Bridging Home Repair and Decarbonization: Integrating Energy, Health, and Equity Data for Scalable Electrification in Detroit

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ABSTRACT

Low-income households experience disproportionately high energy burdens, limited access to retrofit programs, and housing conditions that inhibit electrification. In Detroit, a convergence of funding through the Detroit Home Repair Fund presents a unique opportunity to integrate energy, health, and housing interventions. This paper describes a project developing and piloting a decarbonization-readiness module embedded within an existing comprehensive home repair and energy assessment platform to streamline retrofit decision-making and optimize available funding streams. Fifty households will participate in this project, with ten receiving electrification upgrades, including efficient HVAC systems and building envelope improvements. These homes will be equipped with eGauge circuit-level monitors and indoor air quality sensors to quantify the relationship between energy use, retrofit performance, and health outcomes. The collected data will inform predictive energy models and utility rate optimization analyses. These models include parameterized inputs for home condition, climate, and utility rates, making them scalable to diverse climates and utility territories. In our baseline energy modeling of Detroit's climate and utility rate environment, electric heat pumps alone were not economically viable without accompanying weatherization upgrades. Hybrid configurations that retain legacy heating systems for backup, combining a natural gas furnace with a heat pump, may be a practical and cost-effective solution for reducing costs and greenhouse gas emissions. This paper presents a baseline modeling analysis to establish a transferable blueprint for unifying housing repair with home decarbonization in low-income communities.

Introduction

In Detroit, Michigan, an estimated 33% of residents live in poverty, and 75% identify as Black or African American (Data USA n.d.). The city ranks among the top 10 most energy-burdened metropolitan areas in the country, with some households spending up to 30% of their income on energy costs (Drehobl et al. 2020; Reames et al. 2021). University of Michigan's Poverty Solutions Center estimates that stabilizing housing in Detroit could cost as much as $5 billion, underscoring the scale, urgency, and magnitude of the challenge (Eisenberg et al. 2021). There is growing recognition that no single program can address these myriad needs at scale (Barrett 2022; Detroit Public TV 2022). Program staff and case managers who seek to help residents access funding for home repairs and retrofits consistently report frustration that clients are confused and discouraged from accessing housing services by the need to undergo repetitive and duplicative home assessments across multiple programs. This fragmented landscape, spanning health and safety repairs (including roof repairs, asbestos, and lead remediation), weatherization, energy efficiency, and decarbonization, creates barriers to holistic intervention and leaves potential benefits unrealized, particularly for the households that need them most.

At the same time, decarbonization of the residential sector has emerged as a central goal for addressing the climate crisis. Many cities and states, including Michigan, have set ambitious carbon-reduction targets and allocated new funding streams, including incentives and rebates under the Inflation Reduction Act to support heat pumps, electric vehicles, solar installations, and building-envelope improvements. However, these resources risk bypassing the communities most in need. For low-income households whose homes frequently exhibit poor insulation, deferred maintenance, undersized electrical panels, and structural deficiencies, electrification is rarely straightforward. Decarbonization is often viewed as something that comes at the end of a long sequence of repairs, after all health, safety, weatherization, and efficiency needs have been addressed. This framing leaves low-income households perpetually at the back of the line.

In Detroit, a convergence of funding and organizational momentum has been achieved through the Detroit Home Repair Fund (DHRF). DHRF is a multi-partner initiative launched in 2022 to provide critical, health-and-safety home repairs at no cost to low-income Detroit homeowners. Originally kickstarted by a $20 million investment from the Gilbert Family Foundation, DTE Energy, and other stakeholders, the program aims to preserve homeownership, prevent displacement, and help residents build generational wealth. Building on this momentum, the project described in this paper seeks to integrate energy, health, and housing interventions by embedding a decarbonization-readiness lens within an existing comprehensive home repair and energy assessment platform. We define low-income as 200% of the federal poverty level, which is the income requirement for DHRF. We define decarbonization readiness as a home with the electrical infrastructure, building envelope, and health and safety conditions sufficient for full electrification. In practice this usually means electric panels with adequate size and service rating, wiring that is up to code, and envelope weatherization sufficient for efficient heat pump operation. The housing stock served by the DHRF reflects the broader challenges of decarbonizing older, lower-income urban housing. Detroit's residential stock is predominantly aging single-family housing, with 58% of the homes built before 1950 (Drawing Detroit 2017).

Project Overview

This paper describes an ongoing collaborative research project, funded by the National Science Foundation through the Civic Innovation Challenge (CIVIC) program, that is developing and piloting a Decarbonization Readiness Assessment (DRA) module designed to be embedded within the existing comprehensive home assessment platform of the DHRF. The project is being carried out by an interdisciplinary team of researchers and community-based practitioners, including Pecan Street Inc., University of Michigan, Green & Healthy Homes Initiative (GHHI), and Jefferson East, Inc. (JEI).

The project's vision is a future in which Detroit home repair, weatherization, and efficiency programs can use a single comprehensive assessment protocol to align and braid financial resources from governmental, philanthropic, and industry sources; coordinate delivery of services; and achieve better, more equitable outcomes for low-income residents. To advance this vision, the project pursued several interconnected objectives. The team co-designed a decarbonization-readiness module through a participatory process involving community-based organizations, academic researchers, a national healthy homes advocate, and the regional utility DTE Energy. This module has been integrated with existing assessments of the DHRF and DTE Energy Efficiency Assistance (EEA) programs and tested on forty homes. Ten of these are undergoing electrification upgrades, including more efficient HVAC systems, building envelope improvements, and efficient electric appliances. We are instrumenting these homes with eGauge circuit-level energy monitors and indoor air quality sensors. The energy and air quality monitoring will quantify how energy use and retrofit performance affect health outcomes, and the air quality data could eventually help us determine whether a home needs added health or safety upgrades, and which upgrades to prioritize.

In parallel, the project is developing predictive energy models and utility rate optimization analyses to explore the economic viability of electrification for low-income households in Detroit's climate and rate environment. By grounding the analysis in Detroit's housing stock, climate, and DTE rate environment, the project supports Michigan's residential decarbonization strategy, including the MI Healthy Climate Plan and the statewide goal of 2.8 million heat pump installations by 2040 (EGLE 2022; EGLE 2026). The DRA and its modeling workflow are designed to be replicable by community-based organizations such as JEI and other DHRF partners.

Overview of Paper

The overall project consists of three integrated components. The first is the co-design and piloting of the DRA module itself. A working group of eight representatives from the four organizations convened over six virtual sessions to collaboratively design an assessment tool that evaluates a home's infrastructure readiness for electrification, including wiring, circuits, electrical panel capacity, and weatherization status, while also identifying health and safety repairs that must be addressed before decarbonization can proceed. The tool was designed with priorities of usability, efficiency, and minimal disruption for community partners, home assessors, and residents. It was built to be compatible with the TrueContext digital platform already in use by DHRF administrators, minimizing the need for new technology infrastructure or extensive training. This module has been completed and is now integrated into JEI's DHRF assessment workflow.

The second component, which is not a focus of this paper, involves deploying electrification retrofits, including heat pump installations, building envelope improvements, and related upgrades, in ten participating homes, alongside circuit-level energy monitoring and indoor air quality sensing. Once complete, these instrumented homes will provide the empirical data needed to validate energy models and quantify the co-benefits of decarbonization investments for low-income households, including changes in energy consumption, indoor environmental quality, and thermal comfort.

The third component is the engineering and economic modeling work that underpins the project's decision-support framework. A central goal is to determine when electrification, specifically the adoption of air-source heat pumps, is economically and technically viable for low-income households through modeling of home heating and cooling. However, several modeling frameworks exist for residential electrification studies, each offering trade-offs between accuracy and practicality. Simple calculators provide quick estimates and user-friendliness, but they lack precision (Seddiki et al. 2019; DOE 2024a; DOE 2024b). Load shape modeling relies on historical data and is not flexible for comparing the different building envelope conditions and behavioral patterns of low-income homes (Elmallah, Brockway, and Callaway 2020; Hecht, Das, and Sauer 2020). Thermodynamic models and building simulations provide detailed energy usage data, but they demand extensive data and calibration. For a more detailed review of different residential energy modeling frameworks, we refer the reader to Oyefeso (2025).

In this paper, we compare the equivalent thermal parameter (ETP) thermodynamic model and the Building Energy Optimization Tool (BEopt) building simulator developed by the National Laboratory of the Rockies (NLR 2006). The ETP model models indoor air temperature and inner mass temperature dynamics with physics-based differential equations (Sonderegger 1978; Subbarao 1981; Wilson, Wagner, and Colborne 1985). We employ the simplest version of this model, i.e., a single-zone home with on/off air conditioner control (Priyadarshan et al. 2024). BEopt provides a comprehensive analysis of all energy flows within a residential building, not just space heating and cooling. It solves the heat balance equations for each thermal zone. BEopt can simulate the impacts of various architectural and technological choices on energy consumption, system performance, and comfort. The ETP model uses abstract building parameters – thermal resistance and capacitance – but the link to specific architectural and technological choices is not as direct. On the other hand, the accuracy of BEopt depends on the accuracy of input parameters capturing building geometry, material properties, and construction details, HVAC systems and controls, occupant schedules and behaviors, and weather data; even then, BEopt results must be validated and calibrated to actual building temperature and energy data (Crawley et al. 2008; Magni et al. 2017). The ETP model requires less data than BEopt and incorporates real, measured home temperature and energy data to identify parameters; the accuracy of the ETP model relies on the quality of the data collected and the parameter identification process. Additionally, the computational requirements for the ETP model are much lower than BEopt. Due to these differences, it is interesting to compare these approaches.

We do not have sufficient data on the pilot homes in Detroit to compare the performance of each model in representing these homes. Sensors have not been set up in the pilot homes yet, so measured home temperature and energy data are not available for the ETP model. We have survey assessment data for the homes, which can be used to inform our BEopt model, but other building parameters that have a significant impact on home energy use and cost are not known at this stage. Instead, we model home energy use and cost for a home in Austin, Texas, for which we have sufficient data for both models. We use this case study to compare the results of both models and to investigate the advantages and disadvantages of each in assessing decarbonization potential. We are also able to utilize the information on the Detroit homes from the surveys to model different building configurations in BEopt to identify suitable homes for retrofit.

The contribution of the overall project is demonstrating a replicable model for embedding decarbonization readiness into existing home repair infrastructure rather than treating it as a standalone program. By co-designing the DRA with stakeholders who operate across health, safety, weatherization, and efficiency programs, the project is providing a transferable blueprint for unifying housing repair with home decarbonization in low-income communities. The participatory co-design process, grounded in the principles of collaborative research and led by the community-based practitioners, offers a practical methodology for other communities seeking to develop similar integrated assessment tools. It can also recommend the optimal home improvement suite for a particular building, climate, and rate structure using energy modeling tools. The project also addresses a critical and underexplored question: when is electrification actually feasible – technically, economically, and programmatically – for low-income households? Most decarbonization research and program design have been developed with the general housing market in mind. Low-income homes present a distinct set of conditions: older construction with deferred maintenance, higher rates of under-insulation and electrical deficiencies, constrained household budgets with low tolerance for utility bill increases, and limited access to the upfront capital that electrification often requires. By grounding its feasibility analysis in Detroit's housing stock, climate, and utility rate environment, the project yields findings directly actionable for programs and policymakers serving these communities rather than requiring practitioners to extrapolate from research on more advantaged housing stock.

Methods

Development of Decarbonization Readiness Assessment Module

JEI, with technical assistance from GHHI, currently implements a comprehensive health and safety home assessment as part of the DHRF, which is performed in real-time using a platform called TrueContext via mobile app. This existing DHRF comprehensive assessment, previously developed by GHHI and other local partners, served as a foundation for building a decarbonization readiness module used for this project. Staff from the four partner organizations formed an assessment work group, meeting every two weeks in the spring and summer of 2024 to co-design the decarbonization readiness module. As community-based partners who interact with residents and local stakeholders through DHRF, JEI and GHHI ensured that the development and implementation of the assessment was grounded in the lived experiences of the project's target population. Thus, this project followed a participatory action research framework, which has been shown to strengthen the rigor, relevance, and policy reach of research (Balazs and Morello-Frosch 2013). The active participation of community partners through this process was critical to ensuring that local knowledge, conditions, and lessons were incorporated in the overall research project.

The work group began by cross-walking the existing DHRF assessment with a list of inputs needed for Pecan Street's energy modeling. In some cases, questions needed for model inputs already existed in the DHRF assessment. For example, knowing the presence and type of air conditioning is required for modeling. This was already a question asked in the DHRF assessment, so no changes or additions were needed. Some questions required for modeling did not exist in the DHRF assessment and were therefore added. An example of this type of question was the type and amount of insulation present in a home. After completing a crosswalk between the DHRF assessment and decarbonization readiness inputs, we finalized the new list of DRA questions. GHHI created an add-on assessment module in TrueContext containing the new questions. GHHI and JEI field-tested the module and provided feedback, which was then incorporated into a final version of the module. When JEI conducts a home assessment for this project, they complete the DHRF home assessment and decarbonization readiness module; the data from these two submissions are then used by Pecan Street to complete energy modeling for the household.

The DRA questions are contained in a standalone module in TrueContext, which is a mobile app used by assessors in the field. Typically, the assessor completes the DRA after they have completed the DHRF home assessment, which is a separate module in TrueContext. The DRA contains 147 questions in the following categories: Appliances, Electrical, General Home Details, Home Condition, and Heating/Ventilation/Air Conditioning. Some questions are conditional; for example, if the assessor indicates that the home contains a dishwasher, additional questions appear about the details of the dishwasher. The entire form is hosted on the Pecan Street website (Pecan Street 2026).

Integration and Rollout

The decarbonization initiative was integrated into the existing service pipeline for residents approved for major home repairs through the DHRF. Embedding the project within an established home repair program allowed for direct access to low-income Detroit homeowners already engaged in rehabilitation services, minimizing additional intake processes and streamlining participant identification. Decarbonization measures were presented to residents during the repair approval process. For many households experiencing non-operational heating systems or malfunctioning appliances, electrification upgrades, including mini-split heat pump systems and appliance replacements, were introduced as complementary improvements aligned with ongoing construction work. An in-house inspector played a central role in the rollout, completing both the housing inspection and the required energy survey during the same visit. This dual-function approach reduced scheduling barriers, improved internal coordination, and allowed for immediate alignment between repair scope and energy upgrade opportunities. Engagement occurred directly through existing client communication channels, and staff maintained direct communication with participants throughout the construction and installation phases. Some residents elected not to participate in certain decarbonization measures due to concerns about potential electricity cost increases in light of anticipated DTE rate changes; all participation decisions were respected.

Energy Modeling

We next provide an overview of the ETP model, as applied in this paper, and the parameter estimation method. For an overview of BEopt we refer the reader to NLR (2006). We then describe the case study used to compare the two models. We additionally describe our method for parametric analysis using BEopt, which provides comprehensive prospective analysis across thousands of building configurations. Our analysis highlights the advantages and disadvantages of each modeling method and their application and implications for residential electrification for low-income households in Detroit.

The ETP model considers homes as single-zone thermal units with simple on/off thermostatic control that keeps the indoor temperature within a small range around the temperature setpoint. We use the discrete-time lumped-parameter model to capture the temperature dynamics of the home:

$$T_{in}(k+1) = T_{in}(k) + (1-\alpha)T_{out}(k) + Q(k),$$

where $T_{in}(k)$ is the indoor temperature at time step k, $T_{out}(k)$ is the outdoor temperature at time step k, $Q(k)$ is the air conditioner (AC)/heat pump cooling/heating demand at time step k (the cooling/heating electrical power is $|Q(k)|$/COP, where COP is the coefficient of performance). $Q(k)$ is positive when in heating mode and negative when in cooling mode. The parameters α and β are calculated as $\alpha = e^{-h/(RC)}$ and $\beta = R(1 - \alpha)$, where h is the duration of the time step in seconds, and parameters R (°C/kW) and C (kW-s/°C) represent the thermal resistance and capacitance of the home (Mortensen and Haggerty 1988). We estimate these parameters by solving an ordinary least squares regression using historical indoor temperature, outdoor temperature, and heating/cooling power data. We validate the resulting parameters by first checking that R and C are in a reasonable range, and then by modeling home energy usage and comparing the results to historical data. The full details of the model, parameter estimation step, and parameter validation are given in an electronic appendix (Knudtson and Mathieu 2026).

Case study. For a home in Austin, Texas, we construct a model in BEopt from home assessment information, and we use one-minute interval indoor and outdoor temperature data and AC compressor power draw data collected from June to September of 2022 by Pecan Street to construct an ETP model of the house. Thus, we can directly compare the results of the two models for the same home. Ideally, we would build the models from a home in Detroit, but sufficient home assessment data and temperature and AC power draw data were not available at this point in the project. However, we can utilize Detroit temperature data to simulate the modeled home to understand the cooling and heating energy our pilot homes might consume.

We simulate the heating and cooling needs of this home with Detroit typical meteorological year (TMY) data (i.e., the TMY2 file included with NLR OpenStudio-HPXML v1.10.0). Utility costs were calculated using DTE's Variable Time of Day residential electric tariff (DTE Schedule A, March 2026). We use both models to simulate home heating and cooling with (1) a heat pump system with backup resistance heating and (2) natural gas heating with AC cooling. For the ETP model, we calculate heat pump cooling and heating power used by the home using the equation above and the heat pump COP. We assume that systems (1) and (2) both use the same amount of cooling power and generate the same amount of heat, Q(k). Then the natural gas consumption of the home is the amount of heat generated, multiplied by the efficiency of the natural gas system. In contrast, BEopt has a separate model for the natural gas system. BEopt also models changes in heat pump efficiency due to outdoor temperature. More detail on our approach is given in the electronic appendix (Knudtson and Mathieu 2026).

We also study the sensitivity of energy and cost results from the models to changes in building envelope parameters. For the ETP model, this means varying the values of *R* and *C*; for the BEopt model, we vary attic and wall insulation levels (R-values) and air sealing tier (ACH).

BEopt parametric modeling and analysis. In addition to the case study comparison, we conducted a large-scale parametric simulation study using NLR's OpenStudio-HPXML v1.10.0, the same simulation engine that powers the BEopt desktop application. OpenStudio-HPXML performs hourly EnergyPlus simulations from a standardized HPXML building description, capturing the complex interactions among weather, building characteristics, HVAC equipment performance curves, utility rate structures, and more. The parametric analysis produced results for 34,672 unique building configurations, generating a comprehensive landscape of operating costs, energy consumption, and greenhouse gas (GHG) emissions outcomes. We used the same TMY weather files and electricity/gas rates used in the model comparison, as described above. CO_2 emissions were calculated using eGRID 2023 RFC West factors (1.09 lb CO_2/kWh for electricity; 11.7 lb CO_2/therm for natural gas).

Envelope parameters were varied across five attic insulation levels (R-0, R-13, R-30, R-49, R-60), four wall insulation levels (R-0, R-13, R-21, R-38), three air-sealing tiers (ACH50 of 3, 5, and 15), multiple heating setpoints (66°F, 72°F), cooling setpoints (72°F, 78°F), and building architectures (6). All HVAC equipment was automatically sized by the simulation engine to the building load. Dual-fuel systems that combine natural gas furnaces with electric heat pumps that work in tandem were modeled with switchover temperatures of 35, 40, and 45°F, representing the outdoor temperature threshold below which the gas furnace takes over from the heat pump.

Results

Decarbonization Readiness Assessment Design and Findings

A significant institutional outcome of the co-design process was the decision by DHRF and DTE Energy program administrators to allow the DHRF assessment, augmented by the DRA, to replace the Whole Home Assessment/EEA assessment. Working group members credited strong cross-organizational relationships and their organizations' internal capacity for aligning data requirements as enabling factors. This change eliminated a redundant inspection visit, reducing the burden on residents and laying the groundwork for braiding of funding streams across programs. Focus group participants identified several lessons for replication. First, reaching a shared definition of "decarbonization readiness" early was essential to keeping the group aligned; the working group converged on electrification of appliances and systems as the primary framework. Second, the iterative approach was important: administrators of the integrated assessment module committed to ongoing communication as the tool was piloted and adjusted based on field feedback. Third, a four-organization composition supported diversity of perspective while remaining small enough for consensus-based decision-making. Challenges included the limitations of remote meetings for complex design conversations and staff turnover across partner organizations, a common feature of grant-funded community work that future projects should anticipate and plan for, including clearly defining member roles from the proposal stage.

JEI has administered the DRA in 40 households in the DHRF program. Following assessments, the project team conducts internal decarbonization feasibility reviews for the homes, drawing on assessment data to evaluate readiness, cost implications, and repair sequencing. Several patterns emerged consistently across the assessed homes. Electrical panel capacity was a widespread constraint: 50% of homes had knob-and-tube wiring or panels at or below 100 amps, insufficient for all-electric heat pump installation without a service upgrade. Insulation levels were also frequently inadequate; 60% of homes had attic insulation below R-13, and 60% had no wall insulation. Outstanding health and safety conditions were present in a substantial share of homes, confirming that electrification cannot be sequenced before remediation in much of the housing stock. Although EEA covered most weatherization-related health and safety barriers, knob-and-tube wiring remediation remained a key challenge due to limited contractor availability and high costs. A subset of ten homes is currently receiving electrification upgrades and will be instrumented with eGauge circuit-level energy monitors and indoor air quality sensors. Retrofit performance and sensor data analysis for this cohort are ongoing; findings will be reported in a subsequent publication.

Energy Modeling Results

We summarize the ETP and BEopt model comparison and the BEopt parametric analysis.

Model comparison results. Table 1 details the results from the BEopt and ETP model for the case study. Both models show that the natural gas system uses more energy than the heat pump, but they disagree on the magnitude of that difference. The BEopt model predicts that the natural gas system uses roughly 2.1 times as much energy as the heat pump, whereas the ETP model predicts the natural gas system uses roughly 3.0 times as much energy as the heat pump. The ETP model also predicts higher energy usage and operational cost overall than the BEopt model for both systems. This likely indicates that the ETP model predicts a "leakier" operating envelope than the BEopt model. Indeed, as we vary the building envelope parameters in both models (thermal resistance and capacitance for the ETP model, wall and attic R-values and ACH50 for the BEopt model), we see that as the building envelope worsens, the gap in performance and operational cost between the heat pump and the natural gas systems widens. Figures 1 and 2 show this trend in energy usage and cost for both HVAC system types (heat pump in red, natural gas in blue) as R and C parameters for the ETP model vary. We note that the ETP model is much more sensitive to R than to C.

Table 1. Operational cost and energy usage computed with the two models

	Heat pump		Natural gas	
Output	BEopt	ETP	BEopt	ETP
Energy (MBtu)	41.7	97.4	87.0	290.1
Cost ($)	$2,398	$5,424	$1,235	$2,990

Additionally, we compare the range of results possible with each model. Figure 3 shows energy usage and cost for various HVAC systems modeled with the ETP model and BEopt. The ETP model data is the same as shown in Figures 1 and 2; the BEopt data is from the parametric analysis for many building configurations and system types, including dual-fuel use systems. The shape of the relation between energy and cost is unsurprising, as utility rates are linear with respect to energy use; however, we note that the results using the ETP model approximately cover the same range of energy and cost as the BEopt model.

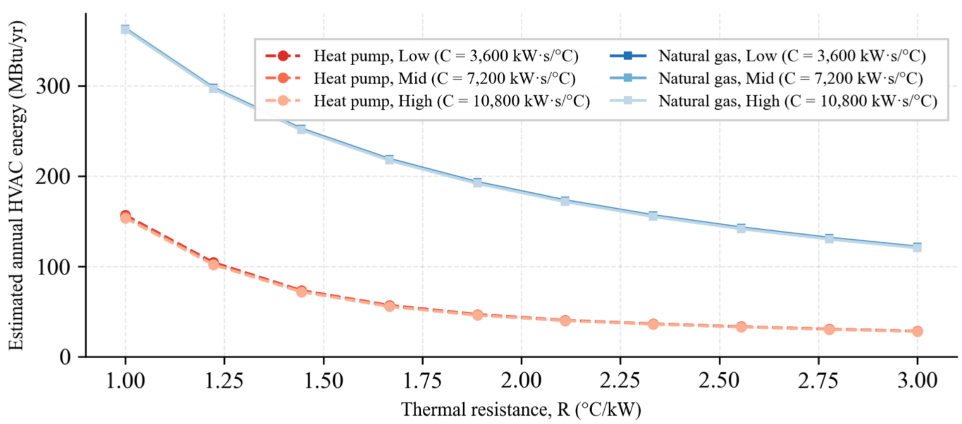

Figure 1. ETP model estimated annual HVAC energy versus thermal resistance at three thermal capacitance levels.

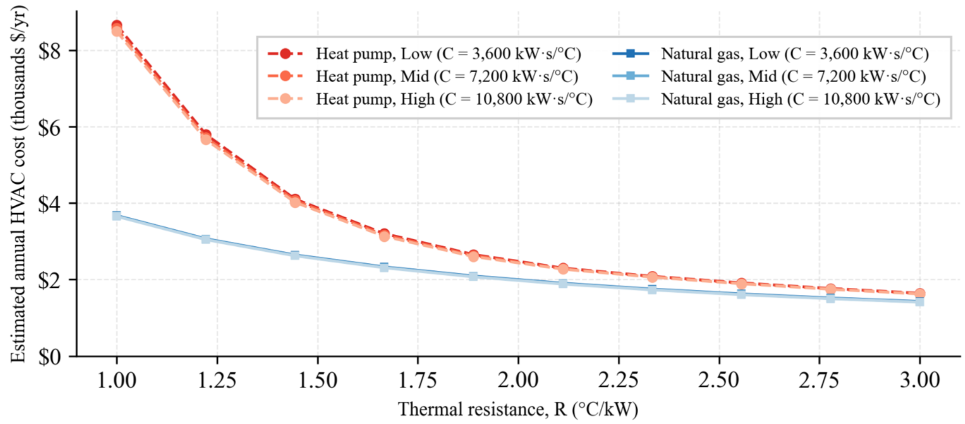

Figure 2. ETP model estimated annual HVAC cost versus thermal resistance at three thermal capacitance levels.

In summary, the models agree directionally for all major changes to the home envelope and HVAC system. Heat pumps consume less site energy than gas systems despite higher operating costs. Gas furnaces remain cheaper at every insulation level under DTE's current rate structure. Envelope thermal resistance is the dominant parameter affecting energy costs, and the first increment of insulation captures a disproportionate share of savings. The main divergence is that the ETP model predicts higher absolute energy consumption than BEopt at comparable thermal resistance levels in the case study home. This likely reflects differences in internal gain assumptions in the models and physical detail of the home. As the project cohort expands, each home receiving both a field assessment and monitoring equipment will provide an additional paired data point. With sufficient paired homes spanning Detroit's housing stock, it will become possible to systematically map model agreement and clarify each model's operational niche.

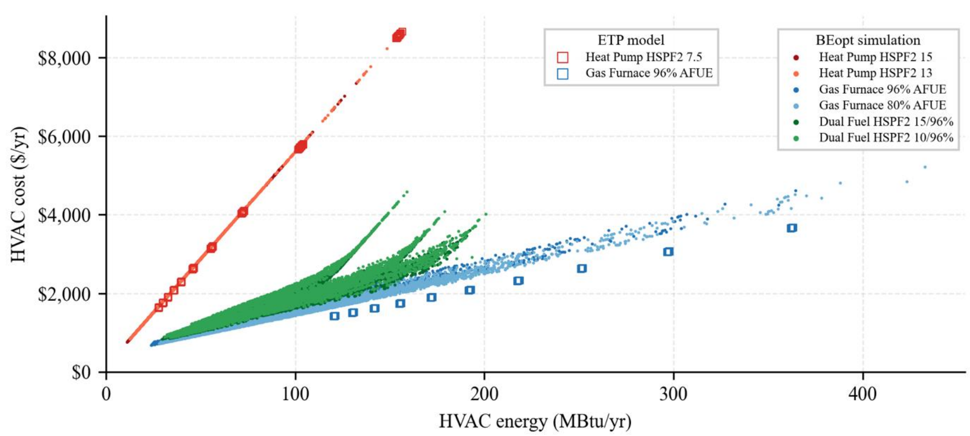

Figure 3. HVAC operating cost versus site energy for all simulation configurations for BEopt and ETP models.

BEopt parametric model results. Across all model runs, HVAC system type had the largest impact on annual energy use and operating cost. The greatest savings came from replacing inefficient systems with high-efficiency equipment and adding insulation to uninsulated homes. Figure 4 summarizes the median annual HVAC system operating cost across all simulated envelope conditions for each system type. The cost rankings reveal a clear hierarchy. Gas furnaces achieve the lowest median operating costs across all envelope conditions. Dual-fuel systems occupy a middle position, and all-electric heat-pump-only systems are the most expensive to operate.

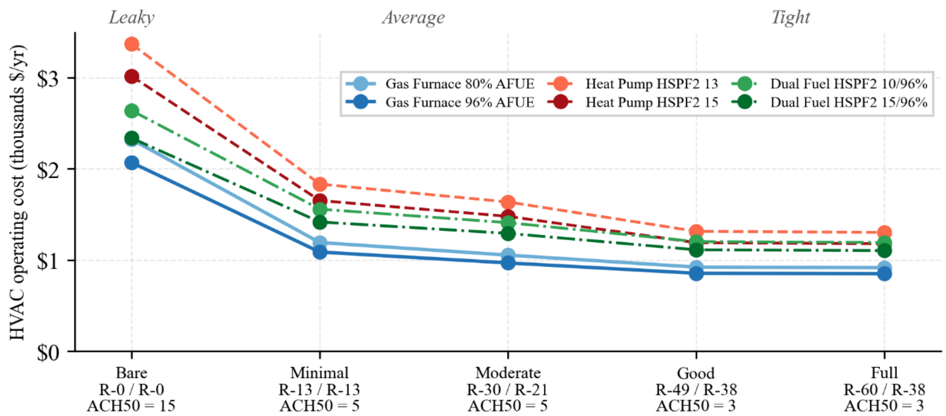

Figure 4. BEopt model annual HVAC operating cost by system type at five envelope tiers.

Figure 5 shows that heat pumps consume substantially less site energy than gas and dual-fuel systems at every envelope tier. The HSPF2 15 heat pump achieves a median of 31.9 MBtu per year across all envelope conditions, compared to 77.4 MBtu for the 96% AFUE gas furnace, a reduction of 58.8%. Gas furnaces underperform dual-fuel systems in leaky envelope conditions but outperform them in tight envelopes where reduced heating loads limit the dual-fuel system's heat pump advantage.

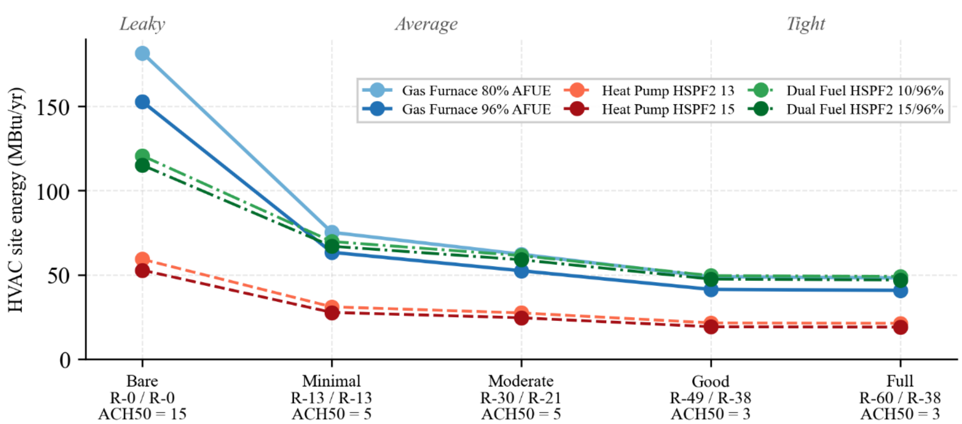

Figure 5. BEopt model annual HVAC median site energy by system type at five envelope tiers.

As shown in Figure 6, CO_2 emissions rankings add further nuance to the cost and energy findings. At the fully insulated tier, the 96% AFUE gas furnace and the HSPF2 15 heat pump produce approximately 5,940 and 6,852 pounds of CO_2 per year, respectively. This near-parity reflects Michigan's carbon-intensive electricity grid. Despite consuming less site energy, heat pumps draw from a generation mix still heavily reliant on fossil fuels. Dual-fuel systems at lower switchover temperatures can produce more CO_2 than gas-only systems because the heat pump operates primarily during moderate weather, while the gas furnace handles the high-load winter hours that account for most annual heating demand.

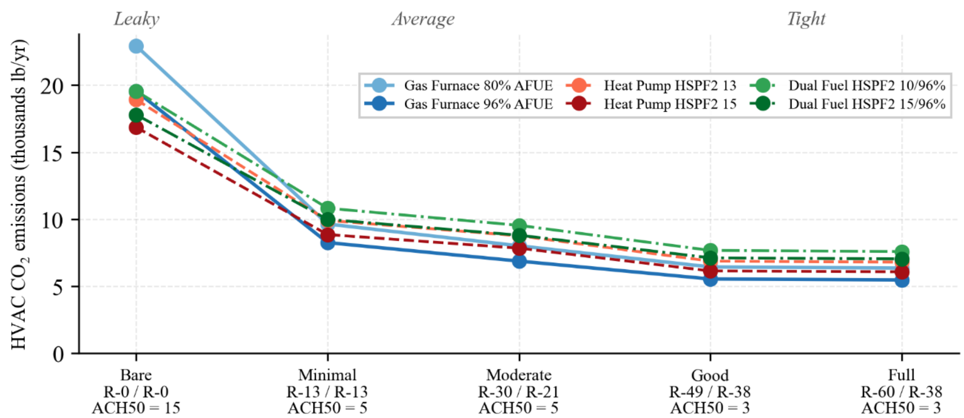

Figure 6. BEopt model median annual HVAC CO_2 emissions by HVAC system type at five envelope tiers.

While decarbonization motivates electric retrofits, operating costs often determine viability for cost-sensitive low-income households. Figure 7 shows utility operating costs at the “Full” insulation level, where the cost hierarchy between heat pump and gas and dual-fuel options narrows but remains unchanged for the top four HVAC systems. Heat pumps have the highest median operating costs among HVAC systems, while dual-fuel systems compete closely with gas furnaces. This is a more practical cost comparison because envelope improvements often coincide with other retrofits like HVAC replacement.

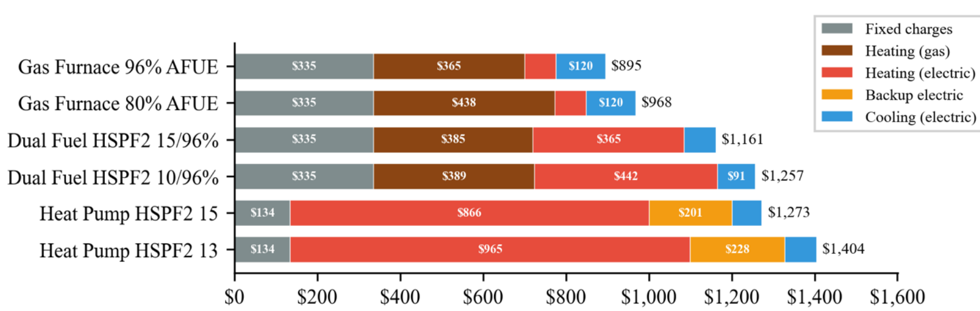

Figure 7. Median annual HVAC operating cost at “Full” insulation level by system type.

Discussion

This project is still in progress but has already generated a range of practical insights spanning technical, programmatic, and collaborative dimensions. The lessons described below are offered as guidance for other communities and organizations seeking to design and implement similar integrated decarbonization and home repair initiatives.

- **Program eligibility boundaries limit retrofits.** The project encountered recurring ambiguity around which measures qualify for coverage under DTE’s EEA program. Certain improvements that are prerequisite to electrification, such as electrical panel upgrades or specific insulation measures, fell into gray areas where EEA eligibility was unclear or inconsistently applied. This resulted in households not receiving measures that would have improved both energy performance and electrification readiness. Clearer program eligibility guidance, or explicit carve-outs for electrification-enabling infrastructure, would reduce friction and improve outcomes. Another example is the Michigan Home Energy Rebates (MiHER) Program, which is funded through the Inflation Reduction Act (IRA) and provides rebates to help households install energy efficiency upgrades. The program does not have funding budgeted for non-energy deficiencies (e.g., roof leaks), so households are effectively shut out from using the rebates for efficient system upgrades like heat pumps that would require building envelope upgrades. To achieve statewide energy and decarbonization goals, policymakers should broaden eligibility criteria and increase funding for enabling upgrades.

- **Relationship and timeline management affect stakeholder participation.** A large part of DHRF's success to date is based on the strong relationships and trust that have been built between nonprofit partners, contractors, and residents. Under this project, JEI solicited bids for decarbonization upgrade measures, and those bids were then used to analyze the cost-benefit for the household. This layer of review and analysis added some additional time to project schedules, and many reviews resulted in not moving forward with the work. This created some level of frustration for contractors and residents, which JEI managed as part of its regular customer service process. Future work involving contractors and residents could consider committing to a quick review period, standard guidance to help manage expectations, and perhaps a stipend for contractors who participate in the bid process, even if the bid is ultimately unsuccessful.
- **Contractor workforce constraints limit implementation capacity.** Heat pump installation, particularly in large, older homes requiring panel upgrades or rewiring, demands contractors with specialized training and experience. In Detroit, the pool of contractors meeting these qualifications and willing to work within the program's cost and administrative requirements was smaller than anticipated.
- **More data is needed to validate building energy models for predicting home energy use.** The ETP and BEopt case study results agree directionally that, while a heat pump with backup resistance heating consumes less energy than a natural gas system with AC cooling, the former places a higher energy burden on the resident. However, exactly how much greater that energy burden would be is inconclusive with the data we have now. Once baseline and post-retrofit home energy data are available for the Detroit homes, we will be able to validate the building energy models and evaluate if one or both is useful for predicting future home energy use and cost.
- **Weatherization before heat pump installation is imperative.** The parametric analysis demonstrates that installing a heat pump in a poorly insulated home can cost significantly more than upgrading the home envelope first, even after controlling for unknown building parameters. Backup electric resistance heat drives up heating costs and activates more often in a leaky home. Programs should require minimum envelope standards before approving heat pump installations with backup resistance heat, or at minimum they should sequence envelope work to precede or coincide with HVAC equipment changeover. This finding is also consistent with prior analyses of weatherization options for 51 Southeast Michigan homes (McKenna et al. 2024).
- **In some cases, dual-fuel systems may offer a short-term bridge to electrification.** If households keep their existing furnace, it can be supported by a heat pump until program incentives, policy, and market transformation open more opportunities for full

decarbonization in the future. However, it's important to note that low-income households have a host of additional roadblocks to electrification, including delayed maintenance needs that can exacerbate energy burden if not treated on a case-by-case basis. The analysis identifies dual-fuel systems that use heat pumps to heat homes at mild temperatures and natural gas systems during the coldest weather as another option to examine for cold-climate electrification in Detroit. The modeling results suggest that in dual-fuel configurations, keeping the existing furnace may offer a short-term bridge between gas dependence and full electrification but it is not a universal fix, especially for low-income families. Although there is no one-size-fits-all solution for households with high energy burdens, programs focused on low-income communities may evaluate dual-fuel options with *existing* highly efficient furnaces in the homes as a short-term transitional option for families alongside all-electric alternatives, particularly for homes with marginal electrical infrastructure or limited budgets for envelope work that can't address the chronic structural deficiencies driving high energy burdens. For those reasons, further piloting with a larger sample size is needed to test the viability of implementing dual-fuel systems in practice.

- **Electrification and grid decarbonization are both needed.** Under DTE's current electric generation mix, residential electrification does not meaningfully reduce GHG emissions. HVAC systems have a 15–20 year service life; however, this emissions comparison is a snapshot of the current grid. A gas furnace installed today locks in its emission rate for its entire service life, while a heat pump's emissions can decline as the grid becomes cleaner. The relevant comparison is not today's emissions but cumulative lifetime emissions. Furthermore, with geopolitically driven volatility in fossil fuel prices, dual-fuel systems also provide utility cost stability to households should natural gas prices suddenly spike. We did not quantify this benefit due to high uncertainties in future gas vs. electric utility costs, but low-income households may perceive this resilience as a benefit of dual-fuel systems.

Conclusion

Low-income households with aging housing stock in cold climates face electrification challenges that span building envelopes, electrical infrastructure, rate design, workforce capacity, and program access. This project demonstrates that decarbonization readiness can be practically embedded within existing home repair programs to address these barriers using a whole house approach. Our baseline energy modeling shows that under current DTE rates, heat pumps cost more to operate than high efficiency gas furnaces. We will collect local energy data during the pilot to explore whether building envelope weatherization and dual-fuel HVAC configurations may offer a transitional bridge as the grid decarbonizes and gas furnaces reach their end of life. In addition to ensuring home interventions are not adding to household energy costs, future studies must look at holistic long-term and short-term needs of low-income households. Future studies must evaluate the health, safety and economic needs of low-income households and communities, including prioritizing households and communities that will see health benefits from air quality improvements inside and outside their home, studies that collect diverse data metrics, build further capacity for program scale and improve overall living conditions for the most vulnerable families in Detroit. The assessment tools, participatory design process, and modeling framework developed here are transferable to other communities seeking to unify housing repair with residential decarbonization.

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AI-assisted tools used: Claude (Anthropic).
Used for: writing analysis code, developing figures and data visualizations, editing text
Extent: light text editing / formatting. Moderate for code and visualization generation.