Achieving Deeper Energy Retrofits with Philadelphia's Built to Last Program

February 2026

Executive Summary

The Philadelphia Energy Authority (PEA) Built to Last (BTL) Program is an anti-poverty effort that initiated in 2021 to restore the safety, health, and the affordability of homes in Philadelphia. With more homes occupied by owners than other major East Coast cities, the transfer of these homes from one generation to next is a major way in which limited income Philadelphians build and retain wealth. However, due to maintenance and renovation deferrals, many homeowners struggle to keep their properties in safe conditions despite the existence of several city-based economic development and health-related programs and initiatives. One of the major goals of the PEA Built to Last initiative (which kicked off during the coronavirus pandemic) is to make access to these programs seamless and streamlined for homeowners, with a recognition that occupant health starts with housing.

In addition to braiding the previously siloed city resources, for the purposes of this grant project, PEA teamed up with New Ecology, Inc. to learn how its innovative BTL platform could advance strategies needed to achieve deep-energy retrofits (DERs). By adding federal resources from the US Department of Energy's Weatherization Assistance Program (WAP), PEA Built to Last not only aimed to improve its own objectives but also to examine how its learnings could help to resolve WAP shortcomings in the region. This Roadmap describes the likely conditions and decision-making factors when pursuing a DER and electrification project in the context of Philadelphia rowhome. The Roadmap also offers guidance, including suggested design elements and considerations with respect to constructability, in addition to identifying areas in need of future research.

The major findings of this ambitious project are summarized below:

1) The average property that enters the BTL program is a century-old two-story rowhome with aging or non-functional building systems. Decades of deferred maintenance have resulted in complexities that cause these homes to be ineligible for WAP assistance, including visible structural damages as well as health and safety concerns.
2) While deep energy retrofits are possible to achieve in these homes, the approach requires thoughtful sequencing and a continuum of interventions that ideally begin with solving underlying health and safety concerns, then moving on to the installation of energy efficiency measures prior to considering electrification.
3) Standard retrofits and deep energy retrofits provided to homeowners under the BTL programs did not differentiate significantly in implementation cost given the prevalence of structural deficiencies as well as health and safety measures that needed to be addressed as prerequisites. That said, homeowners' energy savings outcomes were significantly higher when DER measures were implemented, especially when those were pursued in combination with solar.
4) Many areas of uncertainty remain with respect to pursuing deep energy retrofits in the context of the BTL typology, including but not limited to how to account for the possibility of adjacent vacancies as well as how to size HVAC equipment given air-leakiness. Further work by BTL and its network of providers will help to refine future approach to this work.

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Introduction

Project Goals and Scope

New Ecology worked with the Philadelphia Energy Authority for three (3) years to learn about their Built to Last collaborative home repair and energy efficiency program. The goal of this collaboration was to determine what additional opportunities exist to achieve deeper energy retrofits.

This project has defined Deep Energy Retrofits (DER) as projects achieving greater than or equal to (≥) a 40% reduction in site energy. While initially this definition did not include solar, the impact of leased solar was shown to be significant and was added to the calculated savings to show a more accurate picture of energy savings.

Opportunities to understand the value and challenges of converting fossil fuel fired equipment and appliances to electric were of particular interest to the project team. Electrification is defined here as converting some or all of a home's fuel fired equipment and appliances to electricity. In the home typology addressed in this work, heating systems, water heating systems, stoves, and clothes dryers were all considered for electrification.

Intended audience and how to use this report

This evaluation of retrofit projects is intended for use by local practitioners working in weatherization and home repair in Philadelphia. The information presented also provides important insight and guidance for other cities with similar building typologies and sheds light on areas where more investigation is needed.

This report provides a framework for thinking about deep energy retrofits in the context of working in limited income communities with constrained resources. We hope that it can be used to help guide smart, effective energy retrofits that maximize the efficiency potential of the properties served. No project is ideal, and difficult decisions need to be due to limited funding. The intention of this documentation is to help practitioners to know:

- When and how to transform standard energy retrofits into deep ones.
- What intervention measures drive deep savings.
- When electrification can be a valuable tool.
- When electrification should be avoided.
- How many retrofit project measures may be interrelated and impact each other.
- What communication and collaboration may be needed to maximize funding and energy savings.

Typology Overview

Philadelphia proudly holds a place in history as one of the nation's earliest cities and the nation's first capital. Like many Mid-Atlantic cities, Philadelphia has ridden the booms and busts of urban development and prosperity. Philadelphia's housing stock has risen, fallen, and shifted along with the rest of the city. The majority of Philadelphia's residential housing stock was built before 1941. Masonry rowhomes are the dominant residential housing type in the city (Table 1) and in the Philadelphia Energy Authorities' Built to Last (BTL) project portfolio. The properties evaluated during this project fit solidly into the age and architecture of the city; all but one of the 49 residential properties evaluated were masonry rowhomes.

Table 1: Typical Built to Last (BTL) housing typology

Typical BTL Housing Typology	
Type	Single Family Rowhome (Attached)
No. Beds	2-3
No. Baths	1
Position	Mid-Row
Average Age (YR)	98
Average Size (SF)	1,240
Heating Fuel	Natural Gas

The age, construction type and systems of the properties are representative of many Mid-Atlantic cities. As housing stock in these cities ages, home repair and maintenance become an increasingly significant issue, especially in limited income households.

Age of Homes

The majority of properties were built before 1925, meaning that most homeowners are now dealing with properties that are more than a century old. In the BTL portfolio, only three homes were built after 1940. (Figure 1).

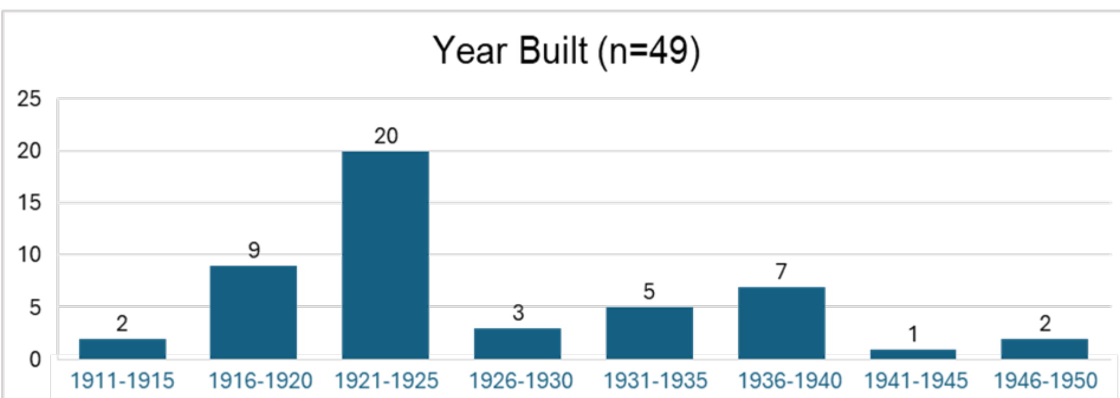


Figure 1: Age distribution of evaluated homes.

Correlation of Building Age and Energy Usage

The BTL properties were grouped by the decade of construction to look for a correlation between the initial energy usage. The overall energy use was measured in thousands of British thermal units (kBtu) which was then normalized by gross floor area (SF) and age. Of the 49 properties evaluated, there was little relationship between the age to the pre-intervention energy usage of the properties, with the average being 80 kBtu/SF. The 3 properties built after 1940 had less energy usage when normalized by gross floor area, but statistical significance cannot be drawn with such a small sample size (Figure 2).

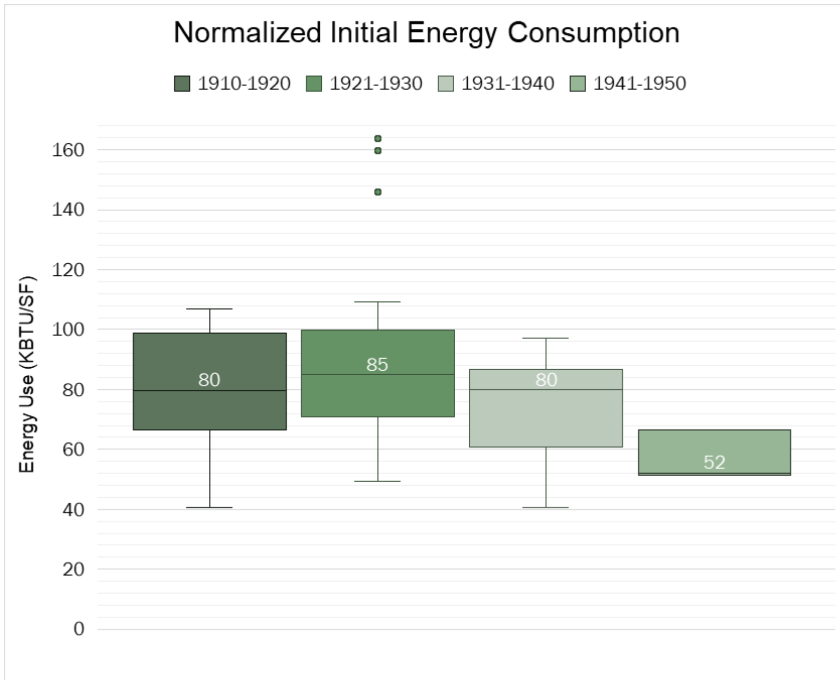


Figure 2: Pre-intervention energy consumption normalized by gross floor area.

Equipment Types

Space heating, water heating, cooling, cooking, and laundry systems are an important aspect of the building typology to understand. As shown in Figure 3, the majority of properties were found to have natural gas boilers followed by natural gas furnaces. Twelve percent of the evaluated properties were heated with fuel oil at the start of the project and only two buildings were heated with electricity. The water heating fuel is predominantly natural gas (88%) and a minority of properties (12%) outfitted with electric resistance storage tanks. The majority of the properties cooled at least portions of the house with window air conditioning units (82%), twelve percent had no cooling system, and six percent (just 3 properties) had central cooling.

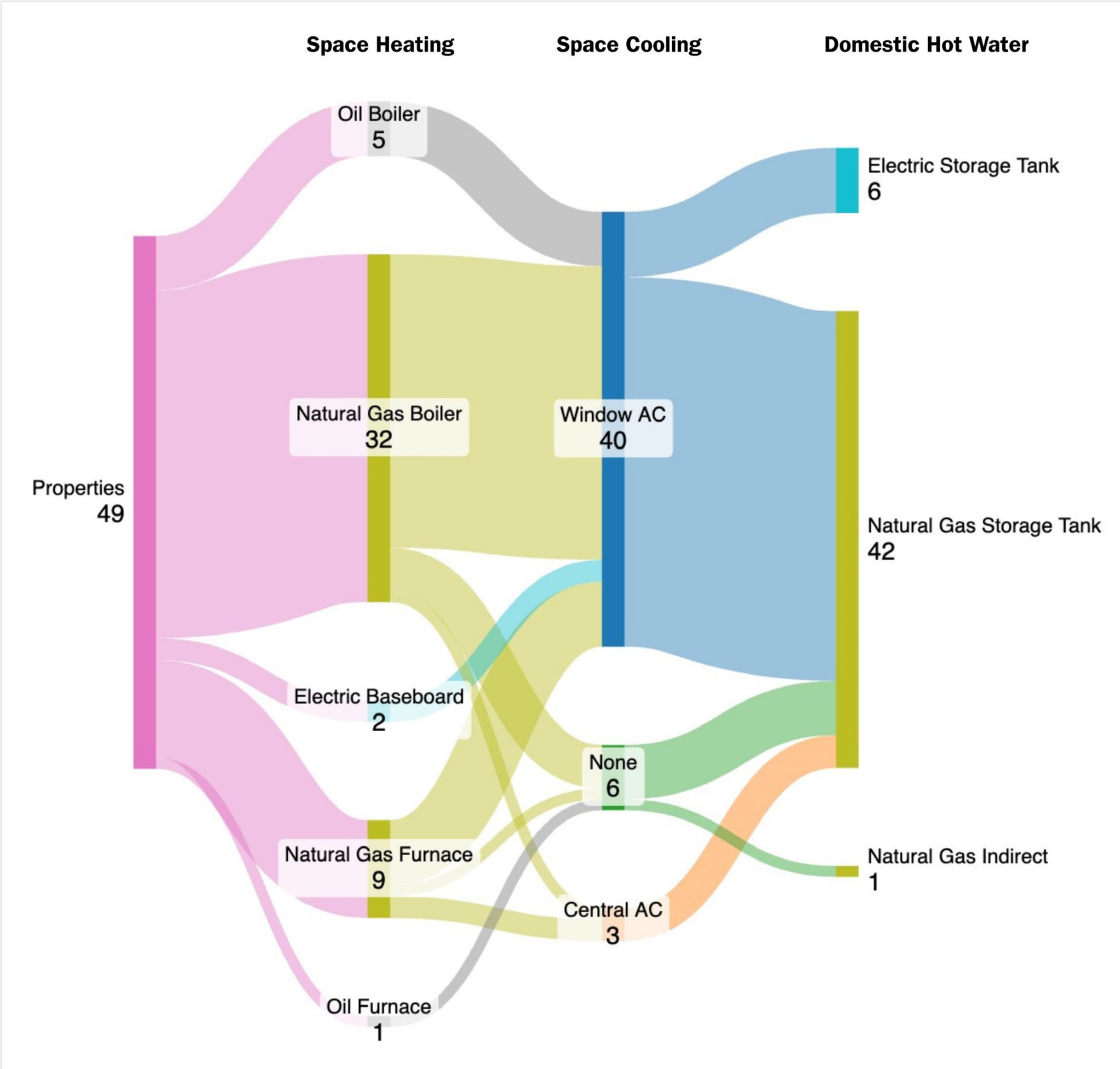


Figure 3: Prevalence of space heating, space cooling, and domestic hot water system types.

Natural gas is the predominant fuel used for cooking in city homes. Forty (40) of the 49 properties evaluated had gas stoves at the start of the project (Figure 4). Data for clothes dryer fuel type was incomplete, but the data available showed that 39% of properties dried clothing with electricity, while 27% used natural gas (Figure 5).

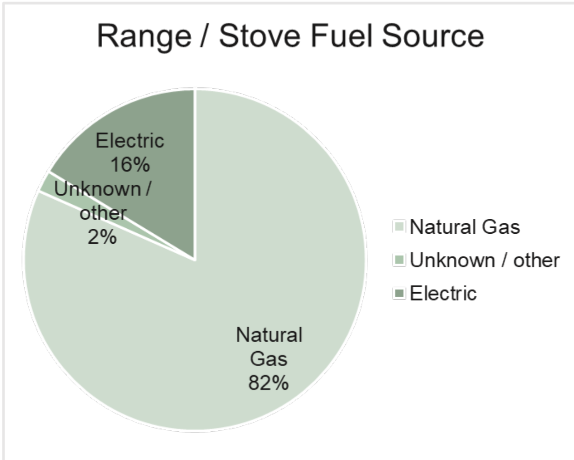


Figure 4: Stove fuel sources

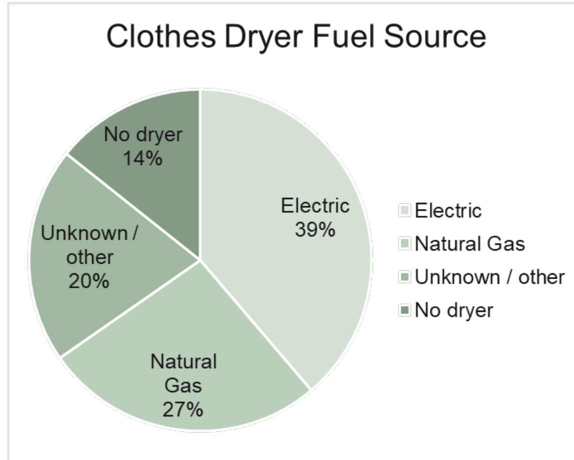


Figure 5: Clothes dryer fuel sources

Pre-Intervention Conditions Driving the Need for Retrofit

As properties age, their maintenance becomes more challenging and expensive; limited income homeowners do not often have the necessary resources to upkeep these older homes. The rising costs of building materials also impact homeowners' ability to perform repairs, maintenance, and necessary upgrades to their homes. This has resulted in a slow, but steady decline in the condition of many Philadelphia rowhouses. This is not unique to Philadelphia.

Retrofits performed by Built to Last are triggered by significant maintenance and repair needs. Figure 6 outlines many common pre-intervention conditions found in homes served by the Built to Last Program.

Moisture

- Primary and Secondary Roof Leaks
- Plumbing: sewer line failure, main stack failure, leaking drains, waterline, toilets.
- Foundation Moisture: basement drain failure, foundation seepage, exterior drainage issues

Electrical

- Knob and tube wiring
- Ungrounded systems
- Unsafe wiring and junctions
- Aging, undersized, or dangerous electrical Panels
- Non-GFCI outlets

Hazards

- Friable Asbestos: boiler or furnace Insulation, boiler piping and duct insulation, deteriorated basement floor tiles
- Suspected Mold

Major Missing Systems

- Un-Useable Kitchens or Bathrooms
- Non-Functional Heating Systems

Figure 6: Common pre-intervention home conditions

Weatherization Deferrals

When a property has significant health, safety, and durability deficiencies, weatherization programs are forced to “defer” properties, meaning that the property cannot be served through the program until the deficiencies are addressed. The deficiencies are reported to the resident and then projects are placed on a deferral list. Ultimately, it is up to the resident to resolve the deferral issues before their weatherization application expires. This is often an insurmountable obstacle for residents.

A 2024 study from the American Council for and Energy Efficiency Economy (ACEEE)[1] surveyed weatherization providers nationally about deferral causes in their region. The most frequently reported reasons for initial deferrals were roof leaks or repairs (estimated median 45% of deferred homes), followed by floor damage (estimated 23%), and unsafe or outdated electric service panels (estimated 23%). See Table 2 for the most commonly reported deferral causes.

[1] *Estimating the Impacts of Weatherization Readiness Programs | ACEEE*. https://www.aceee.org/research-report/b2504. Accessed 10 Feb. 2026

Table 2: Prevalent national weatherization deferral causes.

Top Deferral Causes in 2024 National Survey
Envelope issues such as roof leaks (45%) foundation damage (15%)
Unsafe, damaged, or outdated electrical service panels (23%) and wiring (11%)
Plumbing leaks or standing water in basement (10%), or damaged or missing gutters/downspouts (10%)
Presence of pests (15%), asbestos (13%), or mold (10%)
Occupant behavior (25%)

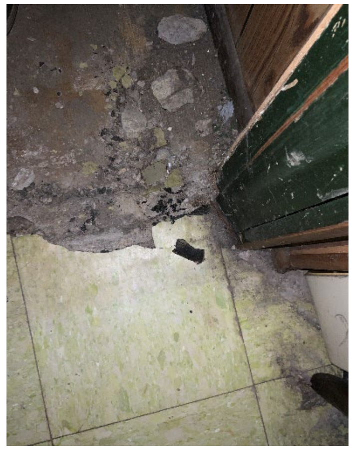
Locally, Philadelphia's Weatherization Assistance Program (WAP) program sees a slightly different breakdown of deferral causes from those presented in Table 2. Asbestos plays a much larger role in Philadelphia deferrals than on a national scale. Forty-nine (49) percent of reported Philadelphia deferrals are a result of friable asbestos in the home, while asbestos is not noted as a deferral cause in all national studies. See Table 3 for the most common deferral causes reported by the local Philadelphia weatherization provider at the time, the Energy Coordinating Agency (ECA) in October of 2023. Photos of many of the reasons for deferrals follow.

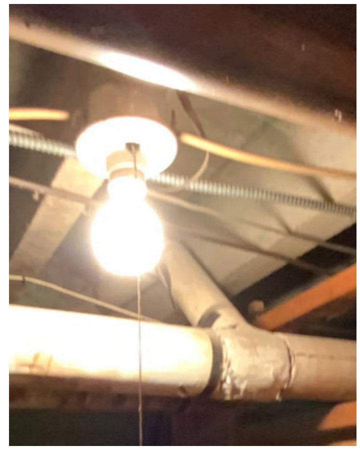
Table 3: Local WAP deferral causes [2]

Deferral Cause	Count out of 51	%
Asbestos	25	49%
Roof Leak	7	14%
Suspected Mold	10	20%
Non-functional heating system	4	8%
Clutter	4	8%
Drywall Repair needed	8	16%
Structural Damage	7	14%
Pest Infestations	12	24%
Sewage	7	14%
Unsanitary	1	2%
Gas utility not active	1	2%
Multiple Issues	*25*	*49%*

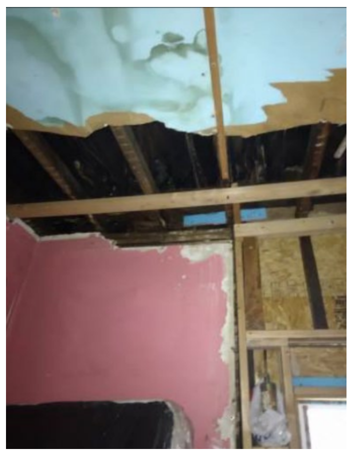
2 From 2020-2023 as communicated by the Philadelphia WAP provider Energy Coordinating Agency (ECA)

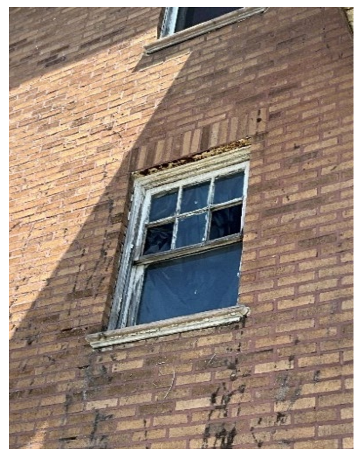

A disconnected water heater wrapped in asbestos.


Cracked floor tile in a basement, likely containing asbestos.


Asbestos pipe insulation on basement boiler pipes.


Ceiling damage from a leaking roof.


Ceiling damage from a leaking roof.


Broken window with deteriorated paint trim.


A deteriorated boiler at the end of its useful life.


A dangerous, improvised solution to a disconnected water heater flue.


A deteriorated range still in use in a BTL home.

At the time of this Built to Last evaluation, 33 of the 51 (65% of deferred properties) had expired applications and it was unclear if they would receive any weatherization work in the future. Many weatherization programs have added Weatherization Readiness Funding to their programs to help resolve deferral issues. Weatherization agencies also tap into local funding sources both private and public to help resolve these issues. In Philadelphia, the Built to Last partnership is working to make resolution of those issues easier and more streamlined.

Weatherization Readiness Funding

Weatherization Readiness Funding (WRF) has been a significant benefit to limited income homeowners. It has allowed WAP providers to address many households that would have previously been unable to take advantage of WAP services. Unfortunately, there is not enough WAP deferral money to handle the high number of deferred maintenance and health and safety issues in limited income housing stock. According to ACEEE's Report: *"About 60% of initially deferred homes were repaired and eventually served by WAP, while the remaining 40% could not be made weatherization ready and did not benefit from the average annual $372 in utility bill savings that WAP unlocks (2022 dollars, as stated by U.S. DOE). This is roughly equivalent to 23 metric tons of carbon dioxide averted per weatherized unit over the life of the measures."*[3]

Baseline Energy Performance Conditions, Constructability Considerations, and Efficiency Challenges

Weatherization and home repair organizations must work within the constraints of building architecture and accommodate the limitations necessary when working on occupied homes. As was discussed in the typology section of this report, a typical Built to Last serviced home is a masonry rowhome that is likely at least a century old. Retrofits must be completed without displacing the home's residents and within the limited square footage of the typology.

[3] *Estimating the Impacts of Weatherization Readiness Programs | ACEEE*. https://www.aceee.org/research-report/b2504. Accessed 10 Feb. 2026

Low Insulation Levels

Attic Spaces

Rowhomes typically have "flat roofs" which are actually low slope roofs that slope gently from front to back. The slope can be as little as ¼" of rise (vertical) across every 12" of run (horizontal). Below these roofs, there is typically little to no insulation on the attic floor. Attic architecture varies. Pocketed rafters as seen in Figure 7 are common as are beam and purloin construction. Most flat attics do have at least a small area of accessible space.

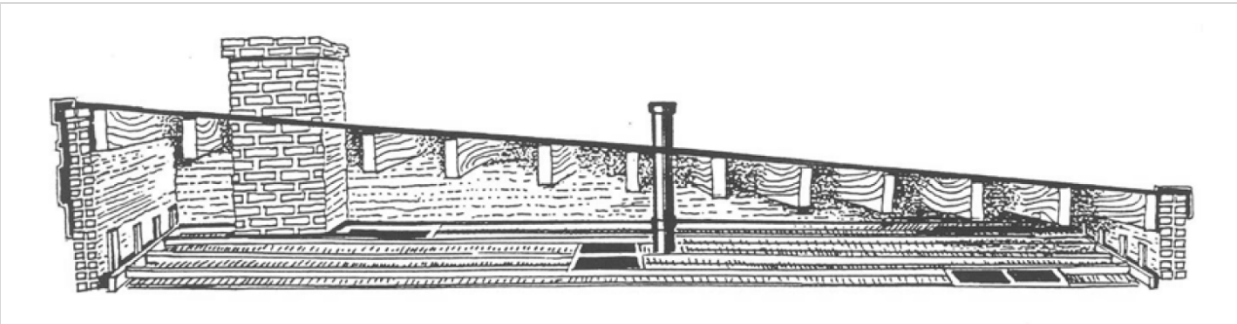


Figure 7: Illustration of a rowhome attic cavity from the February 2011 Weatherization Standards and Field Guide for Pennsylvania.

Retrofit of flat roofs typically involves air sealing and insulating as much of the front 2/3 of the attic as a crew person can reach, sealing all accessible chases and bulkheads in the attic floor and then adding blown insulation starting from the rear. The rear rafter joist cavities are frequently filled entirely and then insulation is installed in the more accessible front sections of the attic.

Exterior Walls

The majority of the exterior walls in a masonry rowhome are comprised of brick with plaster either adhered directly on the brick or installed on thin strips of wood which hold the plaster ½" to ¾" off the brick. Options to insulate walls of this type are limited and outside of the scope of what most weatherization budgets can accommodate. *(Later in the "Areas Needing Further Research" section of this report we will address the opportunity to insulate these walls from the exterior and suggest further research and pilots to explore this opportunity.)*

Figure 8: A 2nd floor bump out and framed in porch. Areas with white siding likely hide wood framed walls.

Framed walls in these homes are usually in the front or rear of the home and enclose architectural bump outs, enclosed porches, or rear additions. Figure 8 shows a front bump out on the second floor of a home and a porch under the 2nd floor that has been enclosed to bring that area into the conditioned area of the house. The framed walls in these areas likely contain little to no insulation. The depth of the wood framed cavities varies, and the number of framing members often creates challenges when considering filling these cavities with insulation. Another complication when attempting to insulate is old wiring that may be located in these cavities. The replacement of knob and tube wiring or other electrical hazards may be necessary before any wall insulation can be installed.

As a result of these challenges, few exterior wall spaces are insulated as a normal part of rowhome weatherization.

Foundation Insulation

The primary foundation type for most rowhomes is a full basement though some have a partial crawlspace. The walls of these are primarily, masonry, often "rubble" or "stone". Joist are typically pocketed into the masonry walls and so there is not a typical "rim joist" to seal and insulate, but joist pocket perimeters to be sealed instead. In some isolated areas batt insulation may be added to the rim joist area to provide additional insulation.

Insulation is rarely added to these foundations as moisture movement though the stone foundations is common and adding insulation could trap moisture between the insulation and the wall. There is limited energy saving benefit to insulation in this below grade area as well.

Even when the foundation is not insulated, elevated humidity is expected in below grade foundations and the installation of basement dehumidification is often needed to ensure that any minor moisture in the basement space is removed. (This should not be confused with more serious basement moisture which may originate from foundation leaks, failed foundation drains, plumbing leaks, major ground moisture, or sewage overflow.)

High air leakage rates

Given the construction, age and deferred maintenance, these homes also have high air leakage rates, reduction of which is an important part of improving the energy efficiency of rowhomes.

A standard metric for measuring air leakage rates in residential single-family buildings is Air Changes per Hour at 50 Pascals of pressure. This metric uses a building's volume and blower door test results to quantify how many times the total air volume in the house is replaced per hour when the building is pressurized or depressurized to 50 Pascals. (50 Pascals of pressure is approximately the equivalent of a 20 mile per hour wind blowing on the house from all directions at the same time.) Figure 9 shows the range of measured leakage for existing conditions:

- The average induced Air Change per Hour at 50 Pascals (ACH50) was 21 ACH50.
- The minimum starting ACH50 was 8.
- The maximum starting ACH50 was 33.

To provide some context to these numbers, Philadelphia adopted the 2021 International Energy Conservation Code (IECC 2021) in 2025. The ACH50 requirement for new residential dwellings is 5 ACH50, four times less than the average air leakage rate of the homes tested in this program. Seasoned professionals working to weatherize this building typology in Mid-Atlantic cities know that 21 ACH50 is not atypical.

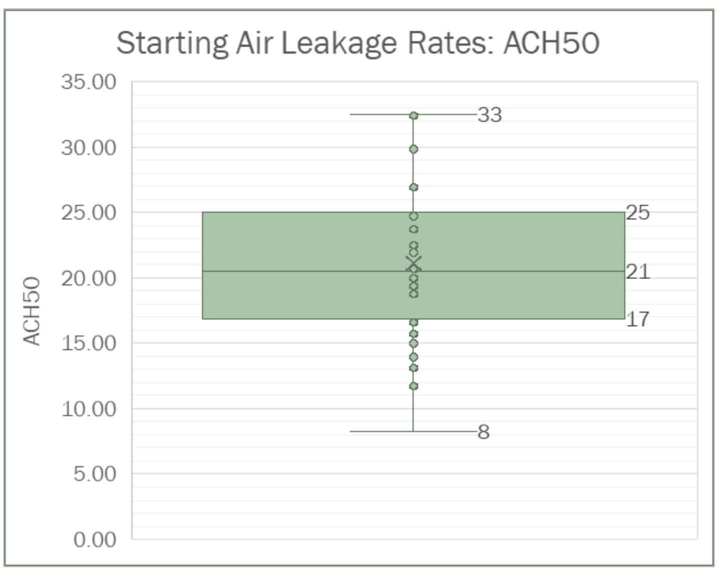


Figure 9: Air leakage rates measured pre-intervention (n=35)

Limited Existing Ventilation to Maintain Indoor Air Quality

Existing controlled ventilation in this typology is limited to spot ventilation in bathrooms and kitchens. Most common are bathroom exhaust fans (often vented into the attic). Kitchen exhaust fans are rarer. Range hoods most frequently circulate air within the kitchen space, if they are operational at all.

Properly venting a bathroom or kitchen is complicated by the rowhome architecture. A roofer or skilled handyperson is needed to vent a bathroom exhaust fan through a flat roof without creating leaks in the existing roofing. Exhausting a kitchen to the exterior often requires cutting through a brick wall.

Low Efficiency Heating and Water Heating Equipment

Equipment efficiencies for both space and water heating systems are typically very low (Most equipment fell between 78%- 83% AFUE for boilers and furnaces and 0.58-0.64 UEF for water heating systems.) Limited finances lead to the installation of the lowest cost option. Equipment is often near its end of life if it has not already failed. Need for a new heating system or water heater is frequently the motivation for a homeowner to reach out to Built to Last Partners for assistance.

Radiators and Ductwork:
As discussed in the “Typology” section of this report and shown in Figure 3. The majority of heating systems in BTL served rowhomes are boilers. Window air conditioners provide the majority of cooling. Distribution of heat from boilers is done with boiler pipes leading to free-standing cast iron radiators. Boilers generate either hot water or steam. Numerous high-efficiency (95% or greater) replacement options are available for natural gas hot water systems, but not for steams systems. Oil systems also face efficiency limitations. Boiler systems utilizing fuel oil rarely hit 90% efficiency. Currently, the highest available efficiency is capped at 91% AFUE.

The limited ductwork currently installed in this home typology often does not reach all areas of the home, is undersized, and has numerous air leaks. These challenges often lead to the consideration of mini-split heat pumps as a heating replacement option.

Floor plan division: challenges for heat pump installation
These homes are heavily divided into rooms on each floor. The homes were built before open floor plans gained popularity in the 1970’s. The first-floor layout is typically a front room, central room, and kitchen with stairs located between the front and central room to reach the next level. The second floor has 2-3 bedrooms with a bathroom nestled in the center which may have small window or operable skylight for ventilation. (Figure 10

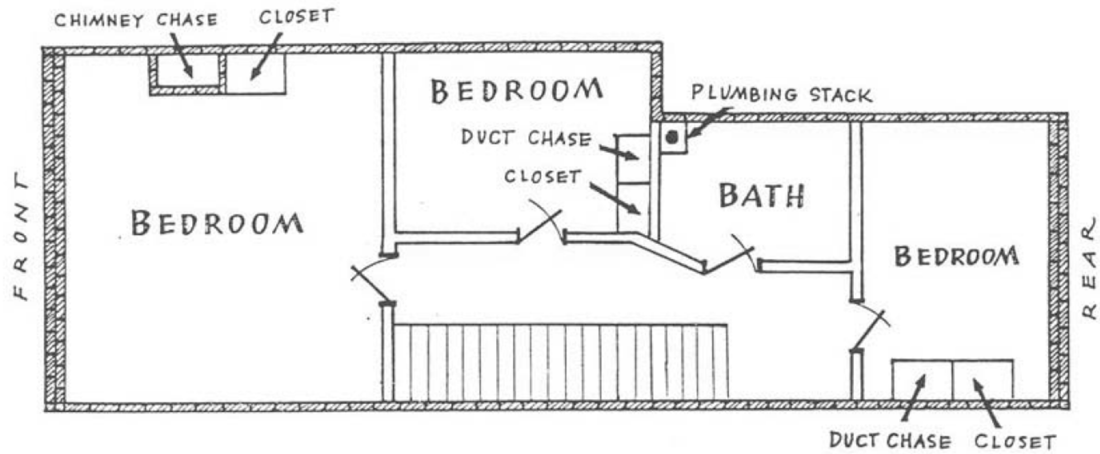


Figure 10: Second floor plan of a rowhome from the Feb. 2011 Weatherization Standards and Field Guide for Pennsylvania.

Additionally, in many neighborhoods where homes were built with front porches, these porches have been closed-in and turned into conditioned, or semi-conditioned space.

The highly divided floor plans make installation of mini-split heat pumps to provide heating and cooling for these homes challenging. A single outdoor condenser for a mini split system can usually be linked to only 5 interior heads. (There are advanced systems which can do up to eight heads, but these are usually outside of the budget parameters of limited income assistance programs.) On the first floor, 2 of the five heads are typically installed in either the front and central room, or the front room and rear kitchen. No head is typically available for a converted front porch room. The additional 3 heads are installed in each of the three second-floor bedrooms. The central second floor bathroom can rarely accommodate a mini split head. Wall space is typically limited in this room. To provide heating in this room, an electric resistance wall or baseboard mounted heating unit may need to be considered. Additional research, brainstorming, and collaboration with HVAC installers and manufacturers is needed to solve this puzzle piece in a more efficient way.

Practical, Health, and Safety Constructability Considerations

The health and safety issues discussed in the “Deferred Maintenance in an Aging Housing Stock” section of this report and outlined in Figure 6 are the first issues that must be addressed. Several of these conditions and their relevance are expanded upon below.

Asbestos: The presence of friable asbestos must be identified early. It is frequently found in basement or kitchen floor tile, pipe wrap, or insulation on an old furnace or boiler.

Active Knob and tube wiring: There is rarely existing access to the buildings attic spaces so determining if active knob and tube wiring is present at the start of an assessment can be challenging. Insulation cannot be safely installed over knob and tube wiring, and it is difficult to verify it is in safe working condition. If discovered in an attic, it must be replaced before the attic retrofit can be completed. Many weatherization organizations plan a second site visit for blower door guided air sealing and attic evaluation. At that visit new access is cut into the attic and the space can be further evaluated before finalizing the work scope (and project budget).

Clutter: Large quantities of stored items throughout a home can limit the ability of a work crew to make upgrades in a home. Careful conversation and strategizing with the homeowner are then needed to prepare the home for work to be completed.

Architectural Considerations

There are numerous architectural elements in the rowhome housing typology which make upgrading the efficiency of rowhomes require some additional consideration.

Rear shed additions
Many rowhomes have wood framed rear additions. They frequently have shed roofs and are built on slabs, crawlspaces, or wood joists placed directly on the ground. These foundation areas are rarely accessible, and they are often the cause of sagging floors, moisture issues, and pest infestations. Roof leaks on the rear shed roofs are also common. Solutions for structurally deteriorated rear additions range widely from demolition, floor or roof removal and replacement to isolation of inaccessible spaces with potential hazards.

Basement under front porch
One common characteristic of Mid-Atlantic masonry rowhomes is the "basement under the front porch". These are often referred to as BUPs (Basement Under Porch) by local weatherization teams. These are another challenging area to weatherize. The decision to include them in conditioned space or exclude them often comes down to whether the porch floor is watertight or not.

Additional Constraints

Application Timeline and Waitlists,

Collecting all the information required to complete a weatherization application is labor intensive for the applicant and the weatherization provider. Once a weatherization application is approved for an audit, that application is valid for one year. If a deferral issue arises at that initial energy audit, or during subsequent stages of evaluation or work, resolution of that deferral issue must happen quickly so that the weatherization work can be completed before the original application expires. If the application expires, the resident must again collect income verification information and work with weatherization to reapply for the program.

If the resident is connected to a home repair partner, the partner often has long wait lists that prevent them from being able to move quickly to resolve weatherization deferral issues and unlock weatherization services for the residents.

Core Decision Framework and the Pathway to DER

Home Condition Continuum:

Built to Last evaluates homes using a home condition continuum (Figure 11) which focuses on basic standards of living first, then moves to durability, safety, and function. When those elements of the building are addressed, the program then focuses on energy efficiency and renewables.

Figure 11: Illustration of the home condition continuum concept. See Appendix A for the expanded home condition continuum.

This focus on minimum standards of living, health, safety, and durability, does not mean that BTL ignores energy efficiency when addressing minimum standards. Built to Last has standard specifications that require efficiency to be considered and energy efficient equipment and building components to be installed throughout projects as replacements are made. These requirements are outlined in BTL's Performance Specifications.

Electrification and Efficiency Decision Tree

Hand in hand with the Home Condition Continuum, is the Electrification and Efficiency Decision Tree. This tool is designed to help with the often challenging decision making process associated with efficiency and electrification upgrades. Images of the Decision Tree can be found in Figure 12 and Figure 13.
A full pdf version of the decision tree can be accessed here: https://www.newecology.org/philadelphia-decision-tree.

The decision tree is designed to be referenced by program administrators, managers, designers, and assessors. It is not an inspection process, but a step-by-step guide to capture the necessary order of work to ensure homes are efficient and electrified responsibly. Health, safety, and durability issues are alluded to in the comments, but not included in the decision tree. Customer utility rates and the need for utility cost change calculations are also referenced, but research surrounding each client's utility rates will be needed and is outside of the decision tree.

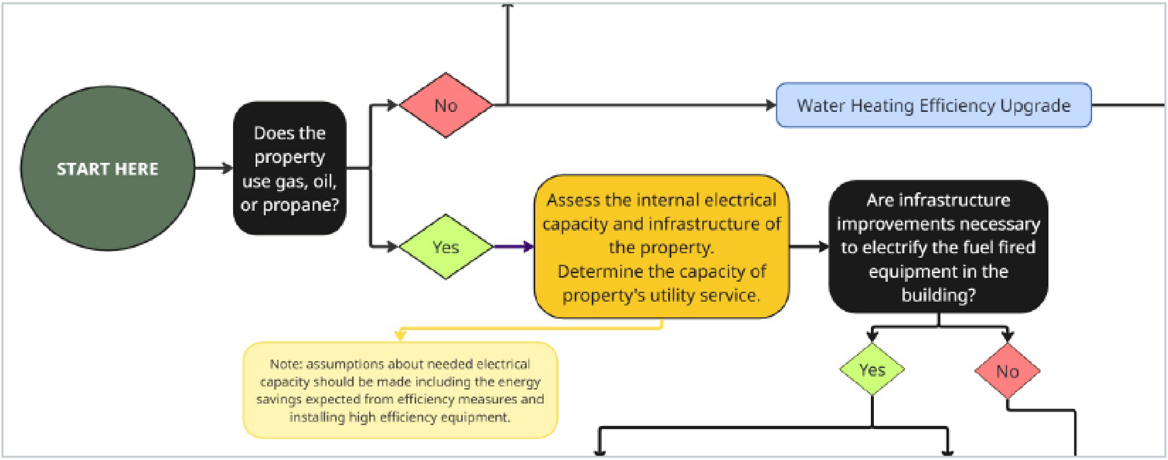


Figure 12: A close up of the electrification and efficiency decision tree for Philadelphia Rowhomes.

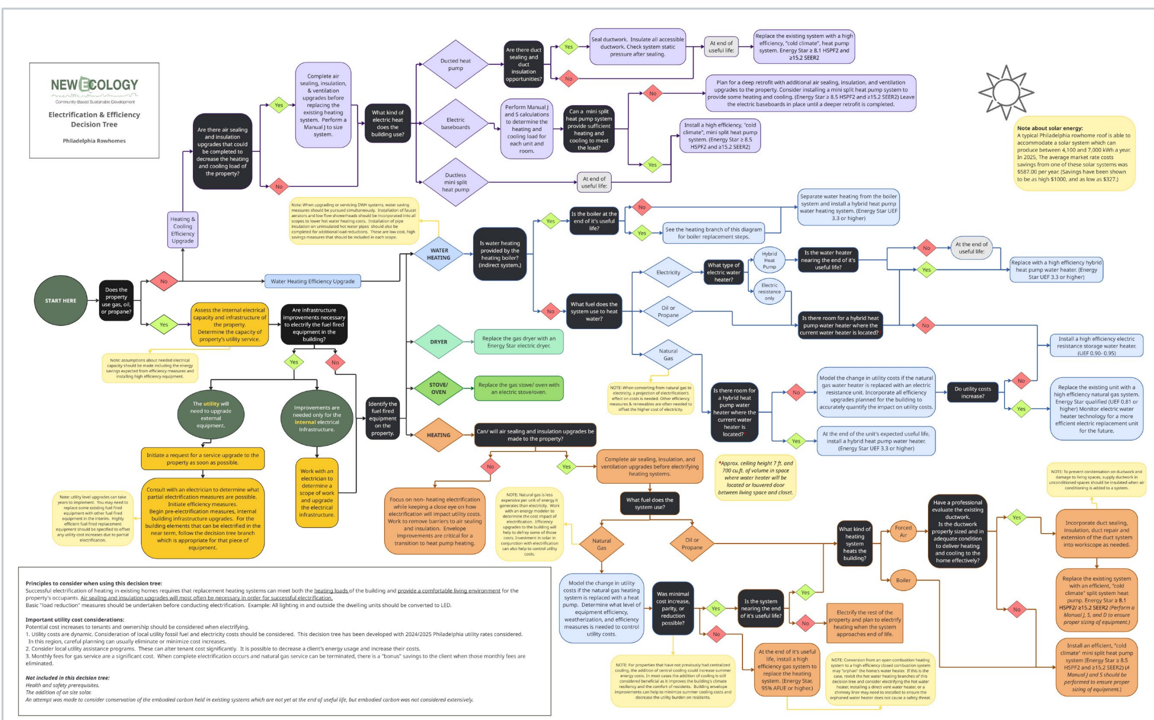


Figure 13: An image of the Electrification and Efficiency Decision Tree Created for the BTL team to reference when considering electrification.

It is important for electrification to be considered with care, and an understanding of the utility cost impacts to residents**. Electrification should not be undertaken if it cannot be implemented well.**

When NOT to electrify

Heating Systems

- If air sealing, insulation, and ventilation are not possible.
- When there is not a solution to provide heating to every room.
- When a correctly sized heating system, sized with a Manual J, is not in the project budget.
- When electrification of the heating system will not decrease a resident's utility bills or at least achieve cost parity.

Water Heating Systems

- If the resident is enrolled in gas utility assistance, but not electric utility assistance.
- When the system to be installed is an electric resistance storage unit, and no calculation of the resident's change in utility costs has been completed.

When to proceed with CAUTION:

Water Heating Systems

- When an electric resistance storage water heater is the only electric water heater option.
    - An electric resistance water heater should only be installed if it has been verified that the unit will not raise resident utility bills.
    - Installing an electric resistance unit may be a reasonable option when other efficiency measures are being completed in the house that will lower water usage, or overall energy costs.

Aggregated Analysis of 35 Built to Last Projects

Thirty-five (35) of the 49 projects were subjected to a more substantial evaluation as more detailed project information was available for those projects. The analysis in this section was done using information collected from multiple partners in the Built to Last partnership.

Standard and Deep Energy Retrofit Projects

Projects were grouped into two main categories, Deep Energy Retrofit and Standard Energy Retrofit. A Deep Energy Retrofit (DER) was defined as a 40% reduction in site energy. This definition was expanded to include savings from leased solar to capture the benefits produced by the Solarize Philly program (administered by Philadelphia Energy Authority) which is an important Built to Last partner. The number of projects which achieved Deep Energy Retrofit energy savings was

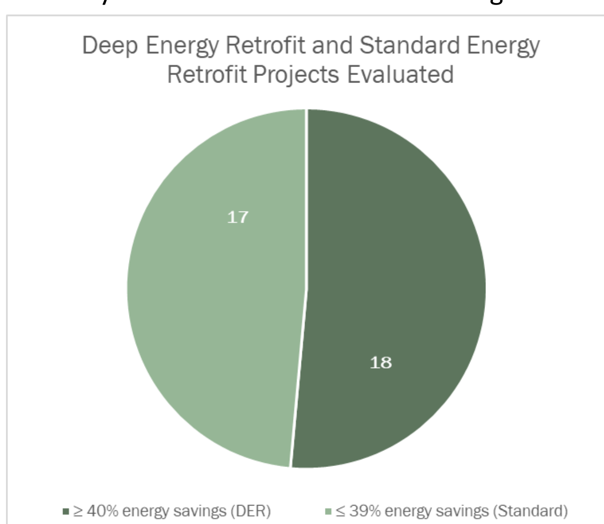
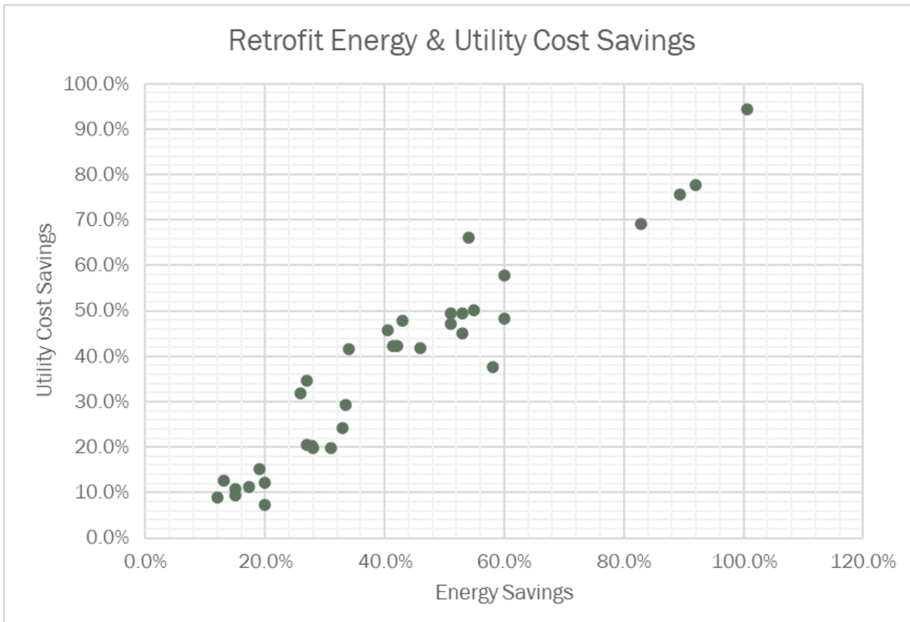


Figure 14: A graphic illustration of the division of properties between standard and deep energy retrofits.

18 of 35. Standard Energy Retrofit savings were achieved in 17 of 35 projects.

Energy savings and utility cost savings were positive for all 35 modeled projects. Projects which achieved over 40% or more energy savings almost all achieved greater than or equal to 40% utility cost savings as well. One exception achieved only 38% utility cost savings. Projects which achieved under 40% energy savings mostly saved less than 40% in utility costs. One exception existed for this group, achieving 34% energy savings and 41.7% cost savings. (Figure 15)

Figure 15: Energy and utility cost savings. n=35



Energy and cost savings for projects did not align directly (Figure 16). The difference in percentage cost saved trended to lower cost savings in comparison to the percent of energy saved (Figure 17). The median of this variance was -4.2%, but results ranged from cost savings 12.2% higher than energy savings to 20.4% less than the energy savings modeled. The full range of the variance between energy savings and cost savings percentages is represented in Figure 18. Variation in fuel costs and the balance of fuels providing energy for each property are likely the cause of this discrepancy between energy and cost savings.

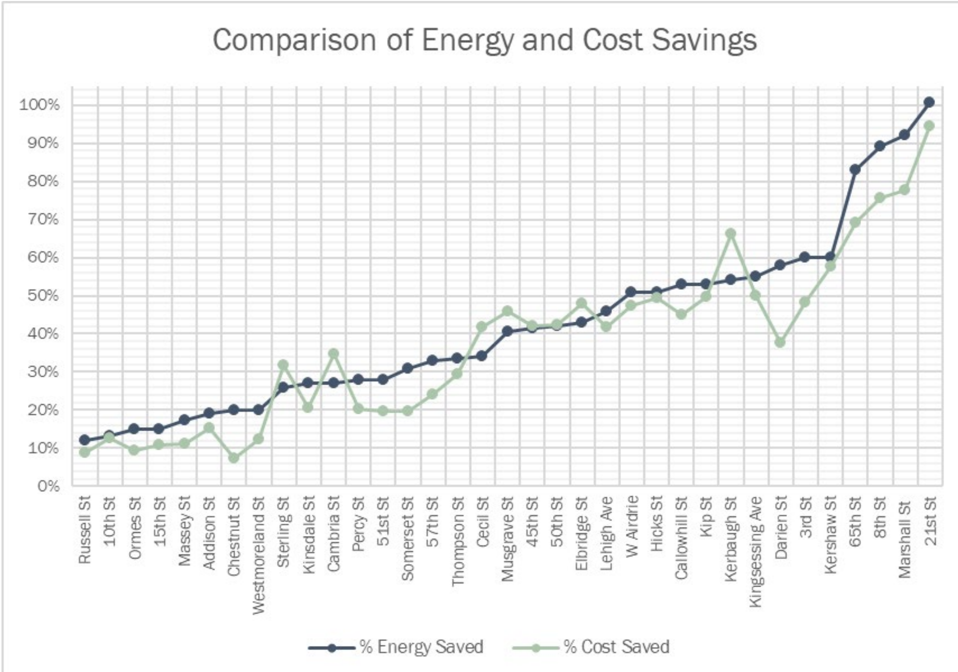


Figure 16: Percent energy savings and percent cost savings do not align.

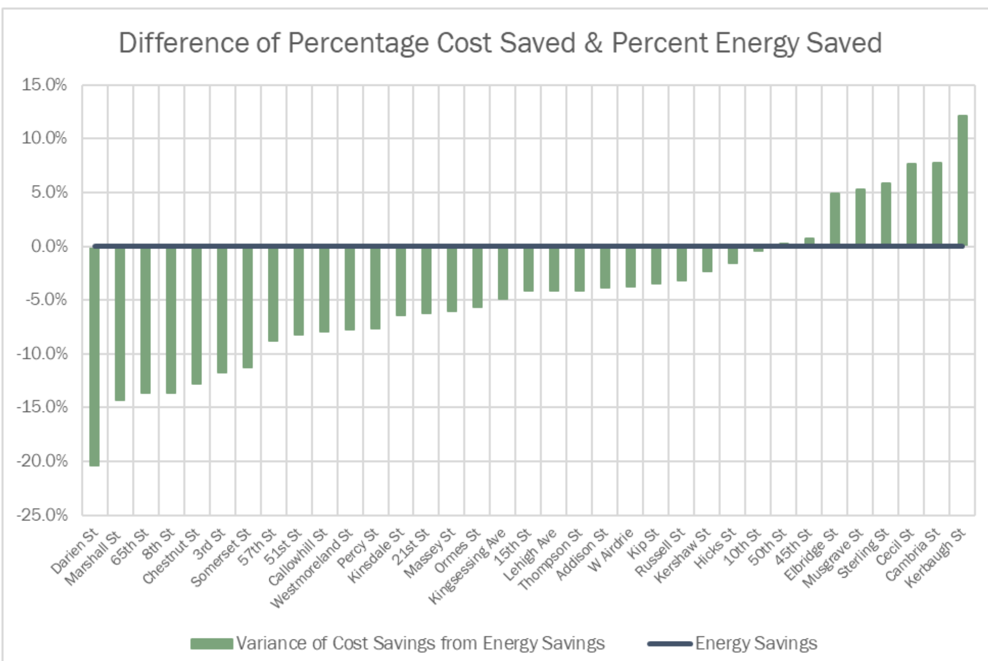


Figure 17: Percentage of costs saved trended lower than the percentage of energy saved.

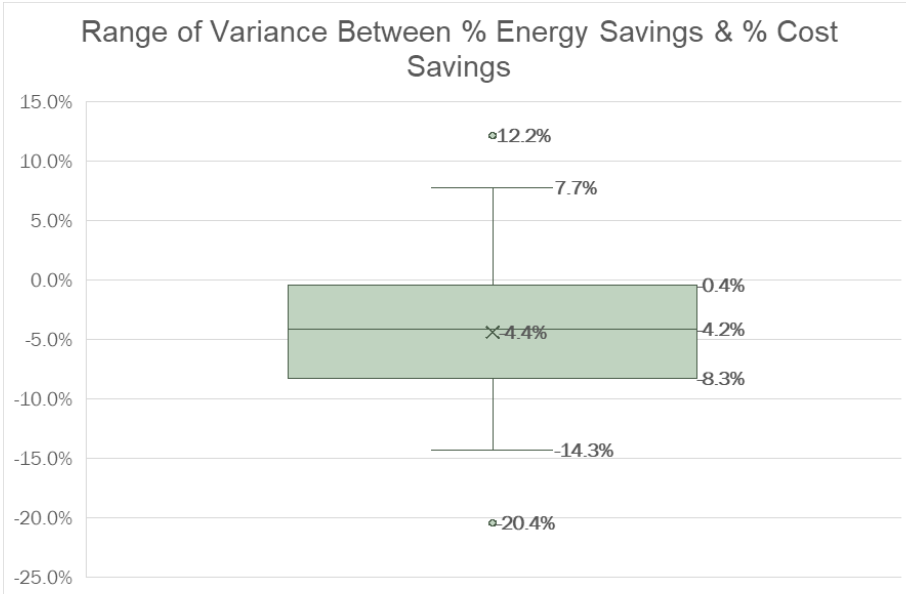


Figure 18: The range and median of variance between percent cost savings and Energy savings. n=35 Energy savings is at 0%.

Resident Utility Costs Savings

Utility cost savings for the different project types is significant. Deep energy retrofit projects saved not just significantly more energy, but more on energy costs as well (*Figure 19*). Median year one utility costs savings for standard projects was $335 while median savings for DER was $1,059.

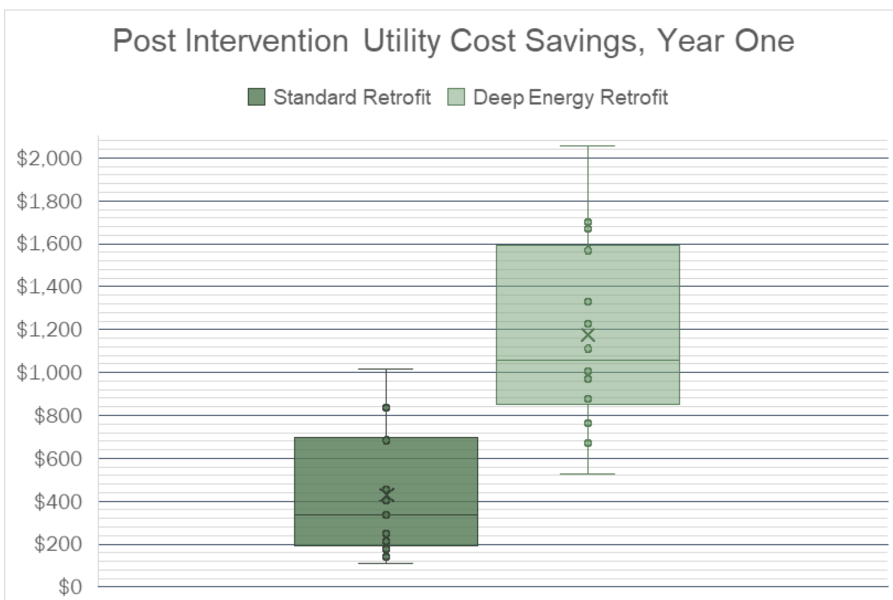


Figure 19: A comparison of utility cost savings. DER n=18, Standard Retrofit n=17

Common Opportunities for Energy Efficiency, Decarbonization, and Cost Savings

Building Envelope Upgrades

Building envelope upgrades save both energy and money. They reduce heating and cooling loads and can set the stage for the downsizing of heating and cooling equipment as well as electrification. These upgrades are an essential first step to improving efficiency and comfort homes.

Typical insulation upgrades included increasing attic insulation levels to R38, filling cantilevered joist cavities with dense pack cellulose (approx. R30). Air sealing scopes included air sealing any accessible attic floor, sealing joist pockets in the basement and performing blower door guided air sealing on the interior of the house (caulking trim, sealing holes, etc.). The projects evaluated had an average air leakage reduction of 20%.

Building envelope upgrades are a necessary pre-requisite before electrifying any heating system. Buildings with high air leakage rates or minimal insulation are not good candidates for heating electrification. Heat pumps can most effectively heat a home utilizing the refrigeration cycle (heat pump rather than electric resistance mode) if heat losses from the building are minimized. A furnace using fossil fuel to heat the home will provide a temperature rise of around 50°F, meaning supply air is distributed at 120°F or higher. The temperature rise of a heat pump may only be half that of the furnace and varies with outdoor air temperature. This results in a significantly lower supply air temperature (approximately 95°F±). Both systems will meet the temperature setpoint of the thermostat, but not without impacts to resident comfort:

1. Even when the air produced by the heat pump is at its proper temperature, it may feel cold or only lukewarm to the building resident (whose body temperature is somewhere around 98.6°F).
2. Vents from the heat pump system will discharge air for longer than a fossil fuel system to meet the desired indoor temperature. This may draw attention from residents who had not previously noticed air from vents, and that the air feel colder than they expect.
3. The lower temperature air produced by the heat pump will cool more quickly when mixed with air that infiltrates into the building from the exterior due to air leaks. To keep up with the thermostat setting in a building with high air leakage on cold days, a heat pump system may need to resort to its electric resistance back up heat. This is an expensive option and negates many of the efficiency gains made by installing a heat pump system.

High Efficiency Equipment Replacement- With or Without Electrification

Space heating and water heating system energy use dominates the energy consumption of homes in the US. For single family attached homes in the Northeastern United States [4] the average end-use energy from heating and water heating combined is 71% of a home's energy usage. See average home breakdown usage in Figure 22.

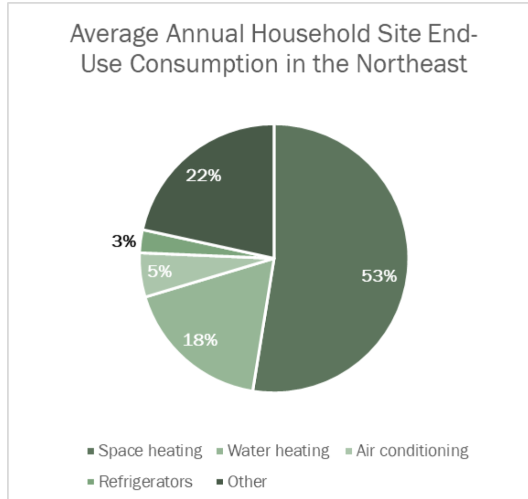


Figure 20: Data from the US Energy Information Administration (EIA) from 2020 Residential Energy Consumption Survey (RECS) [1].

Most equipment replacements completed on properties in this group of projects involved the replacement of an existing heating system with a "standard efficiency", non-Energy Star replacement unit. A clear trend in the projects which achieved deep energy retrofits was the installation of high efficiency heating and water heating equipment.

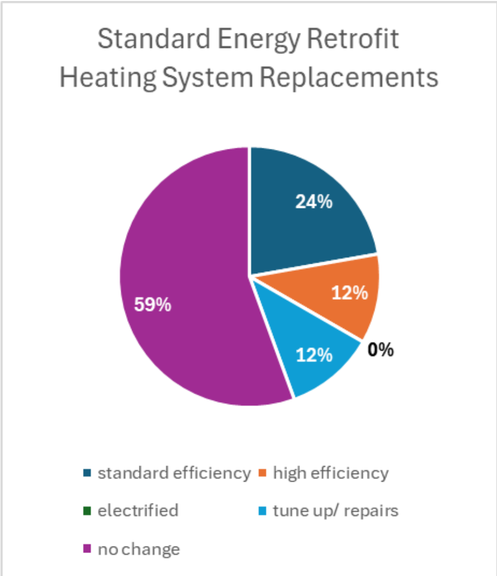
Heating Systems.

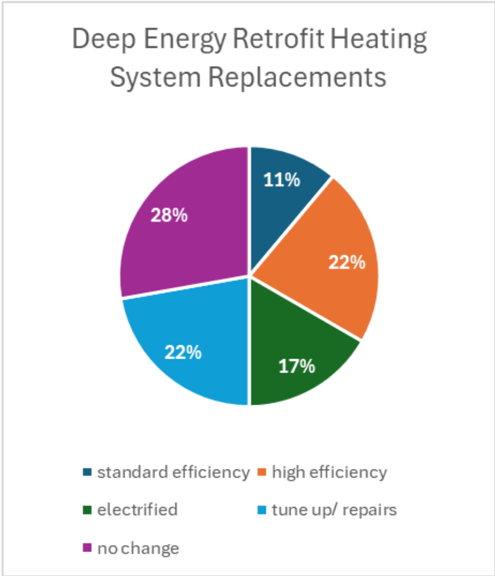
High-efficiency heating system replacements were defined as greater than or equal to Energy Star required efficiency levels.

The installation of new, high-efficiency heating equipment was completed in 26% of the 35 homes evaluated for this change. Homes that achieved a deep energy retrofit were 27% more likely to have high efficiency replacement equipment. Within this high efficiency group were three (3) homes which had their heating systems electrified with the installation of high efficiency mini split heat pumps. In both retrofit groups, 17% of properties received standard efficiency replacements (efficiencies below Energy Star). 17% of homes had tune ups or repairs made and 15% of properties had no changes made to the heating system. Figure 23 shows the breakdown of replacements made for heating systems for standard and deep energy retrofits.

[4] (The EIA https://www.eia.gov/tools/glossary/index.php?id=Census Region defines the Northeast Census Region as nine states: Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.)

Figure 21: Comparison of standard and deep energy retrofit heating system replacement trends.





Standard Efficiency: less efficient than Energy Star

High Efficiency: Energy Star or more efficient.

Electrified: ≥ Energy Star, heat pump installed.

Tune up/ Repairs: Small improvement in efficiency.

No Change: No replacement of system completed.

Recommended Heating Equipment Replacement Options

For all system replacements, the strongest way to achieve deeper energy savings is for all Built to Last partners to increase the required efficiency level of all replacement equipment.

When replacing heating systems there are some choices that are easier to make than others.

Energy and cost savings are easily achieved when replacing an oil or electric resistance heating system with a high efficiency heat pump or natural gas system.

A standard or low efficiency natural gas furnace or boiler (78%-82% AFUE) can easily be replaced with a high efficiency natural gas system. A heat pump system is also an option if building envelope upgrades are maximized, any duct system that will be reused is thoroughly evaluated, Manual J is completed to properly size the system, and cost calculations are completed to ensure resident costs will not rise.

Replacing high efficiency natural gas systems with heat pump systems will result in energy savings, but energy cost increases. Any such replacements should be paired with solar to achieve cost savings.

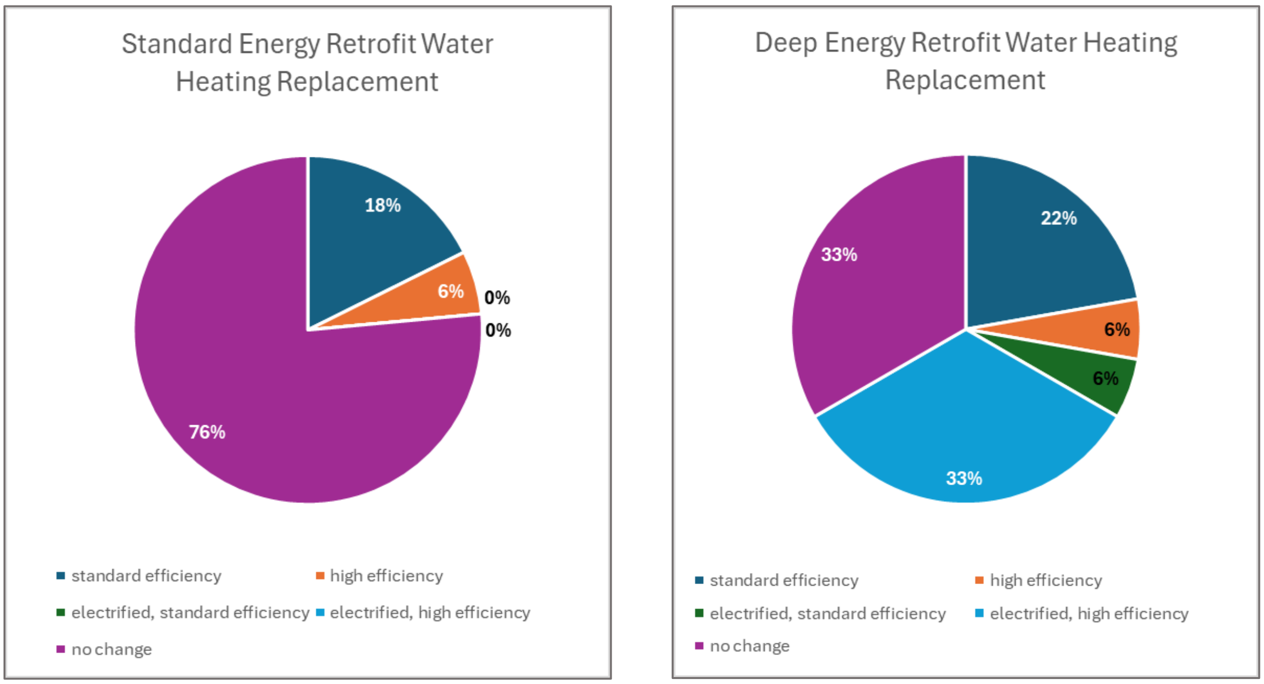
For all heating system replacements with heat pump systems building envelope upgrades, a Manual J, and ductwork evaluation should be completed as part of the scope- even if the replacement is an emergency. If these pre-requisite requirements cannot be completed, replacement with a fuel fired system should be completed instead.

Water Heating Systems

High-efficiency water heating system replacements were defined as greater than or equal to Energy Star required efficiency levels.

The installation of hybrid heat pump water heaters was much more prevalent in deep energy retrofits. Electric resistance storage units, while considered fairly standard in their efficiency, are still in most cases more energy efficient than natural gas systems. They were installed 10% more frequently in the deep energy retrofits than in the standard retrofits. Installing replacement gas units with only slightly higher efficiency units, 0.6 UEF to 0.68 UEF, for example, was implemented in both the deep energy retrofits and the standard retrofits. Figure 24 compares replacement actions for standard and deep energy retrofits.

Figure 22: A comparison of water heater replacement trends for standard and deep energy retrofit projects.



Standard Efficiency: less efficient than Energy Star

Electrified, Standard Efficiency: Below Energy Star, electric resistance storage tank.

No Change: No replacement of system completed.

High Efficiency: Energy Star or more efficient.

Electrified, High Efficiency: Energy Star or more efficient (hybrid heat pump water heater)

Recommended Water Heating Equipment Replacement Options

Hybrid heat pump water heaters (HHPWH) have shown themselves to be a valuable replacement option for both energy efficiency and energy cost savings. The efficiency improvement possible with a HHPWH is usually great enough to overcome high kilowatt hour costs for electricity.

Low efficiency natural gas, fuel oil, or electric resistance systems are a safe bet for replacement with a HHPWH system. Replacement with electric resistance systems may also be cost effective when replacing fuel oil systems or low efficiency gas water heating if combined with full building electrification to eliminate customer service charges. Figure 25 shows domestic hot water equipment replacement options for consideration.

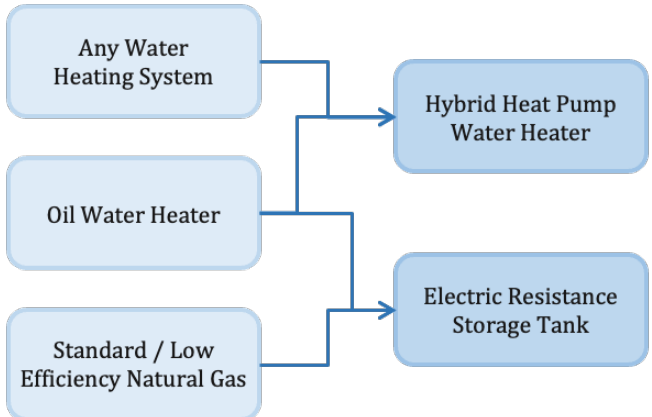


Figure 23: Water heater system conversions to consider based of fuel type and efficiency of starting equipment.

Natural Gas Dryers and Stoves

Electrification of both stoves and dryers is recommended. These appliance replacements are unlikely to make a significant difference in energy savings, but their replacement can have significant cost savings and health benefits.

Cost Savings

Often a gas stove and/or dryer are the last remaining gas appliances in a home after electrification of heating and water heating systems. Fully eliminating natural gas allows the resident to cancel their gas service and save the cost of the monthly service charge which they pay to the gas company.

In one Built to Last Project, the home was electrified with the exception of the gas stove. The homeowner declined an induction stove because they were attached to cooking with natural gas. The gas stove will only use a few therms each year, but the homeowner will pay at least $14.90 per month (2024 monthly customer charge) to the utility company per month for the life of the stove (approximately 15 years). This means they will pay $2,682 over the next 15 years to have the gas stove.

If the clothes dryer was the final remaining piece of gas equipment, the result would be the same. The last piece of gas equipment removed from the home provides freedom from a monthly gas customer charge. Figure 26 shows standard replacement options for stoves and clothes dryers.

Health Benefits

It is well known that gas stoves release numerous pollutants into the indoor living environment. Nitrogen oxides are known to cause respiratory irritation over short periods of time. Over longer periods of time, there is evidence that nitrogen oxides may lead to the development of asthma and respiratory infections.[5]

[5] https://www.epa.gov/no2-pollution/basic-information-about-no2

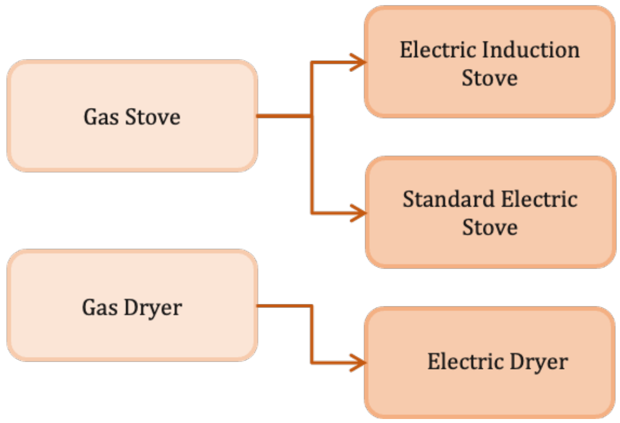


Figure 24: Electrification of natural gas clothes dryers and stoves is recommended.

Combining Electrification & Solar

Electrification measures save energy, but don't always reduce energy costs. Photovoltaics keep utility cost savings trending positive. 72% (13 out of 18) of the projects which achieved DER were projects which had solar added. The value of electrification and solar together is clear. While electrification is highly valuable for energy savings, adding solar changes the utility cost savings significantly. Figure 27 and Figure 28 show the relationship between utility cost savings and energy savings for projects with solar and projects with electrification.

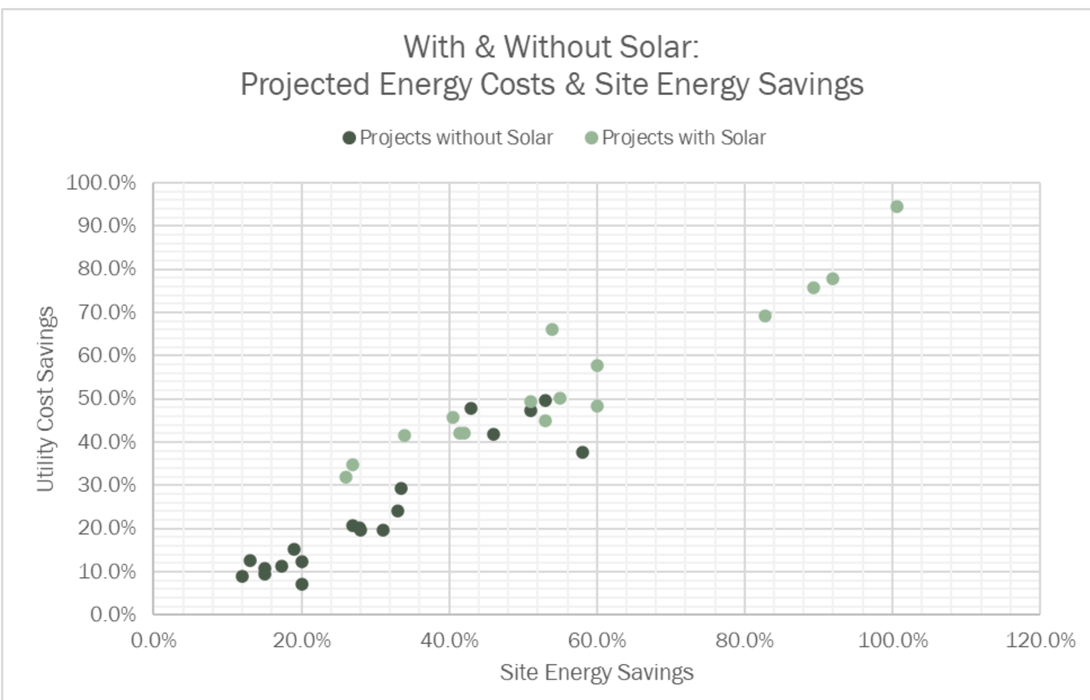


Figure 25: projects with solar installations tended to have higher energy and cost savings.

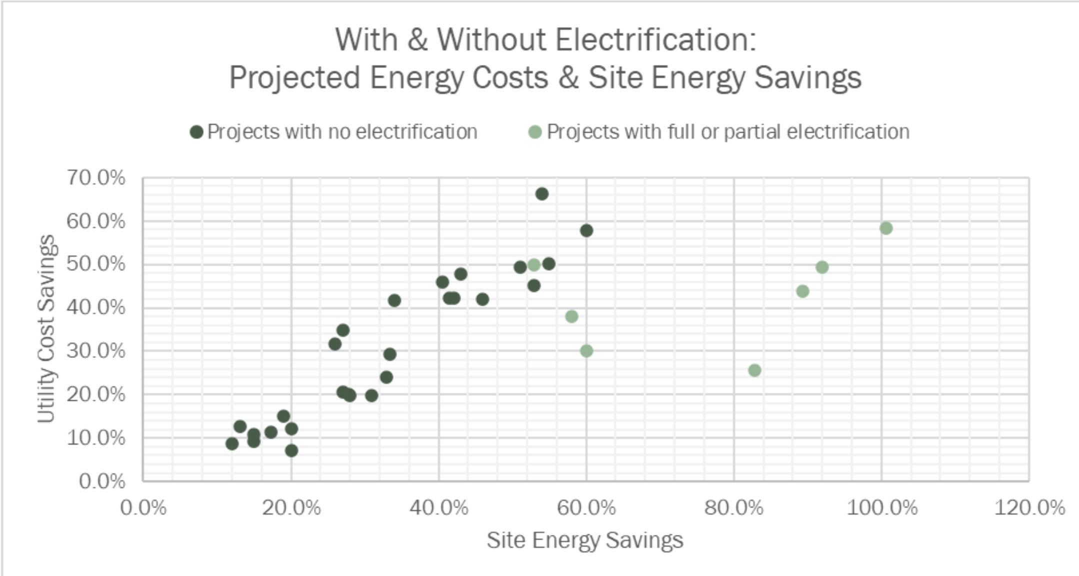


Figure 26: Projects with full or partial electrification showed high energy savings, but those savings did not always result in high energy cost savings.

Retrofit Project Costs

Major Project Cost Drivers Are Health, Safety, & Durability

The often-extreme issues of deferred maintenance appear to be the primary drivers of project costs. Efficiency upgrades are secondary drivers. *As a result of the large quantity of deferred maintenance as well as health and safety issues, those costs frequently exceed energy efficiency dollars.* These retrofit elements fall into the "Minimum Standards" and "Improve Durability, Safety, and Function" categories in the home condition continuum.

The evaluation of retrofit project costs showed that projects which achieved a 40% energy reduction (Deep Energy Retrofits/ DER), were not statistically more expensive than projects with lower energy savings (Standard Energy Retrofits)

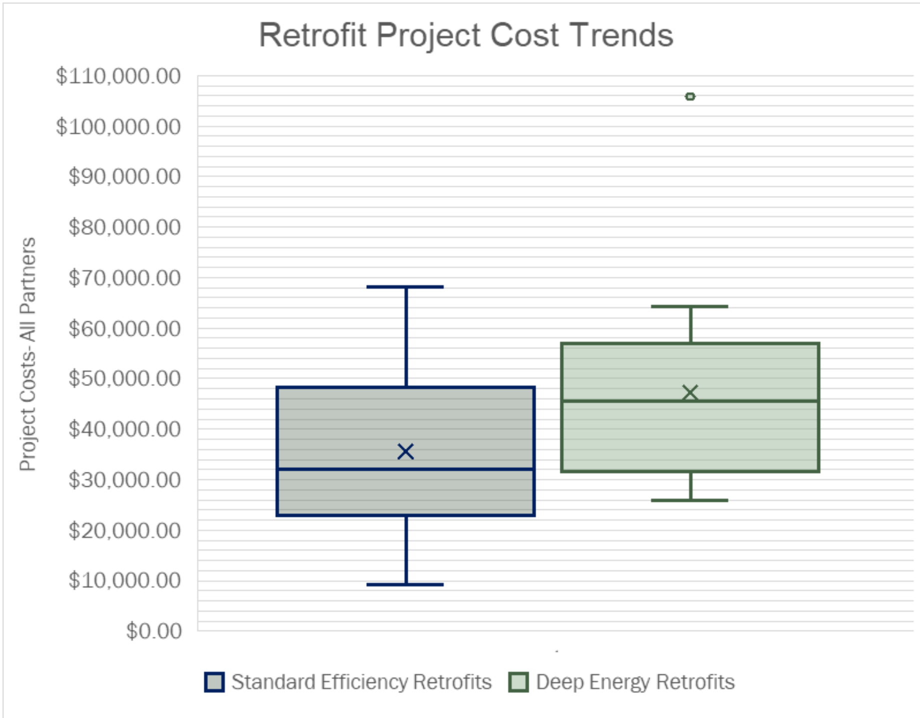


Figure 27: Comparison of standard and deep energy retrofit project costs. DER: n=18, Standard: n=17.

Figure 29 shows a comparison of retrofit costs between projects which did and did not achieve DER. The median Standard Efficiency Retrofit Cost was $32, 139.16 while the median for Deep Energy Retrofit was $45,508.84. The difference between the medians was $13,369.68.

It is important to note that the cost of both types of projects varies widely, and the total cost of the project does not correlate directly to the percentage energy saved. The figures below show the wide variance of project costs across both types of projects and project cost disconnection from the overall energy savings. (Figure 30 & Figure 31)

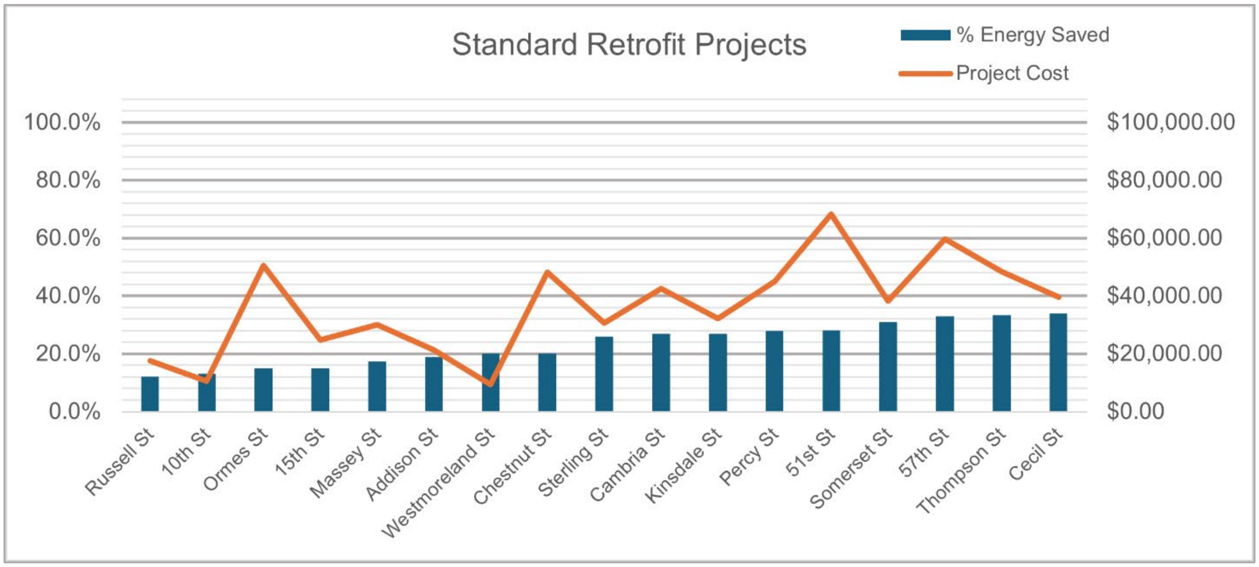


Figure 28: Standard Energy Retrofit Projects: graph showing the percentage of energy saved in relation to retrofit project costs.

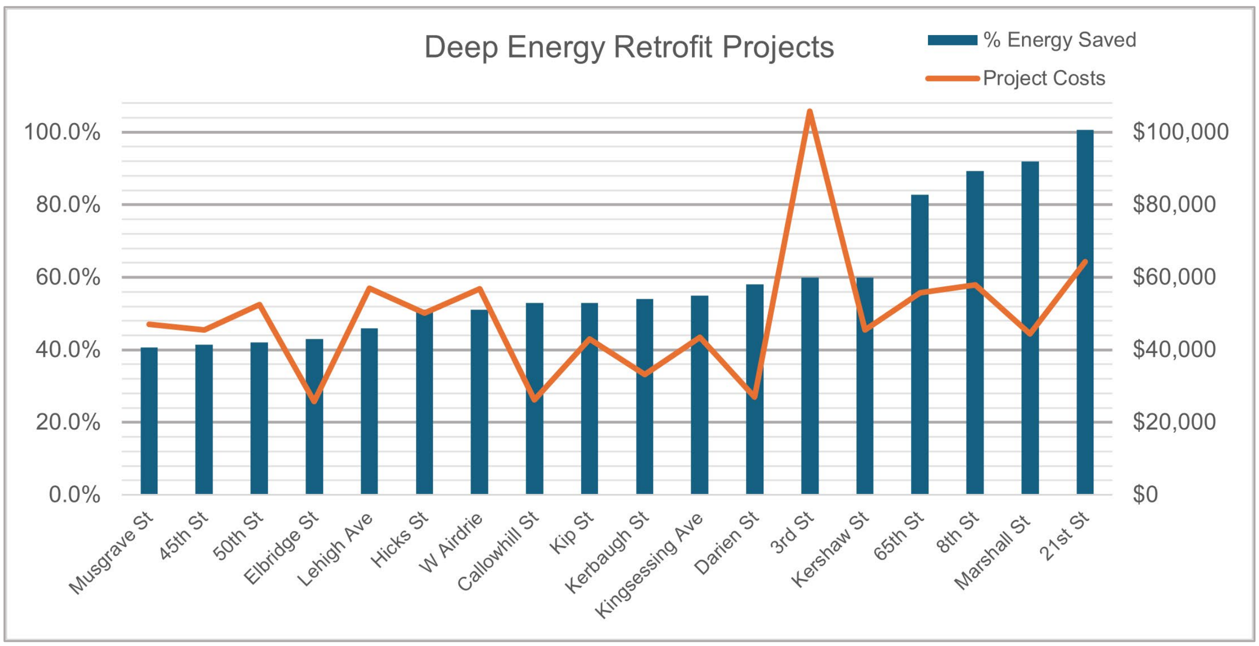


Figure 29: Deep Energy Retrofit Projects: Graph showing the percent energy savings in relation to retrofit project costs.

Partner Contributions

The Philadelphia's Built to Last team acts as the administrative backbone connecting partner organizations. This team pays for project elements like intake and administration. Costs for each of the home repair and efficiency measures implemented are covered by a wide partnership of local Built to Last partners to bring together the resources needed to make a lasting changes to the BTL properties.

Both Deep Energy Retrofit and Standard Energy Retrofit projects had a similar level of partner engagement on average. DER Projects in this sample had an average of 4.2 organizations or funding sources coming together to facilitate the retrofit, while standard retrofit projects had an average of 3.7. Figure 32 and Figure 33 show the breakdown of each property funding stack by partner who provided funding.

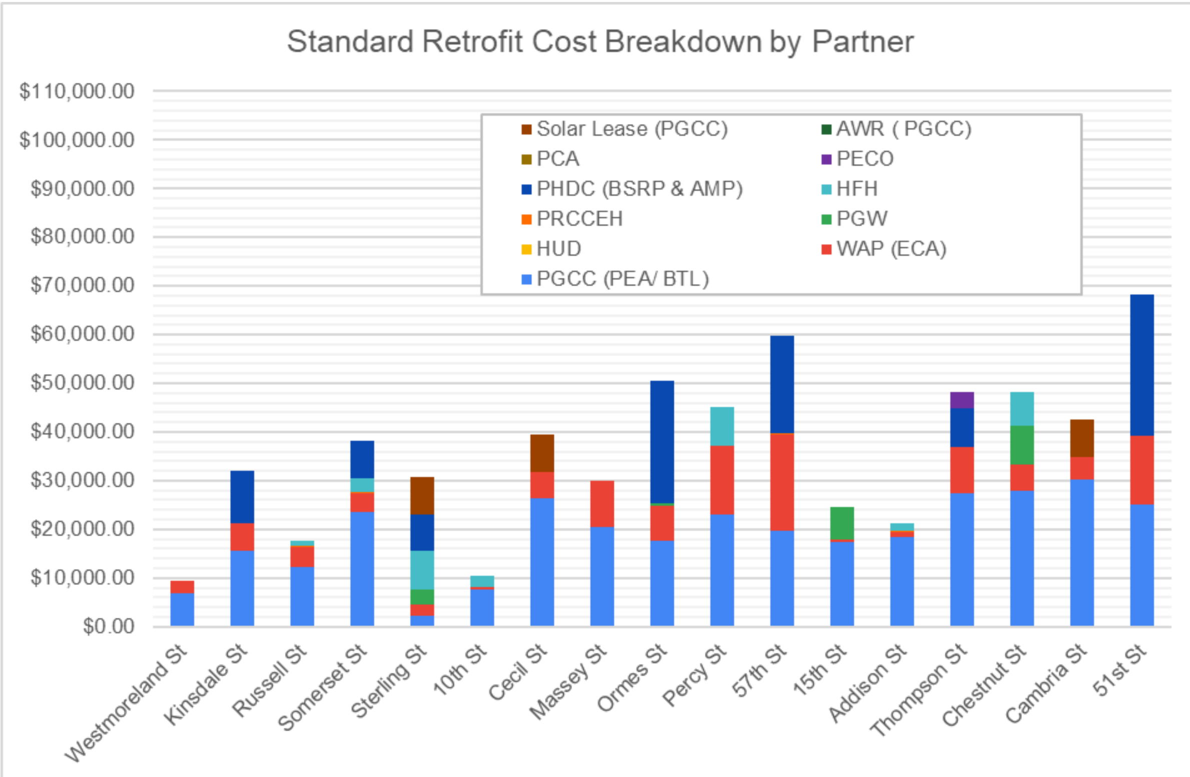


Figure 30: Funding stacks broken out by partner for standard retrofit projects.

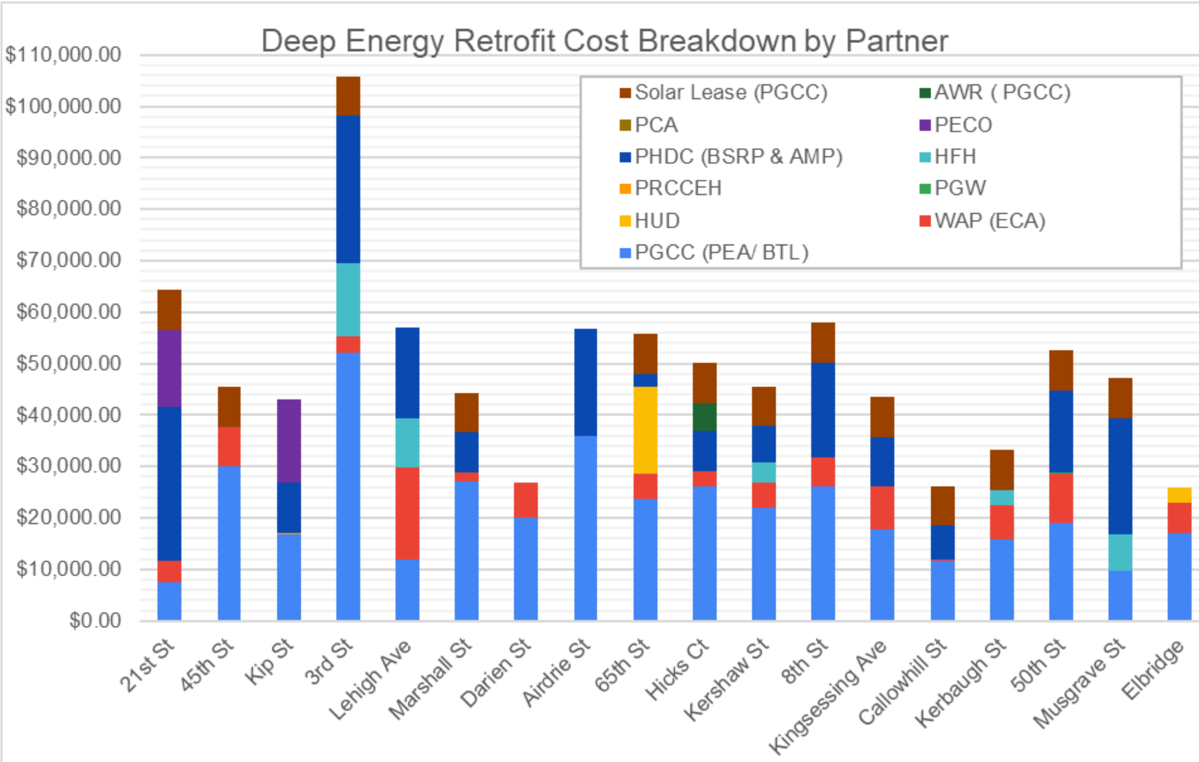


Figure 31: funding stacks broken out by partner for deep energy retrofit projects.

Expanded Legend for Cost Breakdown
Solar Lease (PGCC): Solar was installed in coordination with Solarize Philly a Philadelphia Energy Authority Program. PGCC, PEA's green bank affiliate, provided funding to BTL customers in which the cost of Solarize leases are paid off upfront, on behalf of the homeowner. PGCC paid an average cost of $7,700 per home to buy down solar leases for BLT homeowners. This value is calculated based on the system cost, less the value of the SRECs, adjusted for net present value. **PCA**: Philadelphia Corporation for Aging **PHDC (BSRP & AMP):** Philadelphia Housing Development Corporation (BSRP is the Basic Systems Repair Program and AMP is the Adaptive Modifications Program) **PRCCEH:** Philadelphia Regional Center for Children's Environmental Health **HUD:** Healthy Homes Program Department of Housing and Urban Development (HUD) Healthy Homes administered by the Energy Coordinating Agency (ECA) **PGCC (PEA/BTL):** Philadelphia Energy Authority administers the Built to Last Program (BTL) and pays for program costs such as intake, homes assessments, project coordination, and inspections. Philadelphia Green Capitol Corp. is PEA's green bank affiliate that pays for BTLs direct construction costs. **AWR:** American Water Resources also administered by the Philadelphia Energy Authority **PECO:** Electric Utility formerly called the Philadelphia Electric Company **HFH:** Habitat for Humanity Philadelphia **PGW:** Philadelphia Gas Works **WAP:** Weatherization Assistance Program administered by the Energy Coordinating Agency (ECA)

Cross-Cutting Insights

Scope Overlap between Partners

The power of the Built to Last model of collaboration is that partners working together can provide more comprehensive and lasting services for the clients they serve. The challenge of that same partnership is untangling the scope of services elements to reduce costs and overlap thereby gaining overall efficiency and cost-effectiveness. This section touches on some areas where there is opportunity to maximize energy efficiency to provide cost savings to residents, while taking advantage of opportunities to streamline scopes and save assistance program resources. When a directly related section of the Department of Environment (DOE) Standard Work Specifications (SWS) exists, a link is provided for reference to the current SWS language regarding that topic.

Chimney liners & Water Heater Replacement

https://sws.nlr.gov/spec/505031 (Chimney Liners)

As homes with combustion heating and water heating age, infrastructure starts to fail or becomes ineffective in the face of new technology. Masonry chimneys are one such element. Masonry chimneys are used in most of this housing typology to exhaust fuel gases from atmospheric or fan assisted combustion appliances. During renovations, the decision is made to convert a home's heating system to a high efficiency combustion heating system or a heat pump, the chimney will no longer be used by that appliance to vent flue gases. This can have a significant effect on the ability of the remaining open combustion water heater to effectively vent flue gases out of the house. This scenario is known as "orphaning" a water heater.

When a water heater struggles to draft effectively or is "orphaned" due to the installation of a high efficiency heating system, weatherization teams frequently install a chimney liner to ensure the water heater will draft effectively. While this measure is essential for the safety of the home's occupants, this measure does not have energy savings associated with it. It impacts the savings to investment ratio of the project negatively.

Figure 32: A flue terminating into a masonry chimney with no chimney liner.

Electrifying water heating saves energy and negates the need for a chimney/ flue liner. The cost of a flue liner is estimated at $2,800. Hybrid HPWH have especially high energy savings and even with the current higher cost of electric energy per unit than natural gas, it is rare that these units will increase utility costs for the resident. Figure 14 graphs the estimated costs to install 4 different types of replacement water heating equipment and shows the efficiency range available for that type of equipment. Hybrid heat pump water heaters, while slightly more expensive, are significantly more efficient than the other replacement options available.

If full building electrification is being pursued and a hybrid heat pump electric water heater cannot be installed, an electric resistance storage heater is a reasonable consideration. It is recommended that these only be installed if calculations are performed to verify the residents' hot water costs will not rise. These units are no longer eligible for Energy Star status, but there is a wide range of efficiencies available. Efficiencies for these units can drop as low as 0.80 UEF but a unit with a UEF greater than or equal to 0.92 should be installed when possible.

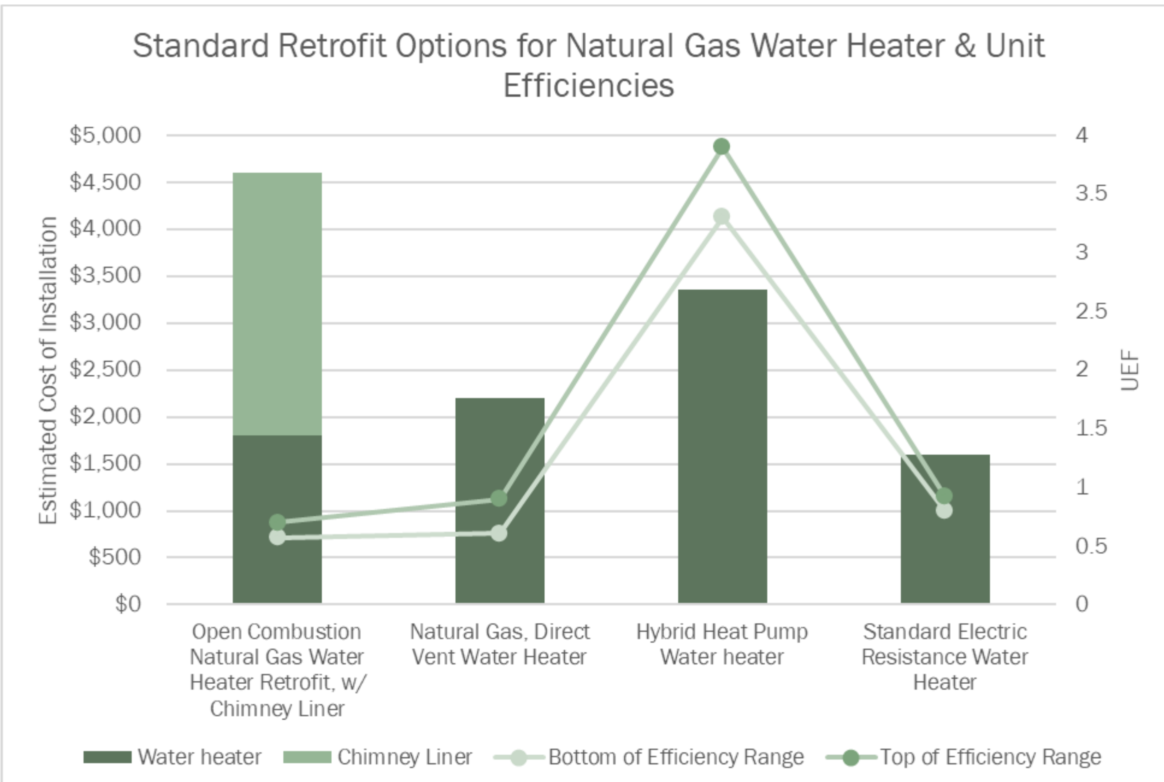


Figure 33: This graph represents the approximate retrofit costs associated with each type of replacement equipment. The secondary axis, on the right show the uniform energy factor, or UEF, range of the possible replacement units.

Exhaust Vent Installation through the Roof

https://sws.nlr.gov/spec/603021 (Individual Exhaust Fan Serving Entire Dwelling)

The bathroom in most Mid-Atlantic masonry rowhomes is located in the center of the second floor of the house. For fresh air they traditionally had operable skylights with small vents at the top which could be opened or closed using a long chain that stretched down low enough to be reached by a person of average height.

To ensure healthy indoor air quality, weatherization teams frequently install new bathroom exhaust fans in these bathrooms to provide both spot ventilation (to remove moisture that accumulates from using the bathroom), and whole building ventilation. The bath fan typically runs on a timer or continuously to depressurize the house, exhaust pollutants, and pull in fresh air. In these central bathrooms, there is no external wall, gable end wall, or soffit to vent the exhaust fan out of the attic space. Almost all exhaust fans in this housing type are vented directly up and out of the flat roof above.

About 53% of the homes served through the Built to last partnership received a new roof as part of the work completed on the house. Installing a roof jack to vent a future bathroom exhaust fan could easily and inexpensively be incorporated in the scope of the roof renovation. This would be less costly than later penetrating a newly installed roof. It would also ensure that the contractor who installed the roof jack was responsible for honoring the roof warranty if a leak were to occur where the roof jack was installed.

Electrical Panel Upgrades

Multiple organizations who work in limited income homes include electrical safety and upgrades in their scope. In this evaluation, at least five different partner organizations included electrical panel upgrades in their scope. This is an area ripe for confusion.

Coordination between partners and agencies could reduce the cost burden for weatherization teams if a clear standard is established requiring that panels be replaced with 150 or 250 AMP panels whenever possible.

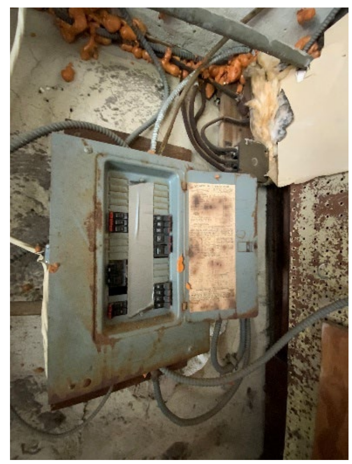


Figure 34: Electrical panel in a BTL home in need of replacement.

Dehumidifier Installation

https://sws.nlr.gov/spec/202031 (Stand-Alone Dehumidifier Installation)

Weatherization often installs dehumidification in basements. This is a health and safety expense that does not contribute to energy savings and can take significant effort to install. The installation of a dehumidifier can involve installing a condensate drain, building a structure to elevate the unit above the level of an existing slop sink, and/or installing a pump (and power for a pump) to move water up and out of the basement.

Installation of a dehumidifier can often be avoided when a HHPWH is installed. The water heater will dehumidify the basement as part of its standard function. Part of the installation of a HHPWH is a condensate line and drainage system.

Areas Needing Further Research

Connected Housing Typology & Prevalence of Vacancy, Demolition of Vacants, and End of Row Units.

One important factor that drives retrofit is the architecture of masonry rowhomes. These homes were designed and built in long rows often stretching the length of a city block. The wall shared between the two houses, the party wall, is both a benefit and challenge in rowhome living. End units tend to have a higher heating and cooling load as they have more wall surface area that is connected to exterior conditions. End units were often built with additional features like additional windows and framed bump outs to take advantage of the additional exposed wall area. Each of these elements adds to the energy load of the building. 10 of the 49 properties (20%) evaluated were built as end of row units. Party walls typically make up the majority of wall surface area in a rowhome. These walls are made of layers of brick with plaster applied directly on brick, or on furring strips attached directly to the masonry. This wall's configuration, directly adjacent to neighboring conditioned space, reduces the heating load of all of homes in the row, but neighboring home conditions can also have negative impacts on their neighbors.

The downside of shared walls is:

- They are not airtight.
- They are not pest or pollutant proof.
- Vacancy and demolition of neighboring homes have a significant impact on the health, safety, durability, and energy load of the remaining homes in the row.

Data collected did not specifically note if homes adjacent to the homes in this subset were vacant at any time during the period of assessment. But the geographies where homes were assessed are areas of Philadelphia that have been reported to have high rates of highly deteriorated vacant homes. 31 of the 49 properties (63%) evaluated in this project were located in Philadelphia zip codes that have been identified as having a high number of vacant properties in "imminent danger of failure or collapse"[6].

Of the properties assessed, four (4) of the forty-nine (49) homes addressed are homes that had once had buildings next door which have since been demolished- leaving them as end of row units. When an attached building is demolished, there is no obligation for the entity demolishing the home to provide any insulation to the party wall which is now an exterior wall. Only stabilization and water control are required and implemented at various levels of effectiveness.

Figure 35: Space next to a home served by Built to Last where an open lot has replaced the home that once stood there. The gray walls have been covered with a layer of stucco by the organization who demolished the home.

[6] https://www.inquirer.com/real-estate/vacant-properties-center-city-apartments-20251211.html

Additional Recommended Research in this area

1. Data collection and analysis focused on:
    a. Comparing end of row and mid-row energy usage.
    b. Comparing energy usage of mid-row versus homes with demolished or vacant buildings next door.
2. Research on the potential energy saving and costs of adding insulation to walls exposed by demolition of a neighboring home.
3. Pilot and evaluation of the impact of providing an insulation system (such as an Exterior Finish Insulation System) on walls which have been exposed due to demolition of a neighboring building.
    a. There is currently a draft Standard Work Specification for exterior insulation systems https://sws.nlr.gov/spec/004011 (Exterior EPS Retrofit Wall System)

Research and standards for heating electrification

Heating system electrification for masonry rowhomes needs to be handled with care. Additional research and implementation pilots are needed to develop a set of standards for programs and contractors to follow when electrifying this typology.

Major questions remain:

- At what air leakage rate can a heat pump efficiently manage the heating load of a rowhome and minimize electric resistance heat use?
- What guidelines can be followed to balance heating and cooling loads in rowhomes in a mixed humid climate to minimizing electric resistance heating, while still sizing cooling to effectively dehumidify the home?

Above roof insulation for flat roofing typology

https://sws.nlr.gov/spec/401011 (Roof Deck Insulation)

Above deck roof insulation is the national Standard Work Specifications (SWS), but additional research is needed before implementation of this measure on a broad scale. Flat roofs in this housing typology are usually above a low attic space; there are additional factors to be considered before adopting insulation over the flat roof as a standard solution. There are several walls that separate these low attic spaces from the exterior and/or the neighbor's unconditioned attic. Standard practices for how to air seal and/or insulation these walls to ensure the thermal envelope is continuous up to the underside of the roof deck is essential for this to be an effective insulation strategy for these homes. Scope details need to be built out and an evaluation of standard costs of implementation completed. Built to Last is in a unique position to support exploratory work and research on above roof insulation as their work includes both roof replacements, and weatherization.

The installation and use of solar and its impact on societal energy costs.

Although not quantified in this study, installing rooftop solar accrues lasting public benefits in addition to the individuals participating in the PEA Built to Last Program. By reducing energy burdens over long time frames, solar decreases long-term reliance on federal utility assistance programs such as LIHEAP.[7] Installations also help lessen homeowners' need to access the City's Utility Emergency Services Fund[8] by dampening unanticipated spikes from volatile energy markets. Lower bills also help to minimize utility accounts being in arrears which have long term consequences for the homeowners' credit ratings and (in)ability to obtain financing. Because solar provides decades of savings after a single investment, local, state and federal governments benefit from reduced repeat applications and administrative processing. Altogether, these effects compound to lower ongoing public expenditures on utility assistance while improving stability and affordability for low-income households.

Solar also goes hand-in-hand with electrification. In the right homes, reducing the cost of electricity helps to enable heat pump conversions that might otherwise have increased energy burdens.

Last but not least, installing solar can raise morale and change perceptions at a neighborhood-scale. Consistent with this view, an older study has shown that solar installations in southeastern Pennsylvania increased property values by at least 2.6%.[9] Unlike many deep energy retrofit measures installed behind walls, solar installations are often visible at the street level. Much like victory gardens during World War II that significantly added to the nation's food supply, solar installations promote a sense of energy independence and community pride that can transcend monetary value.

Workforce Development and Market Readiness

HVAC System Sizing Calculations

An essential element of providing responsible, and effective energy efficiency upgrades to any existing building is *accurate heating and cooling system sizing*. Incorrectly sized heating and cooling systems can both *decrease resident comfort* and *increase resident utility bills*. An important goal of all partners involved in both weatherization and home repair is to provide more comfortable homes and lower utility bills. The inadvertent mis-sizing of heating and cooling systems, often the most expensive piece of equipment in the house, is an important mistake to avoid.

The engineering calculations used to determine the heating and cooling loads for a residential building are:

- Manual J- Residential Load Calculation,
- Manual S- Residential Equipment Selection, and
- Manual D- Residential Duct Systems.

In reality, these calculations are completed for only a small percentage of residential buildings and very rarely in single family residential system replacements. When they are utilized for residential replacements, contractors are often forced by cost constraints to do a "quick and dirty" Manual J using whatever free software that has been provided by the equipment manufacturer they use most

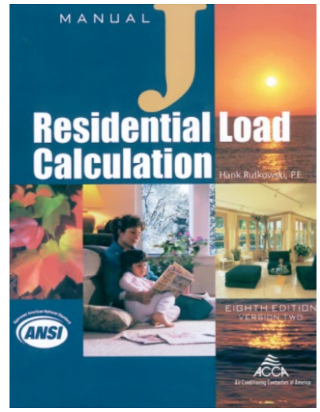
[7] https://acf.gov/ocs/programs/liheap

[8] Utility Emergency Services Fund

[9] https://emp.lbl.gov/publications/appraising-sun-six-state-solar-home

frequently.

The history of these engineering standards is important context to understand when attempting to ensure properly sized systems in home retrofit.



- The Air Conditioning Contractors of America (ACCA) created the Manual J Residential Load Calculation in 1972 to provide a standardized method for calculating residential heating and cooling loads. The standard is now on its 8^{th} addition and is required by nearly every code jurisdiction in the United States. Despite this requirement, few code officials understand or review Manual J calculations as part of the code enforcement process.
- The Manual S for Residential Equipment Selection was accredited in 2004 but initially was focused on proper sizing of air conditioning systems. The 2014 edition expanded focus to include more robust sizing for heating, humidification, and dehumidification. The 3^{rd} edition, not released until 2023, was designed to support the evolution of the HVAC industry and updated technologies with additional focus on electrification and renewable energy.
- The Manual D Residential Duct Systems calculation methodology was first published in 1995 but underwent major changes in the third addition released in 2014.

With this context in mind, it is easy to understand why the general residential, single family, HVAC industry is not skilled in these calculations. The Manual J has been around a long time, but verification that the calculations were completed is rarely done. When verification is made, it is not often done so by anyone with expertise in evaluating its accuracy.

The Manual S is a relatively new standard which may not have even existed when many HVAC contractors were learning their trade. The editions that dig into heating systems, dehumidification, and electrification are very new. Few residential HVAC contractors will have been trained in these calculations as part of their core competencies.

The modern Manual D, went through a transformation in 2014, so any HVAC contractor who trained before then, is unlikely to understand the new, updated standard and its application.

As a result, most HVAC contractors rely on “rules of thumb” for sizing new systems. In residential change outs, it is also common for contractors to simply swap out “like for like”. This means they simply look at the heating (and or cooling) capacity of the existing system and replace the old system with a new system that is the same size. If a homeowner has complaints about comfort, they may replace the existing system with a slightly larger system in hopes that the larger system will provide more heating or cooling and resolve the comfort complaint.

When programs, such as weatherization, require a Manual J to ensure the heating load has been calculated and the new system will meet the needs of the home, there are several important gaps that make that requirement ineffective.

1. A Manual J is only as good as its inputs. Inaccuracy of the inputs listed below (and more) can easily warp the results of a Manual J, leaving an HVAC contractor designing a system to incorrect loads.
    a. Heating and cooling design temperatures
    b. Building dimensions
    c. Window surface area
    d. Insulation levels
    e. Air leakage rates
2. Without knowledgeable quality assurance checks on Manual J calculations, their accuracy is doubtful.
3. A Manual J is only one half or a third of the sizing calculation needed to properly size new heating and cooling systems. The Manual S, to properly match a piece of equipment to the loads, is needed. If the property has ductwork, a Manual D, or at the very least a comprehensive duct evaluation is needed to ensure the ductwork can deliver the heated or cooled air to the whole house effectively.

The Importance of an Accurate Manual J: A Built to Last Example:

When the Built to Last team arrived at 65th street for the initial property assessment, the home had no working heating system. The steam boiler had failed, and the homeowner needed a new heating system before winter. When approached with the option of replacement of her steam boiler with mini-splits the homeowner was enthusiastic about the option. A large part of her enthusiasm was driven by the promise of more consistent cooling throughout the house.

Built to Last asked an HVAC contractor to provide a quote to install mini split heat pumps to replace the steam heating system. The initial mini split estimate included 6 mini split heads to be installed throughout the house in the following locations: living room, dining room, kitchen, and each of the 3 bedrooms on the 2nd floor. Through the DOE Weatherization Enhancement and Innovation grant, the team was able to expand their standard evaluation of the contractor's scope, and a Manual J calculation was run using the building's actual insulation levels and the actual air leakage rate measured by a weatherization auditor. It was discovered that, even with the anticipated air leakage reduction and increased insulation levels, the mini split system proposed, would *not* satisfy the heating needs of the building.

The team worked with the weatherization team and HVAC contractor to

1. Discuss further ways to reduce the building's heating load by increasing insulation levels and further reducing the air leakage of the home.
2. Find a larger mini split system which met the loads shown by the Manual J calculation.

Additionally, the team was also able to address the conditioning needs of the bathroom, which the HVAC contractor had planned to heat "indirectly" hoping the heat from the 3 bedrooms on the top floor would migrate to the central bathroom. The wall surface area and small volume of most rowhome bathrooms is often considered too small to condition with a mini split head. To ensure the homeowner would have sufficient heating in that space, an electric resistance heater was installed in the bathroom to provide heating in this space.

Since electric resistance heating can be a very expensive heating option, additional energy cost projections were also completed to determine that the full scope of work would still reduce the resident's energy bills.

Appendix A: Expanded Home Condition Continuum

	Minimum Standard	Intermediate Standard	Preservation and Efficiency Standard
Roof/Shell	No severe roof leaks and sources of persistent water infiltration through building shell (basement not included)	Main areas of building shell are watertight under normal weather events. Roof and siding have at least 5 years of function life expected	All areas of building shell are solid, secure, and weather tight. Roof and siding have 10+ years of remaining functional life expected. Options for insulation and air sealing upgrades have been explored and fully maximized
Heating	Present-working- central heat system or electric system that is heating at least 50% of the home	Present, working, distribution system servicing house in such a manner that living spaces are conditioned and habitable. Heater has at least 5 years of functional life expected	Heater and distribution system are present and working efficiently- servicing all areas of the home. Heater has 10 years of remaining expected functional life. Options for high efficiency gas heating or/full electrification and heat pump installation have been explored and maximized. Energy Star equipment as budget allows
Plumbing	Hot and cold running water- No major leaks stack/lateral, supply line. No lead *supply* lines present.	Hot and cold running water, supply and drain leaks resolved. Drainlines and water heater have at least 5 years of function life expected. No lead drain lines present.	Hot and cold running water, no supply or drain leaks. Drainlines, supply lines and water heater have at least 10 years of functional life remaining. (all cast iron is in excellent condition, no lead pipes present) Options for water sense upgrades have been explored and maximized
Electrical	Service line and protective casing intact and weather tight, 100 AMP service breaker box	Service line in good condition (protective casing weather tight) min 100 AMP service, breaker box in good condition, electric distribution free of frayed wiring, overloaded circuits, and hazards. GFCI protected outlets near water sources. Each occupied room has adequate outlets and lighting.	Service line and breaker box in good working order and expected to last 10 years or more. Min 100 AMP service. Distribution in good condition with minimal knob and tube wiring. All required GFCI circuits, all circuits properly loaded. All rooms have adequate outlets and lighting. Home electrification has been explored and fully maximized. Appliances are in good working order, and have been updated to high efficiency (Energy Star preferred) as budget allows

Primary Bathroom	Functional toilet and shower/tub	Functional toilet, shower/tub. Fixtures free from leaks and expected functional life of at least 5 years. Tub surround reasonably watertight. Flooring free of major dipping/bowing/bounce.	Functional toilet, shower/tub/sink. Fixtures all in good working order with functional life of 5-10 years. Tub surround in good condition. Bath finish set present (towel rods, etc.). Finished walls and flooring are intact and easy to clean, shower surround is in good condition. Bathroom has adequate ventilation.
Kitchen	Functional sink, stove, fridge, place to prepare and store food	Sink, stove, fridge all in good working order. Kitchen offers adequate places to prepare and store food. Cabinets, sink, countertop free of major damage and deterioration-functional. Flooring free of major dipping/bowing/holes	Sink, stove, fridge all in good working order. Kitchen offers adequate places to prepare and safely store food. Cabinets, sink, and countertop are all in good working order and have a remaining expected life of 5-10 years. Flooring is intact, solid, and easy to clean. Exhaust and/or recirculating fan above stove. Switch to electric induction stoves and Energy Star appliances have been explored/maximized.
Windows	Intact or covered, no missing panes	All windows are intact and can open, close, and lock	Windows are intact, can open, close, lock and are reasonably airtight and efficient. Options for air sealing have been explored and maximized
Exterior Doors	Intact and functional-open, close, lock	Doors are intact, functional, weather tight, and free of major deterioration and wear	Doors are intact, function, weather tight, and in good working order. Options for air sealing have been explored and maximized
Structural	No structural components within the living building shell are in imminent danger of collapse (walls, floor joists, flooring)	No structural components (in living building shell) are in danger of collapse and integrity of members sufficient to last at least 5 years (walls, floor joists, flooring), finish surfaces of walls, and flooring in occupied living areas are intact and sound (no large areas of missing flooring/drywall/plaster). Sources of structural damage such as water/rot and termites are treated/resolved.	Structural components are all solid, free of rot/ movement/ deterioration. Finish surfaces of walls, and flooring in occupied living areas are complete, solid, and sound. Sources of structural damage such as water/rot and termites are treated/resolved.

Health/ Safety Hazards	Combustion gases venting properly out of home, no major gas leaks, no eminent fire hazards. Smoke and co detectors present. No major sources of mold, or friable asbestos in primary living areas. No chipping lead paint in rooms occupied by children. No major insect or rodent infestation in kitchen and primary living areas. Home must be safe and reasonably accessible for workers.	Combustion gas appliances have venting that is compliance with code, no gas leaks, no fire hazards (combustion appliances and/or wiring), smoke and co detectors present on each level of home. No mold in occupied living area, or chipping lead paint homes occupied by children. Home has adequate ventilation. Rodent and insect infestation is managed.	Combustion gas appliances have venting that is compliance with code, no gas leaks, no fire hazards (combustion appliances and/or wiring), smoke and co detectors present on each level of home. No mold in occupied living area, or chipping lead paint homes occupied by children. Home has adequate ventilation. Rodent and insect infestation is managed. Home is free of agents that jeopardize indoor air quality (VOC, formaldehyde, etc.)
Client Needs	Minimum egress in the event of emergency	Client is able to safely enter and exit the home, access sleeping area, kitchen and bathroom facilities regardless of physical limitations. If home has a child with asthma, the child's primary living areas are free of environmental triggers for asthma	All occupants are able to safely access, use and move about the home. Homes are properly equipped/modified to accommodate function needs of occupants with disabilities. If home has a child with asthma, the child's primary living areas are free of environmental triggers for asthma

Appendix B: Energy Star Efficiency Levels for Philadelphia Climate Zone

Table 4: Energy Star efficiency requirements for fossil fuel heating equipment

High Efficiency Fossil Fuel Replacement Options	
Type of system, fuel	**Energy Star Efficiency [10,11]**
Furnace, natural gas	≥ 95% AFUE
Furnace, oil	≥ 85% AFUE
Boiler, natural gas	≥ 90% AFUE
Boiler, oil	≥ 87% AFUE

Table 5: Energy Star efficiency requirements for electric heating equipment.

High Efficiency Electric Heating Replacement Options	
Type of Electric Equipment	**Cold Climate* Efficiency Requirements for Energy Star[12]**
Air Source- Split System Heat Pump, Ducted	≥ 8.1 HSPF2/ ≥15.2 SEER2
Air Source- Split System Heat Pump, Non-Ducted (Mini Split Heat Pump)	≥ 8.1 HSPF2/ ≥15.2 SEER2

**Philadelphia is in ASHRAE Climate Zone 4A, Mixed Humid. In climate zones 4 and above, the US Department of Energy (DOE) recommends cold climate heat pumps are used for heating.*

Table 6: Energy Star requirements for water heating systems.

High Efficiency Hot Water System Replacement Options	
Type of Water Heating Equipment, Fuel	**Energy Star[13] Efficiency Requirement**
Storage Water Heater, Natural Gas	UEF ≥ 0.81 to UEF ≥ 0.86 *(dependent on draw pattern)*
Hybrid Heat Pump, Storage Water Heater, Electric	UEF ≥ 3.30
Gas-fired Instantaneous Water Heater	UEF ≥ 0.95

[10] https://www.energystar.gov/products/furnaces/key_product_criteria

[11] https://www.energystar.gov/products/boilers

[12] https://www.energystar.gov/products/heat_pump_water_heaters/key-product-criteria

[13] https://www.energystar.gov/products/water_heaters/residential_water_heaters_key_product_criteria

Appendix C: Example Project, Full Electrification

Twenty First Street

Project Cost: $64,287
Number of Involved Partners: 5

Projected Savings (Year One)	
Total Energy	101% MMBTU
Natural Gas	100% therms
Electricity	101% kWh
Energy Costs	94% Costs*
Emissions	62% GHGe**

**Note: Market Rate Utility Rates in Philadelphia (2024) were assumed for this analysis. Utility assistance programs offer lower cost utilities to many residents.*

***Note: Ownership of the Solar Renewable Energy Credits (SRECs) were retained and sold by the solar installer. As a result, no GHGe savings from the energy generated by the solar system were included in the savings calculations.*

System or Focus Area	Before Intervention	Work Completed
Heating	Natural Gas boiler- non-functional- homeowner using electric space heaters for heating.	Mini split heat pumps
Cooling	Window units	Mini split heat pumps
Water Heating	Natural gas	Hybrid Heat Pump
Cooking	Natural gas	Electric Induction
Clothes Dryer	None	None

Attic Insulation	R7- R13	R38
Walls	Masonry, uninsulated Bump outs, framed, uninsulated	No change
Foundation	Uninsulated, indirectly conditioned basement	Joist pockets air sealed
Other Efficiency	2 Windows with broken glass	Replaced
Air leakage	16.6 ACH50	12.6 ACH50 (24% reduction)
Solar	None	5.8 kW leased solar system added

Other work completed: electric panel upgrade, plumbing repairs, sewer line replacement, concrete work in basement, roof replacement, accessibility upgrades in bathroom. In Figure 3

Figure 36: Google Earth Image of Solar Array on the roof of the property.

Appendix D: Skilled Professionals to Complete Additional Tasks and Evaluation

Task	Professionals with Skills or Qualifications to Complete Task
Calculating Changes to Utility Costs	Weatherization or energy auditing partners who are already in the house and calculating utility cost changes. Assign an internal team member. Hire an external consultant
Manual J Calculations	HVAC contractor Mechanical engineer
Duct Evaluations	HVAC contractor Mechanical engineer Energy auditor
Air Leakage Testing	Energy auditor
Hazard Mitigation	Remediation Professional
Electrical Panel Upgrades	Electrician
Determine Electrical Service Capacity (from the utility to the house)	Electrician Electrical engineer
Ventilation Calculations (Indoor Air Quality)	Energy auditor
Installation of new types of equipment	All trades

Appendix E: Important Implementation Considerations

Task	Important Considerations
Calculating Changes to Utility Costs	**Cost Components** - What utility costs are being used? - Are non-energy costs of utility service being considered? e.g., customer charges, fees, etc... **Programs & Impact** - Are utility assistance rates and programs being considered in the evaluation? - Is there a system to track projects receiving solar systems and measure its impact on utility costs?
Manual J Calculations	**Process & Oversight** - Is the Manual J shared with the person who makes the decision on what equipment will be installed? - Does that person have experience or training in interpreting the outputs? - What software is being used for the Manual J? **Key Calculation Parameters** - What design temperatures (heating season and cooling season) are being used for the calculation? - What air leakage rate, insulation levels, and glazing are assumed in the calculation? **Use in Decision Making** - How is the information in the Manual J being used to influence the selection of equipment?
Ductwork Evaluation	**Assessment Method** - What procedure or process is being used to evaluate existing ductwork? - What diagnostic equipment is being used? - How are the results of the evaluation communicated to decision makers? - How will decision makers ultimately decide if the existing ductwork can be used to effectively deliver heating and cooling to the home?
Air Leakage Testing	**Testing Decisions** - In what scenarios does the auditor decide not to do a blower door because of indoor air quality concerns? **Results & Metrics** - What type of blower door test results do they provide? - If ACHn or ACH50, how do they measure a property and determine its area and volume?

Electrical Panel Upgrade	**Inputs** - What information do they need from the preliminary assessor to make a good faith estimate of panel upgrade costs? **Site Visit** Do they always need to visit a home to create an estimate?
Determine Electrical Service Capacity (from the utility to the house)	- This can be challenging to determine. Some collaboration with an electrician will likely be needed before a team can be confident that an upgrade is not needed.
Ventilation Calculations (Indoor Air Quality)	**Inputs** - What area, volume, and air leakage rate are being used for ventilation calculations? **Recommendations** What options do they recommend for adding ventilation when it is needed?