States of mind: How decision-making patterns can influence uptake of residential heat pumps and enclosure upgrades

Kieren H. McCord, Tracy L. Fuentes, Chrissi Antonopoulos, Pacific Northwest National Laboratory
Núria Casquero-Modrego, Lawrence Berkeley National Laboratory
Holly Carr, U.S. Department of Energy

Abstract

Like most aspects of American society, home energy upgrade decisions are influenced by where we live and who we trust. It turns out, our location and preferences for our home environment play an important role in how we choose to adopt technology related to residential decarbonization. For decarbonization efforts to be the most successful, we should consider changing how we discuss energy efficiency and decarbonization, depending on what resonates most with home occupants. In this paper, we provide insight from a one-of-a-kind survey conducted in the U.S., reaching 10,000 homeowner and renter households. We looked specifically at how heat pumps and building envelope improvements are adopted, finding that not only are there differences in where these technologies (for heat pumps) and construction solutions (for building envelopes) are being installed, but also in motivations for installing, household socio economics, and general household preferences. We discuss these trends, highlighting opportunities for advancing market transformation efforts for heat pumps and building envelope improvements, focused on messaging and other important factors that resonate with home occupants. Outcomes of this study have important equity implications, which are discussed as part of the findings. We found actual technology adoption is roughly 40% lower than expressed willingness to adopt. This paper explores barriers to adoption and provides a path forward for increasing the presence of heat pump technologies and building envelope improvements in the existing residential building stock.

Introduction and Background

Globally, the building sector accounts for ~30% of final energy consumption and ~37% of greenhouse gas emissions (GHG's), which come primarily from fossil-fuel combustion in buildings (OECD 2020; United Nations Environment Programme and Global Alliance for Buildings and Construction 2020; US EPA 2021). In the residential sector, many building decarbonization strategies and pathways have been identified to reduce energy use and carbon emissions (Yang et al. 2022; Walker, Less, and Casquero-Modrego 2022). Strategies to meet these goals commonly include electrification of primary systems and retrofits that improve the performance of the building enclosure to reduce heating and cooling loads, efficient lighting implementation, renewable energy integration, and installing smart building technologies. To be successful, these strategies need to be supported by households, which ultimately make decisions regarding energy upgrades in their homes (Wilson, Crane, and Chryssochoidis 2015). Moreover, the construction industry plays a critical role in implementing and installing these emerging solutions. They are pivotal in translating theoretical advancements into tangible realities,

bridging the gap between research and practice. Household decision-making dynamics are important considerations for building and energy sectors, because energy efficiency gains using traditional approaches have not yielded robust uptake, especially in existing buildings (Gerarden, Newell, and Stavins 2015; Sunikka-Blank and Galvin 2016). Decision-making at the household level is the action that directly precedes the actual home modification related to home decarbonization.

This perspective aligns with the priorities of the U.S. Department of Energy. The technologies needed to dramatically reduce emissions from residential buildings in the United States, such as efficient electric heat pumps and heat pump water heaters, exist in the market. Although the technical potential of these electrification upgrades in the residential sector was clear, the factors that influence homeowner and renter decision-making around home improvements were opaque. Few studies addressed the question, particularly at a nationwide scale. The U.S. Department of Energy commissioned the study to be representative of home occupants across the country and to gain perspective on how and why residents make (and do not make) upgrades to their homes. The study would address all kinds of home upgrades, including efficient electric equipment, to understand the motivations, barriers, influences, and outcomes at play.

This paper summarizes home decarbonization opportunities using data from a novel survey executed by the Pacific Northwest National Laboratory. PNNL asked 10,000 households throughout the U.S. what energy improvements they made to their homes and what factors influence their decisions. The goal of this paper is to explore relationships between contextual decision-making factors and two specific home energy upgrades: 1) building envelope upgrades and 2) heat pump adoption. Outcomes can support retrofit efforts for decarbonization by informing messaging and program design.

Methods

Study Design

We used a national-scale survey to understand residential energy technology uptake and decision-making. To develop the survey, we first interviewed 121 individual decision-makers within their households regarding planned or completed projects (Biswas et al. 2024). We used the insights of these interviews to design a survey that was distributed to 10,000 households across the U.S. The overarching topics approached in the survey include descriptive information about the respondent, their household, their home, home modifications they have made, and the human cognition-based contextual factors, such as preferences, motivations, barriers, and information sources. Detailed survey methodology, as well as a regional analysis of results can be found in a recent publication by the authors (Antonopoulos et al. 2024). The processed data from the survey was compiled into a dataset entitled UPGRADE-E: Understanding Patterns Guiding Residential Adoption and Decisions about Energy Efficiency and can be accessed at (Fuentes et al. (in progress)) and represents the basis for the analyses included in this paper. The dataset represents a rich repository of home energy technology and modification decision-making results, the largest of its kind to-date. The abundance of contextual considerations within this dataset provides a robust resource for continual analysis, with possibilities for considering cross-cuts of data from a variety of perspectives.

Data Collection

We distributed a national-scale survey to homeowners and renters. The survey, hosted on the Qualtrics platform, included 77 questions to homeowners and 87 questions to renters, reaching households in every state. Available in English and Spanish, the survey ran from August – October, 2022, until 10,000 responses were reached. The full set of survey questions can be found in the regional analysis (Antonopoulos et al. 2024).

Analysis

We focused on two key home upgrade decisions from the UPGRADE-E dataset: undertaking building envelope upgrades and installing a heat pump. For building envelope upgrades, we considered the following eight changes to the home: 1) air sealing; 2) insulating the home; 3) installing new siding; 4) installing a new roof; 5) installing double pane windows; 6) installing triple pane windows; 7) installing window coverings, and 8) abating asbestos and/or lead. We focused on heat pumps used to heat and cool homes, which included both central and minisplit heat pumps and excluded heat pump water heaters.

We used R (R Core Team 2022) for all analysis and visualization. We calculated descriptive statistics from the survey, including key preferences, barriers, and information sources prioritized by participants. We then calculated overall frequency of upgrades, as well as a regional breakdown of these technology upgrades.

To explore the potential drivers of household decisions regarding these upgrades, we focused a subset of potentially relevant UPGRADE-E variables on demographic/home characteristics, geographic, economic, personal preferences and motivations, other home modifications, info sources, barriers, and other miscellaneous variables such as willingness to adopt certain technologies or program participation. We also incorporated Zillow county-level cost data (Zillow 2024) to consistently estimate home values.

We created unique adoption rate plots for each decision type. For building envelope decisions, we plotted co-adoption of technologies within the building materials and envelope category. All rates are presented as percentages within the ‘Material Changes ’($n = 2,208$) category. For heat pumps, we plotted overall adoption rates versus the following 11 variables: 1) household annual income; 2) monthly mortgage or rent; 3) education; 4) climate zone; 5) respondent age; 6) monthly utility bills; 7) home size; 8) Zillow median county home value; 9) year home was built; 10) number of children in the household; 11) years lived in home. We did not plot the same variables for each of the eight different building envelope adoption rates.

Finally, we evaluated correlations between adoption and other potential drivers in the dataset, as described above. Because of the large number of correlational tests, we chose a p value of $p < 0.001$ to indicate statistical significance. Only complete cases were considered for the correlation matrix.

Results

Household Cognitive Context

More than 90% of residents rated relaxation, ease of maintenance, having a family kitchen, or aesthetics as important or somewhat important, with safety and outdoor space not far behind (Figure 1). Residents rated having space for entertaining, for pets, for exercise, for working, and for children as important household preferences (68-82% of respondents), while having maker spaces (shop space, chef's kitchen, craft space) was important to 61%-64% of residents.

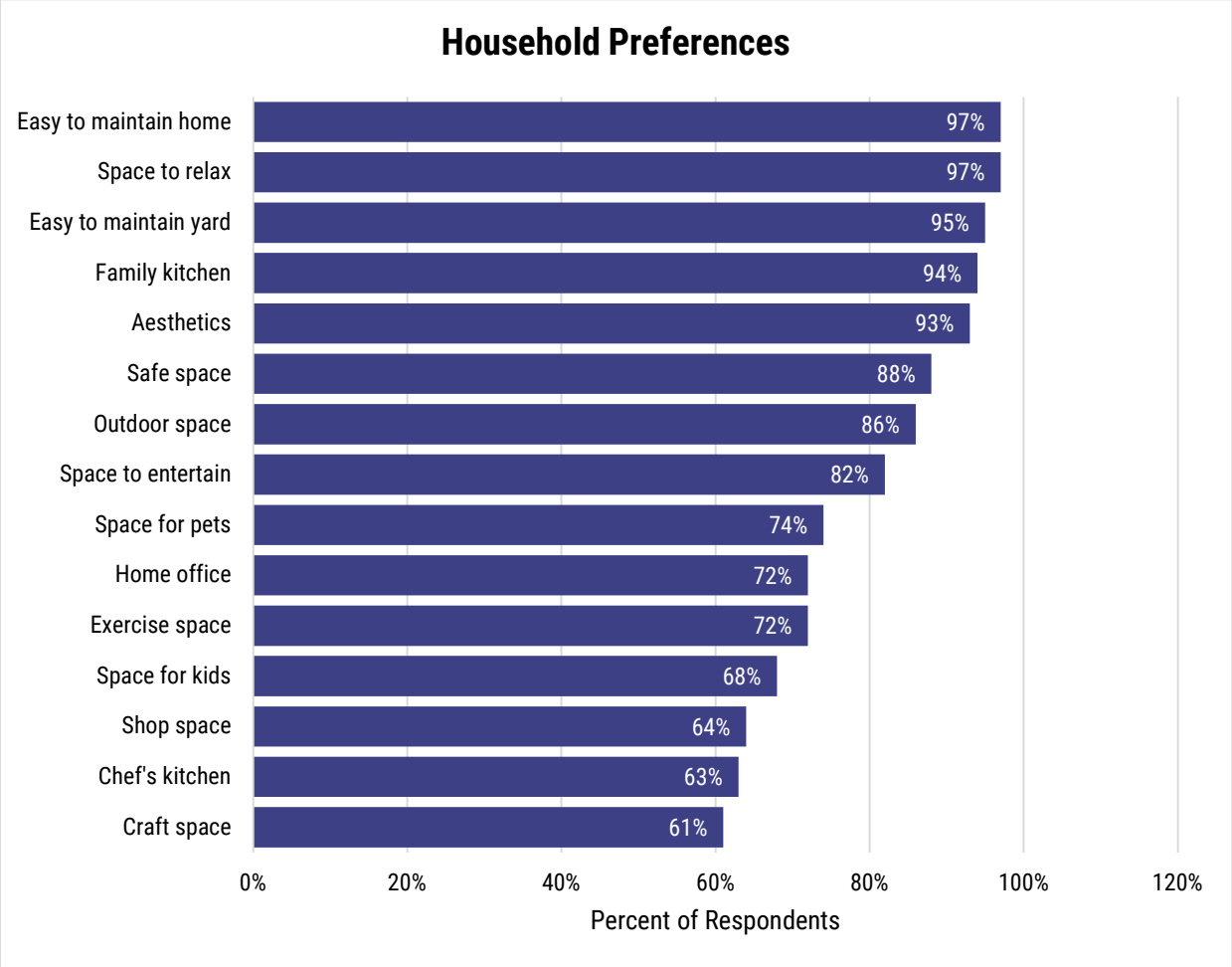

Figure 1. Frequency of respondents rating each living space preferences as somewhat important or important. Respondents could select all that apply.

More than 40% of residents reported that improving comfort or safety, repairing broken systems, improving appearance, and reducing energy bills were motivations for making changes (Figure 2). About 26-30% of residents selected motivations of making spaces more useful and reducing energy bills (26-30%), while about 15% selected reducing environmental impacts and reducing harmful health impacts.

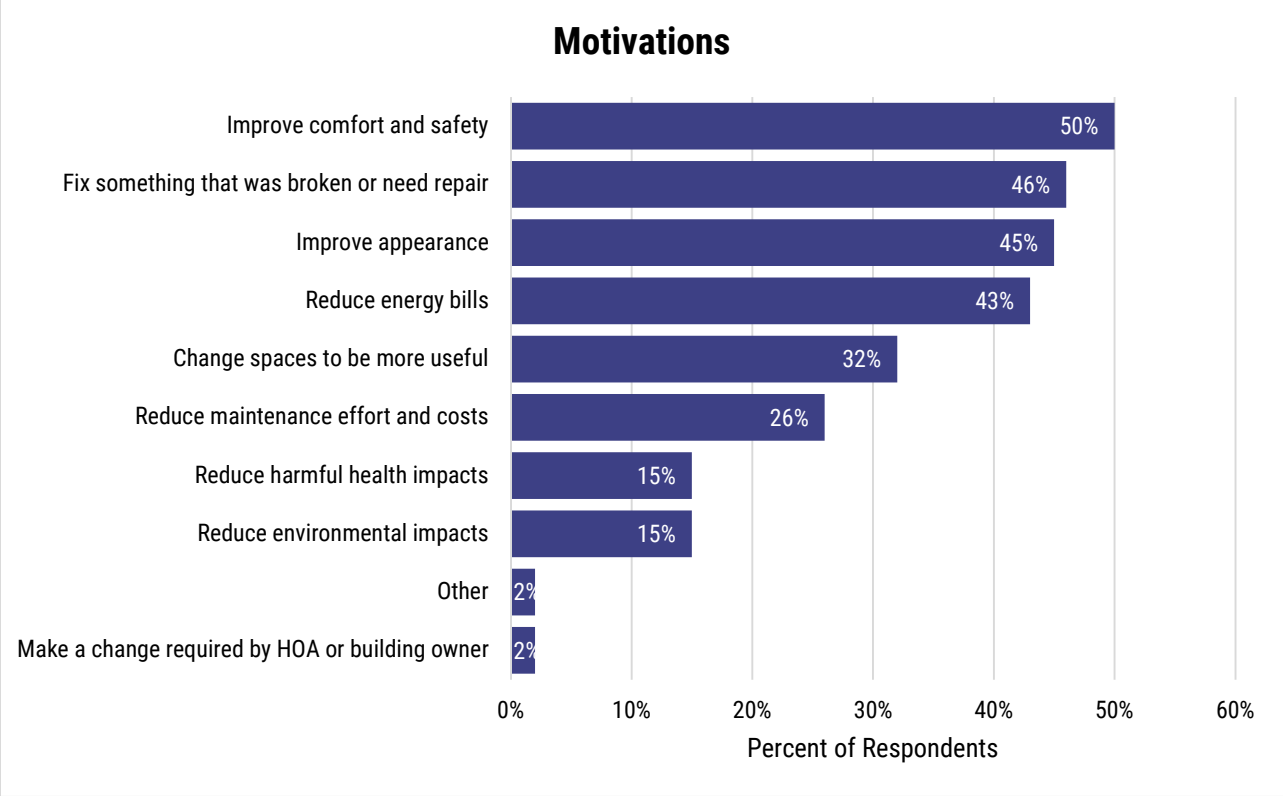

Figure 2. Frequency of respondents selecting motivation as factor in home modification decisions. Respondents could select all that apply.

Project cost and upfront costs are the most prevalent barriers for undertaking home upgrades (Figure 3). More than a quarter of respondents also noted difficulties in finding contractors and materials for their project, pointing at labor shortages and supply chain issues. Unclear warranties were the lowest cited barrier.

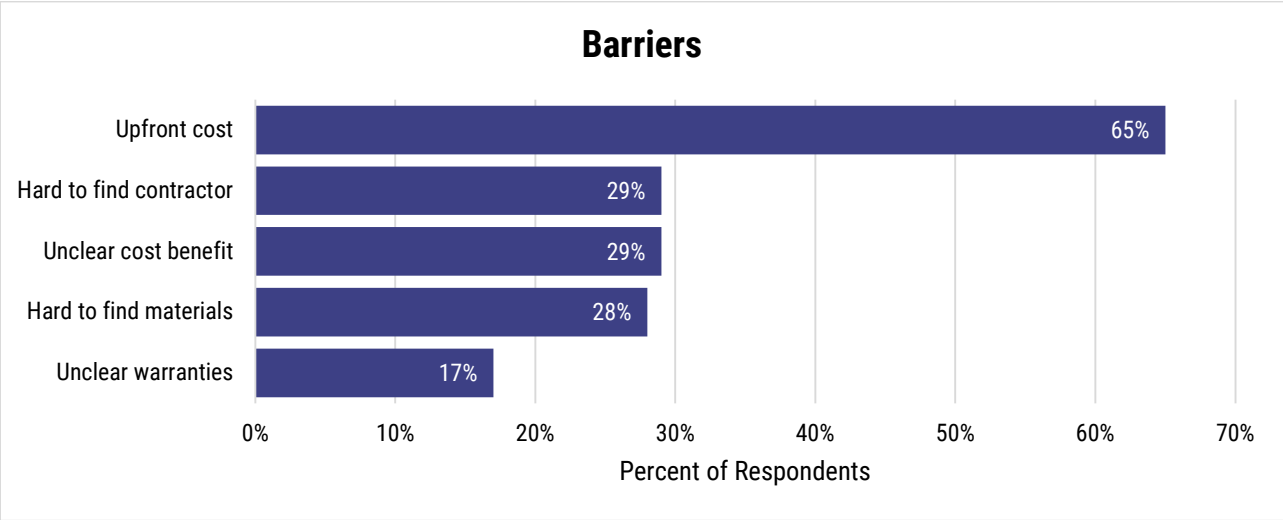

Figure 3. Frequency of respondents identifying each barrier when considering making home energy improvements. Respondents could select all that apply.

Respondents get most of their information from family and friends (Figure 4). They also consult home repair review websites, known retailers like big box stores, and social media (29-37% of respondents). Other information sources were less important (26% or less).

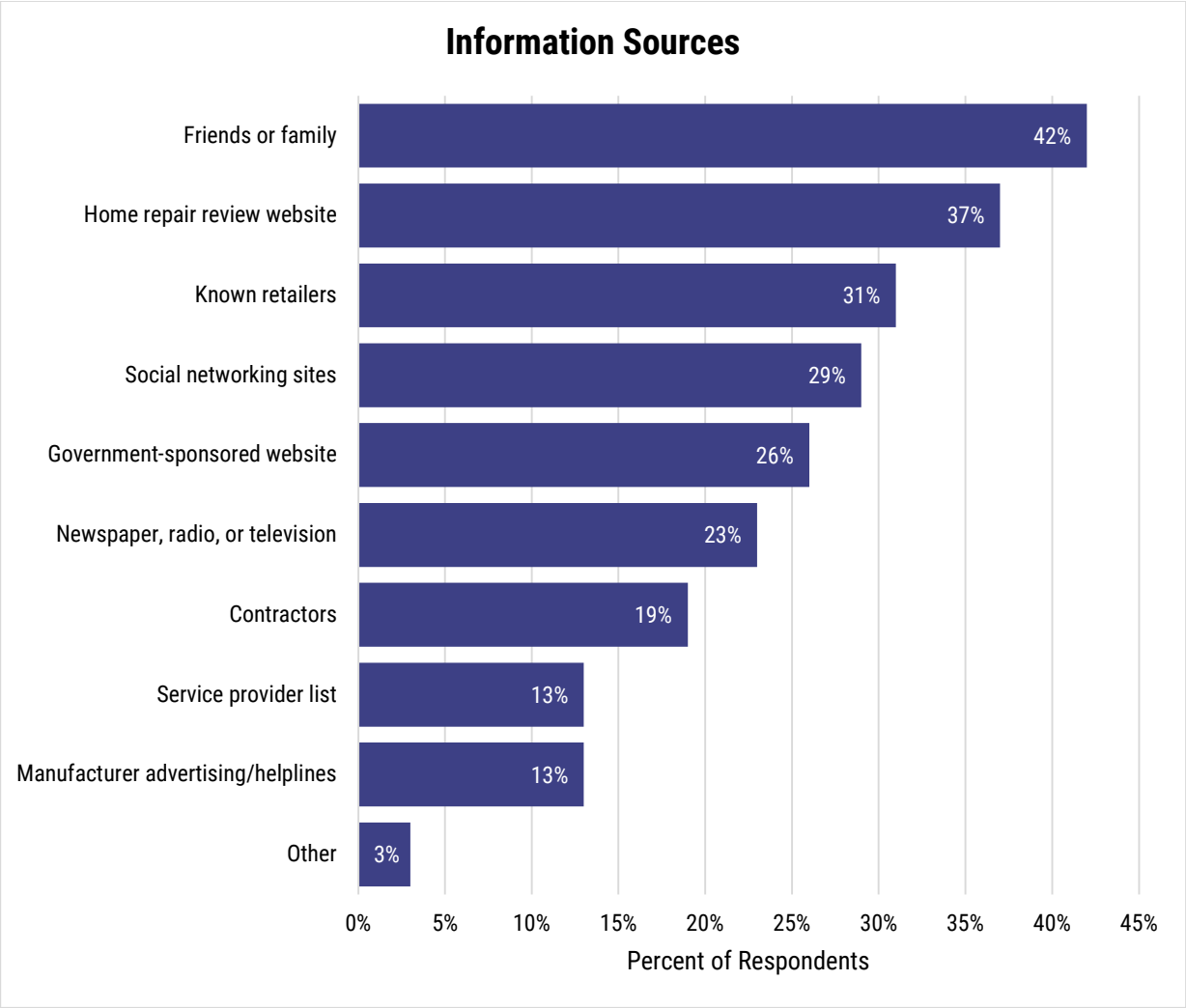

Figure 4. Frequency of selected information sources when considering making home modifications.

Building Envelope Trends

Nearly a quarter of residents (22.3%, n=2,208) made changes to their home's building materials, structure and/or accessories (Table 1). Window replacements (11.4% of residents), air sealing (8.3%), and new roofs (7.3%) were the most frequent upgrades. Window coverings, new siding, and asbestos/lead abatement were less frequent (<6%).

Table 1. Frequency of changes to building envelope or materials.

	West	Midwest	Northeast	Central Southwest	Southeast	Total U.S.
Number of Participants	1,938	1,958	1,764	1,313	2,946	9,919
Air Sealing	149 (7.7)%	170 (8.7)%	146 (8.3)%	128 (9.7)%	235 (8.0)%	828 (8.3%)
Double Pane Windows	160 (8.3)%	158 (8.1)%	151 (8.6)%	100 (7.6)%	226 (7.7)%	795 (8.0%)
Triple Pane Windows	73 (3.7)%	59 (3.0)%	54 (3.1)%	52 (4.0)%	95 (3.2)%	333 (3.4%)
New Roof	109 (5.6)%	183 (9.3)%	130 (7.4)%	104 (7.9)%	206 (7.0)%	732 (7.3%)
Siding	81 (4.2)%	109 (5.6)%	100 (5.7)%	54 (4.1)%	126 (4.3)%	470 (4.7%)
Window Covering	138 (7.1)%	80 (4.1)%	95 (5.4)%	79 (6.0)%	154 (5.2)%	546 (5.5%)
Asbestos/Lead Abatement	58 (3.0%)	23 (1.2)%	45 (2.6)%	24 (1.8)%	49 (1.7)%	199 (2.0%)

Many respondents completed multiple improvements to their building envelope (Figure 5). Among those who made a material modification, 58.9% made two or more of the modifications listed above and only about a third (33.5%) made a single modification within the material category. Note that the two statistics do not add to 100% because some stated ‘other’ or did not specify the type of building material modification. There was an interesting amount of overlap in the adoption of the different material modifications. For example, within the group who updated their insulation (n = 556), we saw a 23-44% co-occurrence with the other material changes except asbestos/lead abatement, where only 12% of respondents who updated their insulation also abated asbestos/lead. The highest co-adoption with insulation was air-sealing, where 44% of participants who added insulation also air sealed cracks and openings. Figure 5 shows adoption rates of the various material technologies within the subset of the group who made material modifications (n = 2,208), including a juxtaposition of each material modification with the others and a visual representation of the co-adoption overlap between categories.

Figure 5. Co-occurrence rates of various facets of home envelope and material upgrades. Percentages are calculated within the subset of participants who made any kind of material change to their home (n = 2,208).

Heat Pump Trends

Respondents relied on electricity (48.3%; n=4,792) or natural gas (41.4%, n=4,108) for home heating and cooling. Slightly fewer than 4% rely on oil (n=385) or propane (n=334). Some respondents did not know primary fuel (1.7%, n=173), while 1.1% (n=114) rely on other fuels.

About one third of respondents (33.5%, n=3,325) made some heating, cooling, or ventilation changes to their homes. Thirty percent of these residents who made HVAC changes installed a heat pump HVAC system of some kind (n=1,009; 10.1% of all respondents). About 7.4% of all residents installed a central heat pump, 3.4% installed a minisplit heat pump, and <1% reported installing both (n=67).

We found a large gap between heat pump adoption and willingness to adopt heat pumps if they were affordable versus actual adoption (Table 2). About 45% of residents indicated they would be willing to adopt heat pumps if they were affordable, with about 9% of residents adding the caveat that they would be willing if it did not increase their rent by very much. About 30% of residents selected "maybe" when describing their willingness to adopt and 9% said they needed more information. Only 14% said they were not willing to adopt heat pumps.

Table 2. Frequency of heat pump adoption and willingness to adopt heat pumps.

	West	Midwest	Northeast	Central Southwest	Southeast	Total U.S.
Number of Participants	1938	1958	1764	1313	2946	9919
Heat Pump Adoption	214 (11.0%)	143 (7.3%)	183 (10.4%)	128 (9.7%)	341 (11.6%)	1,009 (10.1%)
Willingness (yes, including caveats)	887 (45.8%)	792 (40.4%)	710 (40.2%)	597 (45.5%)	1489 (50.5%)	4475 (45.1%)
Willingness (maybe)	604 (31.2%)	640 (32.7%)	529 (30.0%)	391 (29.8%)	841 (28.5%)	3005 (30.3%)
Gap (yes) Gap (yes + maybe)	34.7% 65.9%	33.1% 65.8%	29.9% 59.9%	35.7% 65.5%	39.0% 57.3%	34.9% 65.2%

See (Antonopoulos et al. 2024) for actual-willingness gaps for other energy efficiency and home decarbonization technologies.

*Renters were provided the option "yes, provided my rent doesn't increase by much", which was included in the Willingness (yes) response category

Considering the substantial gaps between willingness and actual adoption encourages exploration of possible contributing factors. Several UPGRADE-E variables appear to have clear relationships with heat pump adoption (Figure 6). Heat pump adoption increases as household income, mortgage/rent, education, home size, and home value increase. Heat pump adoption is also greater in newer homes. Heat pump adoption is lower for older respondents. Home tenure shows a peak of adoption at about four years living in the home. Climate Zone 4 had the highest

heat pump adoption (besides Climate Zone 8, which has too small of a sample size and too much variability to form distinctive conclusions) and Climate Zone 6 had the lowest adoption rate.

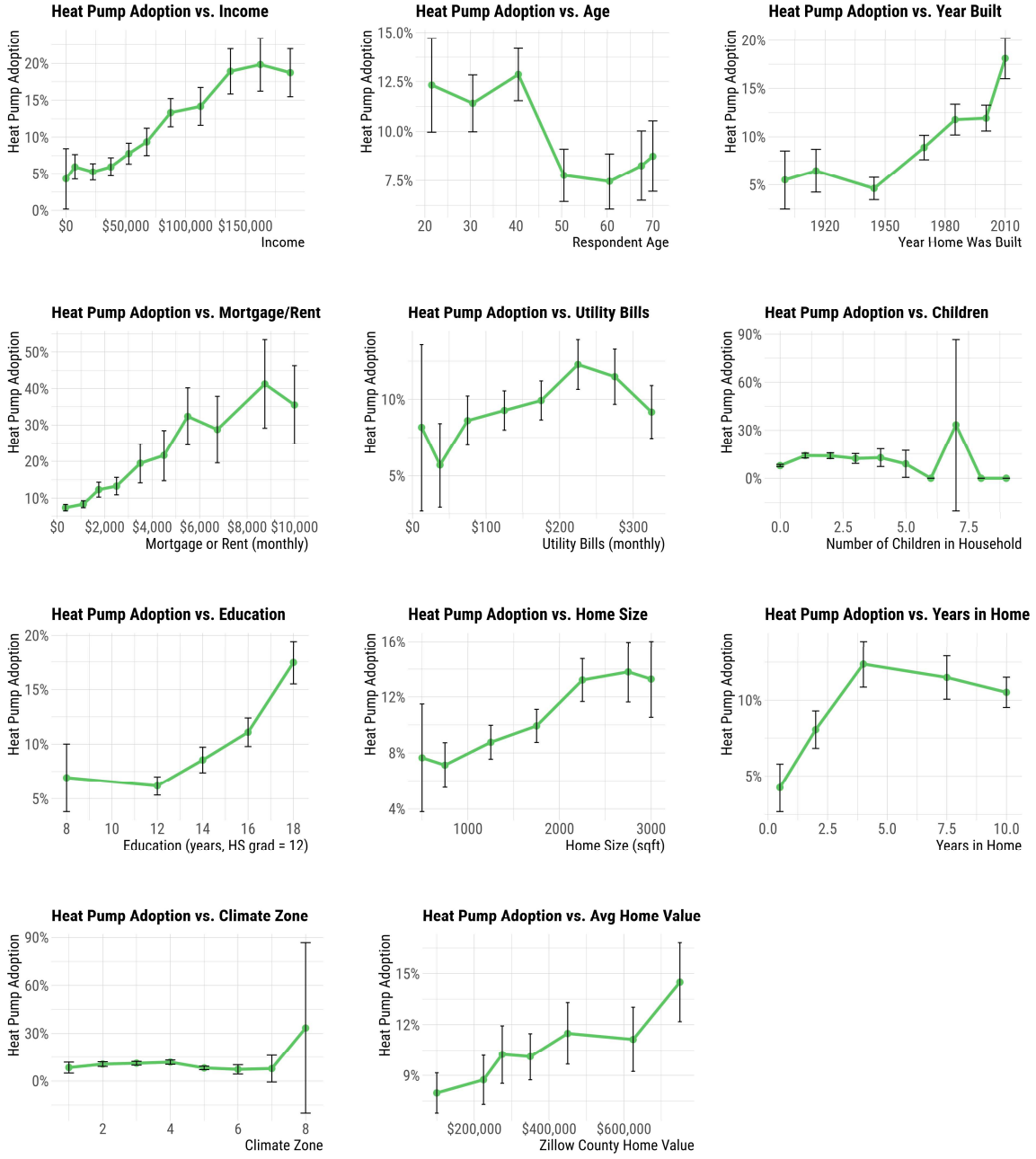

Figure 6. Line graphs showing relationships between variables and heat pump adoption. Standard deviation within each category is shown with black error bars.

Correlations

For building envelope decisions, the most consistently significant positive correlations (Figure 7) are those of co-adoption with other technologies, such as making modifications to a

home's electrical systems ($r \geq 0.12$). Other prominent positive correlations include number of years lived in a home ($r = 0.07$ for double pane windows; $r = 0.15$ for new roof), as well as the motivation to fix something broken ($r = 0.12$ for air seal; $r = 0.015$ for new roof). Amount paid in mortgage or rent was positively correlated with asbestos or lead abatement ($r = 0.18$). Installing triple pane windows was positively correlated with a participant's reported ability to afford a $20k home upgrade ($r = 0.17$). Installing window coverings was positively correlated with the motivation of health ($r = 0.14$). Getting information from a contractor was positively correlated with all envelope upgrades ($r \geq 0.05$) except asbestos/lead abatement and triple paned windows. Getting online reviews was positively correlated with air sealing, installing triple pane windows, and installing window coverings ($r \geq 0.06$). Three household preferences had positive correlations with envelope upgrades: safe space with air sealing ($r = 0.07$), and aesthetics with double pane windows ($r = 0.07$) and window coverings ($r = 0.06$). Multiple respondent motivations for making changes were positively correlated with making several envelope upgrades: improving comfort, improving appearance, easier maintenance, reducing environmental or health impacts, fixing something that was broken, and reducing energy bills ($r \geq 0.05$). The barrier of finding qualified contractors was positively correlated with installing triple pane windows and installing window coverings ($r = 0.05$), and the barrier of finding materials were positively correlated all of the building envelope upgrades except roofs and siding ($r \geq 0.05$). Unsurprisingly, being a renter was negatively correlated with making most envelope changes: double pane windows ($r = -0.08$), insulation ($r = -0.08$), new roof ($r = -0.12$), siding ($r = -0.09$). Living in a rural location was negatively correlated ($r = -0.07$) with air sealing and roofs.

Similarly, for heat pumps, making other home upgrades were the most consistently positive correlations (Figure 7). Making modifications to the home's electrical system, water heating system, and installing smart home technologies all had significant positive correlations with installing heat pumps ($r \geq 0.14$). Other variables with $r \geq 0.14$ were related to household economics: ability to afford a $9,000 or $20,000 home modification or repair, household income, and mortgage/rent. Three respondent motivations for making changes were positively correlated with installing a heat pump: improving comfort ($r = 0.12$), reducing health risks ($r = 0.10$), and reducing environmental impacts ($r=0.06$). The strongest negative correlations were being a renter ($r = -0.09$) and respondent age ($r = -0.06$). The barrier of finding materials was positively correlated with installing a heat pump ($r = 0.09$).

Discussion

Given that home upgrades are embedded within the decision-making processes of households (Biswas et al. 2024) and that home energy retrofit decisions are not purely rational economic decisions (Sunikka-Blank and Galvin 2016), we chose to explore a range of household cognitive contextual variables, along with more traditional sociodemographic and building characteristics in our preliminary investigation into how households make these home energy upgrade decisions. The UPGRADE-E dataset allowed us to link household concerns and influences, demographics, and building characteristics to actual upgrade decisions regarding building envelope upgrades and heat pump adoptions. Our study found frequencies of these upgrades to be rather low (<10 % of all respondents; Table 1, Table 2). What can we learn to produce actionable strategies for increasing envelope upgrades and adopting heat pumps?

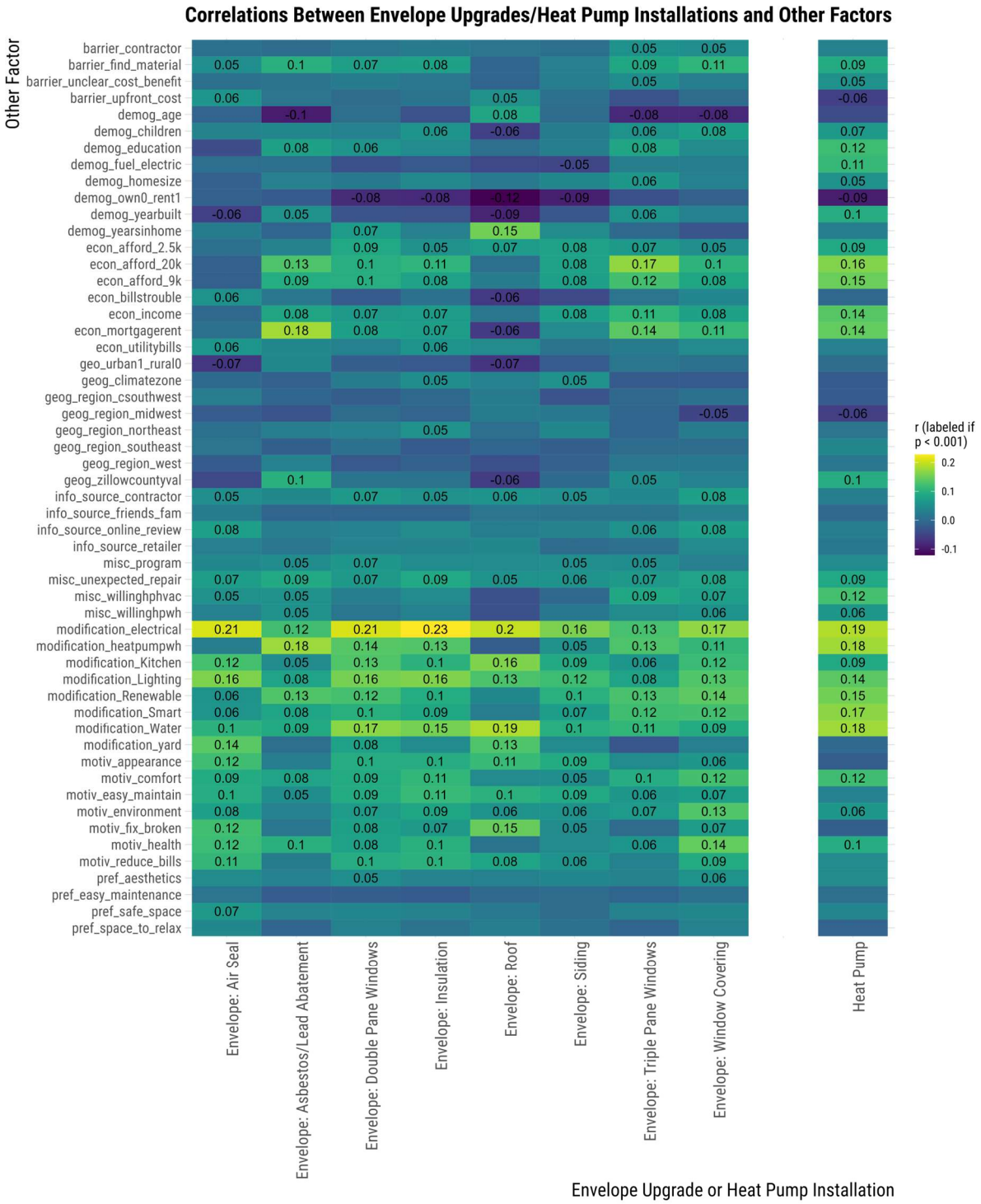

Figure 7. Correlations between envelope upgrade components or heat pump adoption and various contextual factors. Correlations significant at the $p < 0.001$ level have a text label for the correlation (r). Those that are not statistically significant ($p >= 0.001$) are blank.

Many respondents have made multiple types of building envelope upgrades (Figure 5). In fact, many of their envelope upgrades and heat pump installations are positively correlated with other changes to the home, including yards, kitchens, lighting, hot water heating, and renewable systems (Figure 7). This finding points to opportunities for these technologies to be paired with other remodel or upgrade work through contractor networks, especially for envelope upgrades which are positively correlated with contractor guidance.

Preferences around comfort, low maintenance and environmental benefits were noted for most envelope and heat pump categories. This shows that beyond cost, occupants value other important factors that inform their decision making when choosing envelope and HVAC technologies. These are all factors that should be considered by policymakers and industry when promoting these technologies, as they will influence the household decision-making process. This is supported by recent literature that shows that purely economic approaches exploring low adoption rates of energy-efficient technologies fail to account for behavioral explanations (Gerarden, Newell, and Stavins 2015) and the fact that homeowners often have multiple, simultaneous projects in different stages (Biswas et al. 2024). To improve adoption of home energy technologies, utilities, planners, and researchers need to consider the lived experiences and desires of the residents (Sunikka-Blank and Galvin 2016) who are making decisions to upgrade (or not) all living spaces, including interiors, exteriors, and yards. When evaluating the importance of barriers to making home upgrades, the two most frequent categories related to project costs and benefits (Figure 3). Clearly, relations between upgrades and economic variables (cost concerns, home and energy bills, income, ability to pay for planned upgrades and unexpected repairs) shows how rational economic thinking underpins many household decisions (Figure 6, Figure 7). However, we found a very large gap between actual adoption of heat pumps versus willingness to adopt heat pumps if they were affordable (Table 2). In fact, only 13.6% of respondents said they would be unwilling to adopt heat pumps. This willingness gap points to the need to improve and expand the role of energy programs at all governmental levels to make heat pumps more affordable, particularly for renters and for households unable to afford upgrades costing $9,000 or more. Additional transparency on costs and benefits may also help residents in deciding to upgrade and pursue financing through programs or loans.

Intriguingly, the second most frequently mentioned barrier group, finding contractors and materials (Figure 3), is not negatively correlated with making any upgrade (Figure 7). Instead, the contractor barrier is positively correlated with installing triple pane windows and window coverings. Similarly, the finding materials barrier is positively correlated with all but two envelope upgrades (roofs and siding) and with installing heat pumps. While we do not doubt that finding qualified contractors and appropriate materials are true barriers to making upgrades, these unexpected results may reflect residents who completed these upgrades remembering how challenging these projects were to start and finish.

We chose to explore four highly rated home preference variables in our correlation analysis: aesthetics, ease of maintenance, safe space, and space to relax. Aesthetics was positively correlated with window-related envelope upgrades, and safe space was positively correlated with air sealing. The link between aesthetics and window decisions suggests that residents have different decision drivers for these more visible, high interaction envelope upgrades. However, appearance as a motivator for making home upgrades (as compared to the aesthetic home preference ranking) was positively correlated with six building envelope

upgrades but not asbestos/lead abatement, triple pane window installation, or heat pump installations. Improving comfort was also positively correlated with several building envelope decisions, along with heat pumps. Appearance and comfort as household concerns for several building envelope decisions is consistent with what other researchers have found (Sunikka-Blank and Galvin 2016). Unsurprisingly, fixing something that was broken and reducing energy bills appeared to motivate some upgrades. Other motivations also deserve further exploration to understand household decisions, e.g., reducing environmental impacts and reducing health risks.

In considering household decision-making perspectives, it is also essential to consider the other players in the home energy modifications ecosystem, such as contractors. In a sister study to this homeowner survey, building professionals were asked to provide insights on promising technologies and approaches in the energy upgrade market. The "one-stop-shop" approach, simplifying decision-making for homeowners, was rated most promising. "Energy plus healthy home" retrofits, combining energy upgrades with indoor air quality solutions, were also popular. Heat pump technologies, smart ventilation, real-time energy IAQ monitoring, and smart building controls were viewed positively. Less promising were approaches focused on the building envelope, with electrification, especially integrated heat pumps, considered the most promising advancement. Respondents highlighted the need for education and market support to overcome barriers to technology adoption, suggesting innovations like high-performance heat pumps and ventilation systems to increase customer demand (Casquero-Modrego et al. 2022).

Future Work and Limitations

Future work will explore the viability of applying predictive modeling techniques, such as machine learning or predictive regression, to accurately estimate who might adopt heat pump technology or make an envelope upgrade. Additionally, the synergistic work regarding the impact of building envelope energy retrofits for decarbonization on non-energy impacts such as health and thermal comfort is currently being pursued.

Household relationships with contractors in making decisions deserves further exploration. Although only 19% of respondents selected contractors as a source of information when making home energy decisions (Figure 4), six of the eight building envelope upgrade decisions were positively correlated with the contractor as information source variable. However, triple pane window installation, asbestos/lead abatement, and heat pump installations were not. Moreover, although family and friends were rated as the most frequent information source (42% of respondents), this information source was not correlated with any building envelope upgrade or heat pump installation, suggesting that the information from friends and family is either not catalyzing action or is not encouraging heat pump adoption or envelope upgrades. Along with contractors as information source, getting online reviews was positively correlated with envelope upgrades: triple pane windows and window coverings. Our preliminary correlation analysis suggests that residents may seek out more specific information when they have already decided to upgrade and that they directly seek contractor expertise when they pursue the more challenging building envelope upgrades.

We recognize that the complexities of household decision-making involve a multitude of factors that cannot be covered by a single study. However, we posit that this robust dataset provides the most comprehensive approach to-date and provides many opportunities for future

exploration of nuances and alternate analyses and encourage readers to download and explore the dataset and how it might assist in addressing their research questions.

Conclusion

Residential building envelope upgrades and heat pump installation decisions rely on well-understood economic drivers and building variables, along with less-understood unique household sociodemographic factors and personal preferences. By comparing multiple drivers of envelope upgrades with heat pump installations within the same households, we found similarities and differences in motivations for the two upgrade types. Both envelope upgrades and heat pump installations tend to occur in combination with other projects, which highlights opportunities to integrate these technologies into workplans for larger remodels and upgrades. Electrical system upgrades decisions appear to be a key decision to understand, because it was one of the strongest correlations with envelope upgrades and heat pump installations. Addressing the willingness gap requires focusing on renters and households unable to afford expensive repairs ($9,000 or more). Understanding information to decision pathways is challenging; family and friends, the most frequently selected information source, was not correlated with any changes. Understanding why residents select specific technologies when they decide to make a change requires incorporating household concerns about their spaces, how they spend their time, and what they value. Comfort, easy maintenance, and reduced environmental and health impacts were also important decision-making factors for both envelope and heat pump installations, as were aesthetic factors for envelope upgrades. Including the unique household cognitive contexts may improve our understanding of home upgrade decisions, leading to improved programs and actionable strategies for increasing envelope upgrades and adopting heat pumps to meet climate goals. These contextual factors, when taken in combination, can help policymakers and industry with program development and messaging to help increase uptake of these technologies.

Key Takeaways

- Utilities, contractors, and retailers should consider household decision contexts beyond economics and building factors to reach new customers and improve uptake.
- Reaching undecided households requires different outreach strategies. Online reviews and contractors appear to be important information sources for households who have already decided to upgrade.
- Aesthetic considerations appear to be more a factor in visible building envelope decisions than in heat pump adoptions.
- Comfort, easy maintenance, reduced environmental and health impacts are important decision-making factors for most envelope upgrades and heat pump installations.

References

Antonopoulos, Chrissi A., Tracy L. Fuentes, Kieren H. McCord, Adrienne L. S. Rackley, and Saurabh Biswas. 2024. “Regional Assessment of Household Energy Decision-Making

and Technology Adoption in the United States." *Energy Policy* 185 (February): 113940. https://doi.org/10.1016/j.enpol.2023.113940.
Biswas, Saurabh, Tracy L. Fuentes, Kieren H. McCord, Adrienne L. S. Rackley, and Chrissi A. Antonopoulos. 2024. "Decisions and Decision-Makers: Mapping the Sociotechnical Cognition behind Home Energy Upgrades in the United States." *Energy Research & Social Science* 109 (March): 103411. https://doi.org/10.1016/j.erss.2024.103411.
Casquero-Modrego, N., W. R. Chan, B. D. Less, and I. S. Walker. 2022. "Getting to Scale for Decarbonizing Homes in the US: An Industry Survey." *IOP Conference Series: Earth and Environmental Science* 1085 (1): 012036. https://doi.org/10.1088/1755-1315/1085/1/012036.
Fuentes, Tracy L., Kieren H. McCord, Adrienne L. S. Rackley, Saurabh Biswas, Wilfried Kabre, and Chrissi A. Antonopoulos. (in progress). "UPGRADE-E: Understanding Patterns Guiding Residential Adoption and Decisions about Energy Efficiency."
Gerarden, Todd, Richard G. Newell, and Robert N. Stavins. 2015. "Deconstructing the Energy-Efficiency Gap: Conceptual Frameworks and Evidence." *American Economic Review* 105 (5): 183–86. https://doi.org/10.1257/aer.p20151012.
OECD. 2020. *Energy Technology Perspectives 2020 - Special Report on Clean Energy Innovation*. Paris: Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/energy/energy-technology-perspectives-2020_ab43a9a5-en.
R Core Team. 2022. "R: A Language and Environment for Statistical Computing." Vienna, Austria: R Foundation for Statistical Computing. http://www.R-project.org/.
Sunikka-Blank, Minna, and Ray Galvin. 2016. "Irrational Homeowners? How Aesthetics and Heritage Values Influence Thermal Retrofit Decisions in the United Kingdom." *Energy Research & Social Science* 11 (January): 97–108. https://doi.org/10.1016/j.erss.2015.09.004.
United Nations Environment Programme, and Global Alliance for Buildings and Construction. 2020. "2020 Global Status Report for Buildings and Construction: Towards a Zero-Emissions, Efficient and Resilient Buildings and Construction Sector - Executive Summary." https://wedocs.unep.org/xmlui/handle/20.500.11822/34572.
US EPA, OAR. 2021. "Sources of Greenhouse Gas Emissions." Overviews and Factsheets. 2021. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.
Walker, Iain S., Brennan D. Less, and Nuria Casquero-Modrego. 2022. "Pathways to Home Decarbonization." Lawrence Berkeley National Laboratory. https://eta-publications.lbl.gov/sites/default/files/pathways_to_home_decarbonization_9.13.2022.pdf.
Wilson, C., L. Crane, and G. Chryssochoidis. 2015. "Why Do Homeowners Renovate Energy Efficiently? Contrasting Perspectives and Implications for Policy." *Energy Research & Social Science* 7 (May): 12–22. https://doi.org/10.1016/j.erss.2015.03.002.
Yang, Xining, Mingming Hu, Chunbo Zhang, and Bernhard Steubing. 2022. "Key Strategies for Decarbonizing the Residential Building Stock: Results from a Spatiotemporal Model for Leiden, the Netherlands." *Resources, Conservation and Recycling* 184 (September): 106388. https://doi.org/10.1016/j.resconrec.2022.106388.
Zillow. 2024. "Housing Data." Zillow. 2024. https://www.zillow.com/research/data/.