerns, by access barriers such as difficulty finding materials, and by motivations such as reducing bills or addressing broken equipment. Translating these gates into practice suggests concrete design moves, routing households into different service tracks, sequencing supports so that prerequisites and coordination barriers are addressed before incentives, and aligning delivery channels (e.g., landlord engagement, rapid-response contractor networks, or financing defaults) with the binding constraint for each segment.

For program administrators, the contribution is a practical framework that can be deployed with minimal analytic burden: a short intake that routes households by tenure and urgency; a small set of segment-specific supports; and a set of gate-aligned metrics that reveal where drop-off occurs. Future work should validate and refine these segments using local operational data and pilots, particularly across housing markets and contractor conditions. Even in its simplified form, however, the tree-based translation demonstrates how transparent decision rules can help programs better align offerings with what households perceive as feasible - improving both participation and the equity of program benefits.

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Disclaimers

This submission is intentionally positioned as a conference translation paper focused on program design implications from an interpretable decision-tree representation. It does not reproduce the full modeling contributions, benchmarking, or comprehensive interpretability analyses contained in the companion journal manuscript under review. Overlap is limited to background, a brief description of the modeling approach, and a simplified tree depiction to support program-facing discussion. The manuscript is under review at current stage and anticipated to be released prior to publication of this conference manuscript (Vijayshankar et al. 2026a). In addition, AI was used to improve the readability of the manuscript.

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