Building Technology and Urban Systems Division

Behavior-Based Energy Efficiency: A Case Study of the Oakland EcoBlock
Final Project Report

Jared Langevin[1], Handi Chandra Putra[1], Jingjing Zhang[1], Therese Peffer[2]

[1] Building Technology and Urban Systems Division, Lawrence Berkeley National Laboratory, Berkeley, CA
[2] California Institute for Energy and Environment, University of California, Berkeley, Berkeley, CA

Summary

The Oakland EcoBlock is a whole-systems urban sustainability project that aims to prototype a pathway to affordable urban decarbonization by means of block-scale retrofitting that can reduce more than 50% of home energy usage. Considering the behavioral dimension of the energy retrofit process is key to understanding how household decision-making can enhance the adoption and performance of building efficiency measures – particularly in the EcoBlock, where low-to-moderate income constraints may limit accessibility to energy efficient upgrades. This study uses two survey instruments to explore key drivers of energy efficient technology adoption and operational behavior amongst EcoBlock residents.

The first instrument investigated the key factors and considerations that influence the choices that residents make between various home improvements that influence energy use. This instrument was deployed in the summer of 2021 and garnered responses from 16 EcoBlock households. Key findings include:

- Results suggest a clear gap between how residents perceive energy efficient home improvement options and the likelihood that they will install these improvements in their homes. While the general favorability of efficient home improvement options is high (76% favorable/very favorable on average across options), far fewer residents indicate that they are likely to purchase and/or install these improvements (47% likely/very likely on average across options).
- Residents cite cost and the lack of a need for replacement as the top factors preventing home improvements.
- Efficient lighting replacements are the measure that residents have the most direct experience with, view most favorably, and are most likely to install in the future. On the other hand, installing an induction range is the least favorably viewed upgrade we surveyed, together with smart thermostats.
- Residents have the least experience with heat pump installations and consider these as among the most expensive and high-effort improvements, alongside replacing windows and adding insulation; however, insulation measures are perceived to have particularly high impacts on utility bills and comfort improvements relative to other measures.

The second instrument focused on how EcoBlock residents use energy and adjust their behavior in response to different weather conditions. This survey was conducted across three seasons – fall of 2021, winter of 2022, and summer of 2022 – and garnered a total of 38 responses from EcoBlock residents. Key findings include:

- Results suggest that the COVID-19 pandemic impacted home occupancy patterns, with nearly 60% of residents at home for more than 10 hours between 8 a.m. and 8 p.m.
- Residents least frequently adjust thermostat settings, though nearly half express a willingness to adjust the thermostat in response to utility bill incentives for temporary energy use reductions.
- Eighty seven percent of residents pay utility bills, and bill savings are the second most common reason for taking adaptive actions after addressing discomfort.
- Satisfaction with lighting is much higher than for temperature–while 89% of residents are somewhat or very satisfied with lighting, just 39% indicate this for temperature. Perhaps relatedly, 69% of residents report recent upgrades to lighting–compared to 6% of heating equipment–in the last 5 years, and 63% of residents say their heating equipment has never been replaced or they don't know if it has been replaced.
- In terms of appliance and electronics use, computers are far more frequently used than other devices, and computer use is more evenly distributed across time periods. Residents are also least likely to adjust computer use in response to utility incentives compared to less frequently used appliances like clothes washers and dryers.

Survey results can inform how the EcoBlock research team engages with participating homeowners and renters about energy efficiency upgrades and how they are used. As an example, heat pumps are often included as a central component of home decarbonization plans; however, our results suggest residents need more information about their cost and benefits to facilitate adoption, and guidance on operation of the new equipment is essential to ensuring that it can address existing issues with temperature dissatisfaction. More broadly, the survey designs and lessons learned from the EcoBlock project may be leveraged to further explore residential end-use technology adoption and operation at the city, regional, and national scales.

1. Introduction

The Oakland EcoBlock (U.C. Berkeley, 2021; California Energy Commission, 2019) is a whole-systems urban sustainability project that aims to prototype a pathway to affordable urban decarbonization by means of block-scale retrofitting. The EcoBlock model is designed to be deployed in residential and mixed-use neighborhoods in a two-step process: (1) deep energy efficiency retrofits in buildings to reduce upward of 50% energy usage, and (2) solar-powered energy and steep water conservation and reuse systems that, together, significantly reduce household energy, transportation, and water footprint. Adding a behavioral dimension to the energy efficient retrofit stage is important for understanding how household decision-making can enhance building retrofit performance. Research questions concerning this behavioral dimension include:

- What technology attributes are most strongly associated with energy efficient and/or flexible equipment purchasing decisions in the EcoBlock resident sample?
- What are typical patterns of energy-related equipment operation in the EcoBlock resident sample, and which variables (e.g., demographic, environmental, other) are most strongly associated with these typical operational patterns?
- How might the EcoBlock resident sample respond to disruptions to typical operating patterns (e.g., during a demand response event or similar), and which variables are most strongly associated with these responses?

To investigate these questions, we developed and distributed two survey instruments that explore key drivers of energy efficient technology adoption and operational behavior amongst EcoBlock residents.

The remainder of this report details the process of developing and distributing these surveys (sections 2 and 3), highlights key findings (section 4), and discusses the implications of our findings for the deployment of energy efficient building retrofits and operational strategies in communities like the EcoBlock (section 5).

2. Literature review

To inform the development of survey instruments, we began by reviewing existing literature on household energy use upgrade decisions and patterns of energy-related operational behavior, seeking to identify variables that emerge consistently across studies. We placed a particular emphasis on studies with a focus on low-- to moderate--income households to match the general focus of the EcoBlock project. Our review found a diverse range of potential explanatory variables for energy upgrade and operational decisions, spanning technical, social, cultural, economic, and behavioral dimensions. Key findings informed the design of survey instruments that further explore potential drivers of energy efficient and flexible technology adoption and operational behavior in the EcoBlock resident sample; these instruments are described in section 3.

2.1. Decision-making on home energy upgrades

Low-income households spend a higher proportion of their income on energy bills compared to other groups --- perhaps nearly 20% (Drehobl & Ross, 2016) --- even though they consume less energy per capita (Brown et al., 2020). Home energy upgrades[1] can help low-income households mitigate their energy cost burden while improving the quality of their indoor living environment; yet, the uptake of HEU in this group is much lower than others (Park Associates, 2019). To improve the uptake of HEUs in such settings, many financial incentives and policy targets have been developed, including federal and state level low-income bill assistance and weatherization assistance programs (ACEEE, 2020). However, studies reviewed in this report point out that non-financial factors such as energy security, knowledge, perceptions, and cultural factors may also be influential on purchasing behaviors in these settings.

Figure 1 summarizes key steps in the diffusion of innovative technologies as originally proposed by Rogers (Rogers, 2003); this process can be taken as a reasonable outline for key elements of the HEU decision--making process. Depending on the prior conditions such as current practices and perceived needs, the decision process moves from having knowledge of available options to perceiving technology attributes, making choices, and finally adapting to the technology's implementation. In each of these steps, both exogenous and endogenous variables have varying degrees of influence; several such key variables are summarized for the context of homes in **Figure 2** and described further here.

Figure 1. Key steps in the diffusion of innovative technologies, as proposed by Rogers.

[1] In this report, home energy upgrades or HEUs refer to a set of measures that improve the energy performance of a residential building, including: seal air leaks, add insulation material to walls, attic/ceiling, and/or floors, install energy-efficient windows, install advance thermostats, install heat pumps for space cooling/heating, water heater, and clothes dryers, install induction cooking range, install energy-efficient lighting, and upgrade refrigerator and/or freezer, etc.

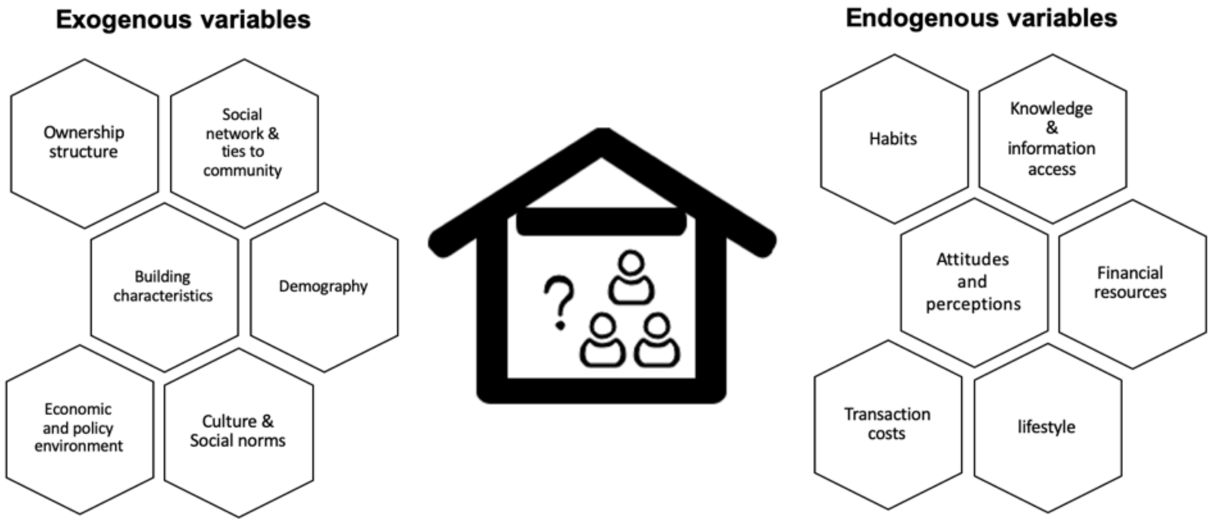


Figure 2. Key exogenous and endogenous decision variables relevant diffusion of home technologies.

Ownership structure affects the degree to which residents have power over and investment in HEU decisions. Langevin et al (2013) find that there are clear differences between the responses of those who pay the bills and those who do not. In the case of programmable thermostats, for example, those who do not pay bills tend to discuss HEU measures primarily in terms of comfort, while those who pay the bills evaluate programmable thermostats from more of a potential energy savings perspective.

The effects of one's **social network** on their propensity to adopt new technologies have been widely studied across different topics (Bale et al., 2013; Wilson & Dowlatabadi, 2007). Regarding channels of communication, Southwell (2012) finds that one third of a sample of people in the U.S. reported sharing information about energy use. Among these households, 85% shared information verbally and only 3% reported sharing through online social networking sites (Bale et al., 2013). Research also suggests that the strength of relations between individuals is more important to technology information diffusion than the number of connections individuals have (Du et al., 2016), and that community ties also impact how residents receive information and value energy services for community development.

Building characteristics such as building size, type, vintage, and number of occupants can influence HEU decisions. In general, residential buildings that are larger and/or older consume more energy than newer ones, especially for space heating, and therefore offer larger potential economic benefits to residents from HEUs; older homes offer additional comfort benefits from improving poorer indoor environmental conditions. Santin et al (2009) compare the effects of building characteristics and occupant behavior on space heating consumption in Dutch households, finding that occupant behavior affects energy use by 4.2%, while building characteristics determine 42% of a dwelling's energy use. Seryak and Kissock (2003) analyze the influence of occupant counts and behavioral effects on campus housing energy consumption, finding a clear correlation between occupant counts and electricity use while showing that gas consumption is more influenced by building characteristics than occupant count.

The **economic and policy environment** can also have significant impacts on HEU decisions. Low-income households are more vulnerable to economic downturns, during which energy burden and energy security issues can be exacerbated. As mentioned, several policy programs have been developed to address energy equity issues. Research suggests that these programs can be improved by better interagency coordination, expansion to include overlooked low-income household markets, and including assistance for more technological options to realize untapped energy and non-energy benefits (Brown et al., 2020).

Culture can be loosely defined as the set of values, habits, and beliefs shared by members of a society, while **social norms** refer to the ways people express the values of their culture when interacting with one another and can be different from one country to another (Mazur-Stommen, 2015). Past studies showed that social norms can be applied to promote energy conservation in both public and residential settings (Bergquist & Nilsson, 2018). Many energy efficiency programs have been successfully deployed based on normative feedback insights (Ireland, 2019). Culture and social norms are particularly important factors to consider in studying HEU decisions in low-income households, which tend to be more ethnically diverse than those of other income groups.

Demographic variables such as gender, age, education, and income level have all been found to play important roles in shaping technology adoption decisions (Cannizzaro et al., 2020). A previous study (Kim et al., 2020) that looked at different age groups found that these groups have varying daily routines, needs, and lifestyles and suggests that different age groups and household structures prioritize HEU measures differently and their preference over technology attributes also vary, such as preferences on connectivity, convenience, and non-energy benefits. Regarding income-associated impacts, studies demonstrate that different types of technologies are adopted at different levels of income (Leicester & Stoye, 2017; Mills & Schleich, 2014). Low-income households are in general less likely to purchase energy efficient technologies due to concerns for high-upfront capital costs, credit constraints, and other socio-economic, cultural, and behavioral factors (Schleich, 2019).

Attitudes and perceptions are important endogenous variables for HEU decisions. Key perceptions in the context of HEU could be of costs, degree of risk, compatibility, ease of use, and usefulness associated with HEU options. One's perceptions of these variables may be biased by differences in one's prior knowledge, degree of access to and ability to process relevant information. In the context of low--income housing, perceptions of a technology's non--energy benefits may be particularly important -- for example, residents may purchase energy-efficient appliances simply because they are perceived as newer and more functional than existing equipment. Regarding attitudes, Schleich (2019) suggests that most empirical analyses of energy efficiency technology adoption find pro-environmental attitudes to be positively related with adoption outcomes (Mills & Schleich, 2014) but less relevant for predicting high-cost investments such as envelope retrofits. Asensio et al (Asensio & Delmas, 2015) find that health and environment messages, which communicate the public health externalities of electricity production such as childhood asthma and cancer, outperform monetary savings information as a driver of behavioral change in the home. Furthermore, Galassi and Madlener (Galassi & Madlener, 2017) point out that concern for air quality is more important than thermal comfort for adopting deep retrofit measures. These findings suggest that non-energy benefits are critical for the successful adoption of HEU measures. Regarding other attitudes and perceptions, Cannizzaro (Cannizzaro et al., 2020) shows that anxiety about the likelihood of a security incident is a prominent factor influencing adoption of smart home technology; Hubert (Hubert et al., 2019) identifies risk perception as a major barriers for technology adoption, and; Shin (Shin et al., 2018) shows that compatibility, perceived ease of use, and perceived usefulness have significant positive effects on purchasing intentions.

Knowledge and information access are widely acknowledged as important inputs for the adoption of technology innovations and are closely related to other variables such as demography and social network. These variables play a mediating role in the decision making process and to some extent can determine attitudes about and perceptions of HEU options. Many studies highlight lack of owner and tenant knowledge about how, when, and why a building should be sustainably retrofitted as a key barrier to retrofit adoption (Benzar et al., 2020).

As mentioned, low-income households have a higher energy cost burden than other income groups and typically cannot afford the higher capital costs of HEUs. In addition to the **financial constraints** on upfront investments, **transaction costs** for these investments can be high as well. Transaction costs occur when individuals search for and process information (Wilson & Dowlatabadi, 2007) and in the specific case of low--income housing may include applying for government or utility backed assistance programs and demonstrating satisfaction of eligibility criteria for such programs. Transaction costs may be even higher if the process requires coordination between landlords and tenants (Hernández & Phillips, 2015).

Finally, HEU purchasing decisions may be influenced by patterns of operational behavior as covered in the next section. Indeed, household **habits** (Huebner et al., 2013) such as adjusting clothing adjustments, adjusting blinds and curtains, turning off lights when rooms are not in use, or using the microwave instead of the stove can establish important reference points for technology purchasing decisions. For example, one may not value a purchase of new HVAC equipment as highly if they are often able to maintain comfort via opening windows and adjusting clothing.

2.2. Household operational behaviors

The Residential Energy Consumption Survey (RECS) conducted by the Energy Information Administration establishes a high--level historical context around U.S. residential energy use patterns, showing that the 2015 total energy consumption per year in the residential sector was the lowest since 1987 at 9.114 quadrillion Btu per year **Figure 3**. Reductions are mainly attributable to migration to less energy-intensive regions in the West and South and improved appliance efficiencies (EIA, 2018}. Indeed, while energy use has decreased, comparison of the 2015 RECS to earlier versions shows an increase in equipment for air-conditioning, and water heating, as well as more households with second refrigerators.

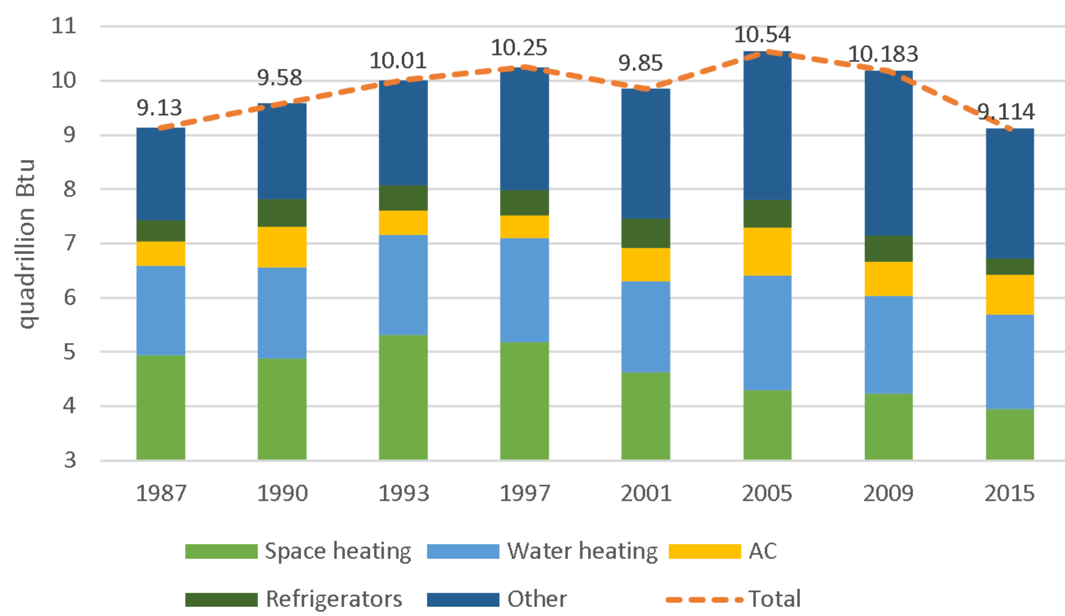


Figure 3. Total energy consumption by end use from EIA RECS 2015 data.

The national surveys only implicitly address resident's operational behaviors and their influence on overall consumption patterns. Compared with occupants of occupants and other commercial settings, residential occupants tend to have more degree of influence over operational schedules and settings, and prefer to have control over air quality, acoustical condition, visual and lighting conditions, aesthetic, and thermal comfort (Bluyssen, 2009). Residential energy-related operational behaviors may include opening and closing windows or doors, adjusting lighting and solar shading, turning HVAC systems on or off by adjusting thermostat temperature set points, and using hot water and electrical appliances. Several types of factors that may influence these behaviors are summarized here (Delzendeh et al., 2017).

The first set of factors relates to residential occupants' **socio-economic and demographic characteristics**. Here, household income is one of the most important factors influencing energy use and conservation (Chen et al., 2013; Steemers & Yun, 2009; van Raaij & Verhallen, 1983). Chen et al (2013) note that occupants' economic status determines the quality and size of their housing, which has a high degree of influence on energy consumption patterns. As mentioned, low-income households tend to spend a larger proportion of their income on home heating, cooling, and electricity than affluent households (Cooper et al., 1983); these households consume more electricity for cooling than other households due to poor insulation of their dwellings (Romero et al., 2013) and are financially constrained in their inability to purchase energy-efficient devices. Dillahunt et al (2009) conduct a comparative study on the motivations of different types of households in energy use and conservation. Money, habits, ethics, and future generations are important factors in both affluent and low-income households, while inefficient appliances are more prominent among low-income households. Wang et al (J. Wang et al., 2019) find that women in a household use air conditioning more, and therefore exert more influence on cooling electricity demand; however, thermal preferences have a more noticeable influence on cooling electricity demand for men than for women. In a study of low--income public housing residents in Philadelphia, Langevin et al (Langevin et al., 2013) find that most occupants experience a lack of control over the household environment, which constrains their ability to change operational schedules and settings.

Household characteristics and social relations factors -- such as household size and composition, socio-cultural belonging, and awareness on energy issues -- can also influence how occupants' operate home appliances and energy-consuming technologies (Martinaitis et al., 2015). Children in households often have limited controls to the indoor environment for safety reasons (Andrews, 2017). Households in the same neighborhood may also interact with each other in a manner that could inform each other’s energy use behaviors, stemming from education and communication on energy use and conservation (Hori et al., 2013; Z. Wang et al., 2011). Multiple studies examine the effects of social interactions across households on energy use behavior (Ek & Söderholm Patrik, 2010; Owen & Videras, 2006). For example, Hori et al (2013) use a survey instrument to ask questions relevant to the “social interaction category,” including communication with neighbors and local governments and consciousness of community participation.

The next type of factor that is common in existing literature is occupants' **presence and activity schedules**. This category relates to lifestyle and typical daily usage patterns for appliances (Al-Mumin et al., 2003; de Meester et al., 2013). Large appliances account for approximately 30\% of all electricity used in the residential building sector in the U.S. (EIA, 2020). Four large appliances including refrigerators, clothes washers, clothes dryers, and dishwashers, are among the most common large appliances found in U.S. homes (Cetin et al., 2014; Hewitt et al., 2016). This, together with small appliances, home electronics, and lighting, accounts for more than two thirds of total residential electricity use. Occupants use of home appliances such as cookstoves, dishwashers, clothes washers and dryers depends strongly on the time of day or week (Kazmi et al., 2016). Appliance use patterns have not changed much in the past few decades except for dishwashing, which exhibits an increasing morning peak (Pratt et al., 1993). Patterns in the use of manually--controlled appliances vary more between homes and between days than for automated appliances. A more consistent use-pattern in appliances is found on weekdays, when most residents are at work. Households where residents work at home use 2-28% more of their daily appliance energy use during regular work hours between 9 AM and 5 PM than households with residents who work outside of the home (Pratt et al., 1993). Among large appliances usage, clothes dryers utilize the greatest percent of daily load (36%) during peak use times, while the second highest consuming appliance, the dishwasher, is typically under operation around mealtimes. Dong et al (2015) find that household use of major appliances and thermostat schedule adjustments are strongly correlated with patterns of occupant presence, with the most frequent adjustments between 6--10 PM.

Physical building characteristics have been highlighted in multiple studies as a key exogenous factor influencing occupant tendencies to adjust the indoor environment (Augustin et al., 2009; Caan, 2011; Lee et al., 2013). Lee et al (2013) suggest the influence of interior design can affect occupant's operating behavior in opening windows and doors to adjust visual comfort. The study also finds that interior circulation, colors, and materials may also change occupants' perception towards room temperature and accordant thermostat adjustment behaviors. Interior arrangement of and access to particular controls such as thermostats, windows, blinds, and overhead lighting can affect the degree to which these controls are used by occupants (Lee et al., 2013). Rinaldi et.al. (Rinaldi et al., 2018) finds that heating set points and total hours of heating system utilization tend to increase with a building's age.

Environmental conditions are another important external factor, particularly those time-dependent conditions that affect thermal comfort such as outdoor temperature, relative humidity, and solar radiation (Indraganti, 2011; H. Rijal, 2014; H. Rijal et al., 2015; H. B. Rijal et al., 2013). Such conditions are associated with occupants' tendencies to open windows (H. Rijal, 2014), use fans (Park & Kim, 2012; H. Rijal, 2014), and turn on/off AC (Romero et al., 2013). Researchers often employ surveys and interviews, (Aldossary et al., 2014; Chen et al., 2013) field measurements (X. Wang et al., 2015), and smart meter data analytics (Kavousian et al., 2013) to capture the relationship between changes in environmental conditions and in environmentally adaptive occupant behavior.

Few of the reviewed studies examine energy—related operational behavior in residences under atypical conditions, such as extreme weather events or demand response events in which electric utilities offer payments for adjustments to normal operating patterns to improve the flexibility of energy demand. Regarding extreme weather, an investigation of summertime conditions in public housing by Tsoulou et al (2020) finds evidence of increased adaptive behavior under challenging heatwave conditions --- particularly in residences without air conditioning --- including lowering the thermostat setpoint, open the windows, turning on fans, or wearing fewer clothing layers. Regarding demand flexibility, (Mancini et al., 2019) conduct surveys on Italian residential occupants over their operations during DR, finding low potential for flexibility in each residential unit due to low electrification; the study also suggests that end-user economic benefits for flexibility are small and that dwelling maintenance can significantly reduce a household's flexible potential by lowering the need for energy consumption.

2.3. Summary of key variables from literature review

Successful deployment of energy efficiency retrofits in households requires a deep understanding of residents' decision making process, both in terms of why they would adopt high efficiency technologies and how they operate the building once such measures are implemented. Drawing from existing literature, we synthesize a range of key variables that may help explain technology choice and operational behavior in households.

For technology choice, we identify macro-level variables that range from economic and policy environment to demography, and culture and social norms --- in total, six exogenous and six endogenous variables per Figure 2. Among these variables, favorable economic and policy environment, social network, knowledge and information access, attitude and perception such as pro-environment, perceived usefulness, perceived ease of use, and compatibility, and financial resources (i.e., higher income) have positive influence on adoption of home energy upgrades. Other variables, including culture, habits and lifestyle, are less predictable but can be inferred from demographic data. The non-energy benefits of energy efficiency upgrades are an important variable highlighted in several studies, which suggest that energy-related technology purchasing decisions are not driven by energy and cost considerations alone; these benefits should be explored further for low-income households, where improved quality of service from new energy-consuming equipment may be a particularly attractive benefit.

For operational behavior, we similarly find a wide range of potentially influential endogenous and exogenous factors in the literature, including socio-economic and demographic characteristics, household characteristics and relation to other households, occupant activity schedules, and physical or environmental conditions. Notably, many of these factors overlap with those that are found to influence technology purchasing decisions, and indeed these purchasing decisions themselves may influence operational behavior by constraining the options a resident has for managing their home's energy use. In low--income settings with limited space conditioning equipment, passive adaptations such as clothing adjustment or opening the windows may be significant and should be recorded alongside any adjustments to energy-consuming equipment settings. Moreover, certain behaviors, such as appliance use, appear more determined by regular activity schedules (e.g., every morning, every evening, etc.) that are in turn tied to a resident's occupancy schedule. Finally, most literature concerning operational behavior in the residential sector focuses on behavior under typical operating conditions -- investigation of changes to behavior under atypical conditions (e.g., extreme weather, demand response events) is an important area for further research.

3. Survey design, review, and implementation

3.1. Technology choice survey design

The technology choice survey is designed to understand household energy upgrade decisions. The survey covers the possible motivations for and barriers to these decisions, channels for information about upgrades, and resident perceptions of key upgrade attributes. The five main sections of the survey are summarized as follows (see Appendix A.1 for full survey instrument):

- **General information:** questions about household ownership, gender, education, income, household size, etc.
- **Participant and building information:** questions about building types, vintage, sizes, energy bills, who pays the bill, energy sources, etc.

- **General purchasing information, motivations and barriers:** questions regarding who makes purchasing decisions for home improvements; key motivations, barriers, and budget available for home energy upgrade decisions.
- **Knowledge and information channels:** questions regarding participant familiarity with home energy upgrade measures and how they have learned about the measures, including from public and utility programs and social networks.
- **Perceptions of energy efficient improvements:** questions about how participants view different home energy upgrade measures; how likely they are to purchase/install the measures; how expensive they believe measures are; the extent of perceived measure impacts; and other perceived measure attributes such as burden of installation and operation, visibility to others, etc.

3.2. Operational behavior survey design

The operational behavior survey is designed to understand household energy use patterns. The survey asks questions how and when energy-related equipment and appliances are used and upgraded/maintained, typical occupancy patterns, environmental satisfaction, and adaptive actions that relate to energy use. Where applicable, survey questions that are seasonally-specific are tailored to the season in which the survey is deployed (e.g., we ask about cooling set point adjustments in warmer conditions vs. heating set point adjustment in cooler conditions). The five main sections of the survey are summarized as follows (see Appendix A.2 for full survey instrument):

- **Participant and building information:** questions about household ownership, gender, health, HVAC type, windows and shading type, etc.
- **Upgrades and maintenance:** questions concerning the history of equipment replacements and degree of functionality.
- **Occupancy:** questions about occupants' typical daily schedules on weekdays and weekends.
- **Satisfaction levels:** questions about occupants' degree of satisfaction with indoor environmental conditions (temperature, humidity, lighting, noise, etc.)
- **Energy-related actions:** questions about occupants' operational behaviors to adjust thermostat; lights; fans; window A/C; windows; blinds; air purifier; dehumidifier; communication with landlord, etc.

3.3. Survey review and implementation

In early March 2021, initial drafts of the two survey instruments were distributed to five subject matter experts for review and feedback. The reviewers were also provided with a general description of the project, key research questions, and plans for deploying the surveys, and were instructed to assess the survey instruments with that broader project context in mind. Feedback from the reviewers provided a basis for further revising the surveys before their final implementation. Further information about the reviewers and specific points of feedback are provided in Appendix A.3.

Before implementing the surveys, an application was submitted to the Lawrence Berkeley National Laboratory and University of California Berkeley Institutional Review Boards (IRBs); IRB approval was received in July 2021 (Protocol ID: 2019-10-12680).

The initial IRB-approved versions of our surveys included a prompt for participants at the beginning of the survey to print, sign and return a consent form before proceeding further. Due to restricted access to printers and digital signature options, however, the collection of consent forms proved to be challenging. To address the issue, we applied for and received a consent form waiver from the IRB in October 2021, which removed the need to collect consent forms for all survey distributions after that point. We also separately submitted a Protocol Deviation Report in September 2022 to ensure that we could use the data collected from two subjects who had not yet returned consent forms for the technology choice survey distribution, which occurred before the October 2021 waiver had been granted, as described further below.

Surveys were coded in Qualtrics, a leading online survey tool that supports the matrix tables and conditional logic display capabilities that are required by our survey design. Once implemented in Qualtrics, the survey design can be distributed to respondents via an e-mail link, and responses are recorded in a CSV format that facilitates further data processing and analysis.

EcoBlock survey participants were accessed via an existing EcoBlock e-mail distribution list that is managed by UC Berkeley. To encourage interest in survey participation, a $25 VISA gift card was offered for survey completion. In Qualtrics, prompts for personal information needed to distribute the gift cards digitally were separated from the main survey instruments to ensure that the collected survey data from the main instruments limited personally identifiable information. We also included notifications about the surveys in monthly newsletters that the UC Berkeley EcoBlock team distributed to residents. To ensure that results concerning home energy upgrade decisions reflected a household unit of focus and would not be biased towards households with multiple residents who each responded to the survey, the choice survey was limited to one response per household. Both surveys were restricted to residents who are over 18 years old. The technology choice was distributed to residents or homeowners with an address on the EcoBlock – 33 potential household responses, in total. The operational survey was distributed only to residents who are living on the EcoBlock – 75 potential respondents in total before accounting for the age restriction.

Surveys were distributed in multiple phases spaced months apart to avoid potential issues with survey fatigue. In the context of the rest of the EcoBlock project, the survey distributions all occurred before retrofits were installed in residents' homes but after the EcoBlock team had begun regular outreach to residents about the project/project goals and potential energy efficient retrofit options. The technology choice survey was implemented first, in the summer of 2021. The survey was initially distributed on July 27th with a reminder e-mail on August 17th and the close of the survey in late September. The operational behavior surveys were distributed subsequently across three seasons to capture a range of outdoor environmental conditions and their possible influence on behaviors: fall of 2021, winter of 2022, and summer of 2022. Initial survey distributions were on November 2nd, January 18th, and June 28th, respectively; reminder e-mails were on November 24th, February 22nd, and August 2nd, respectively; and these surveys closed in early December, late February, and early August, respectively.

4. Survey Results

4.1. Technology choice survey

A total of 16 of the possible 33 households responded to the choice survey distribution. Figure 4 shows that a plurality of respondents are property owners that live on the property (47%), an additional 40% are renters, and another 13% own property on the block but don't live there. Most of the respondents are male (53%) and a plurality are White (40%), with another 40% of respondents reporting race as Asian or multi-racial. Respondents tend to be in their 30s, but their age range extends to 70 years old.

Most respondents have at least a Bachelor's degree (53%) and a wide range of respondent income levels is observed, ranging from less than $25K to up to $200K.

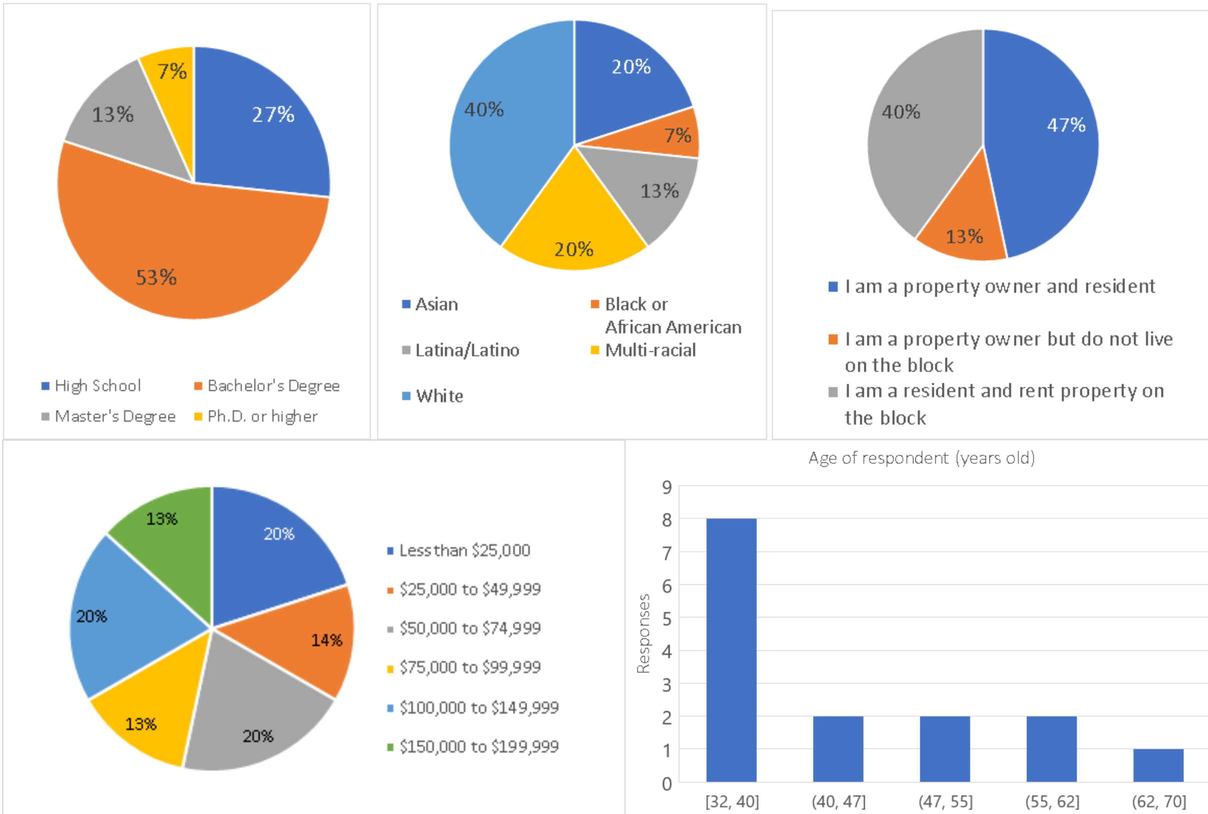


Figure 4. Demographic profiles, income levels, and homeownership/renter profiles.

Regarding building characteristics (see Figure 5), most respondents (60%) live in or own property in 2-4 unit apartment buildings on the block, and the remaining 40% live in single family detached homes. Those who live on the block have done so for an average of more than 5 years, while those who own property on the block have owned it for an average of more than 9 years. All respondents report that their building was constructed before 1980, and most homes have 4-8 rooms with floor areas between 750-1500 square feet. Respondents largely use natural gas for heating (60%), water heating (87%), and cooking (53%).

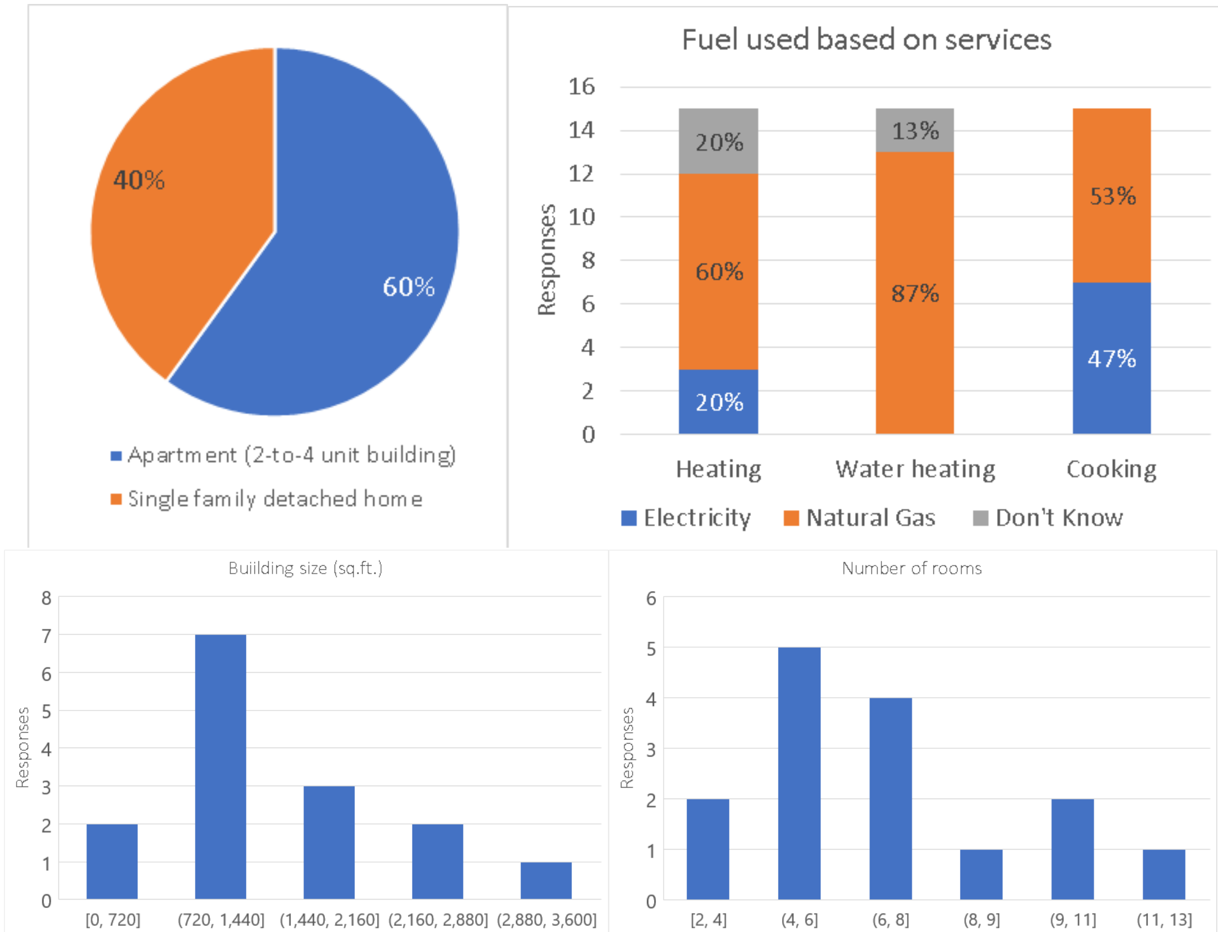


Figure 5. Choice survey respondent building characteristics.

Figure 6 shows that a strong majority of respondents (87%) pays for at least water, gas, and electricity services, and average energy bill costs are $129 and $171 per month in the summer and winter, respectively. Among 6 renters in our sample, only 1 household does not pay for energy services. Residents appear heavily constrained in their home improvement budgets: 80% of respondents report budgeting less than $5K for home improvements, and a majority of respondents (54%) report budgeting less than $100. Moreover, just 13% of respondents report that they alone control home improvement decisions; a plurality of respondents indicate that their landlord makes the decision (40%), while another 33% indicate that they make such decisions in conjunction with others in their household.

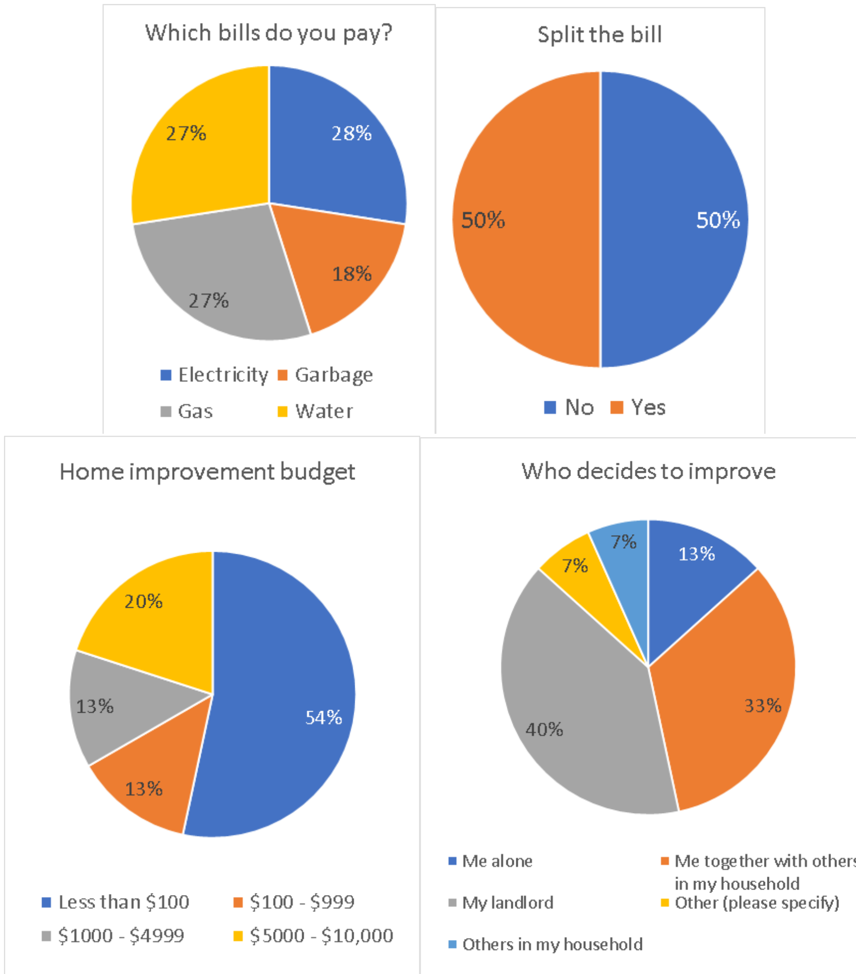


Figure 6. Energy bills, home improvement budgets, and decision-makers for home improvements.

Survey results suggest a clear gap between residents' attitudes about home energy upgrade options and their propensity to adopt these options (see Figure 7). Specifically, while the general favorability of efficient home improvement options is high (76% favorable/very favorable on average across options), far fewer residents indicate that they are likely to purchase and/or install these improvements (47% likely/very likely on average across options). Lighting is by far the most favorable upgrade (93% favorable/very favorable) and the one residents are most likely to install (80% likely/very likely). Installation of induction cooking is the least favorable upgrade (20% very unfavorable/unfavorable), and some unfavourability is also seen for smart thermostats (13% unfavorable). Induction cooking and smart thermostats are also among the three options that residents are least likely to install, together with heat pump clothes dryers (27% likely/very likely).

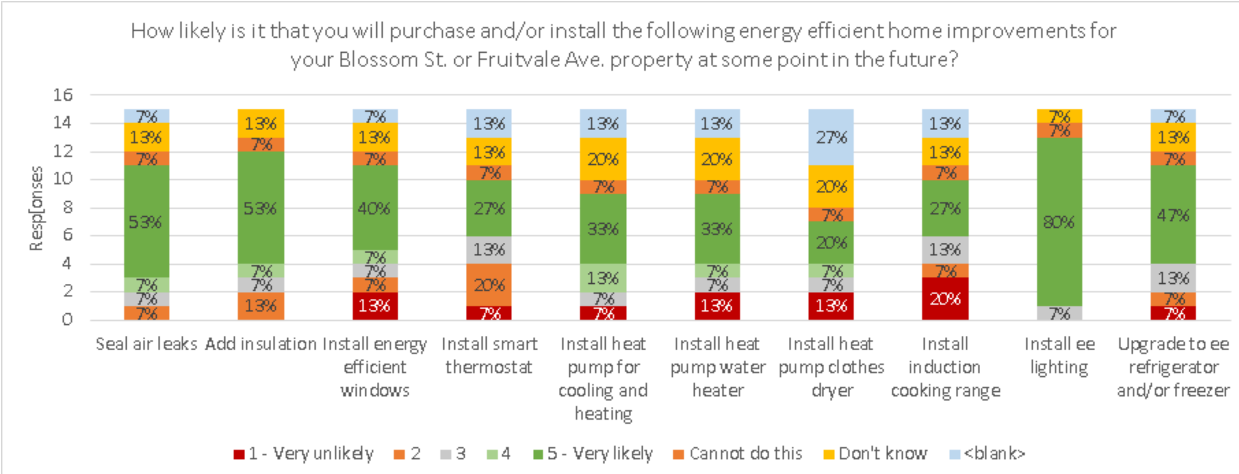
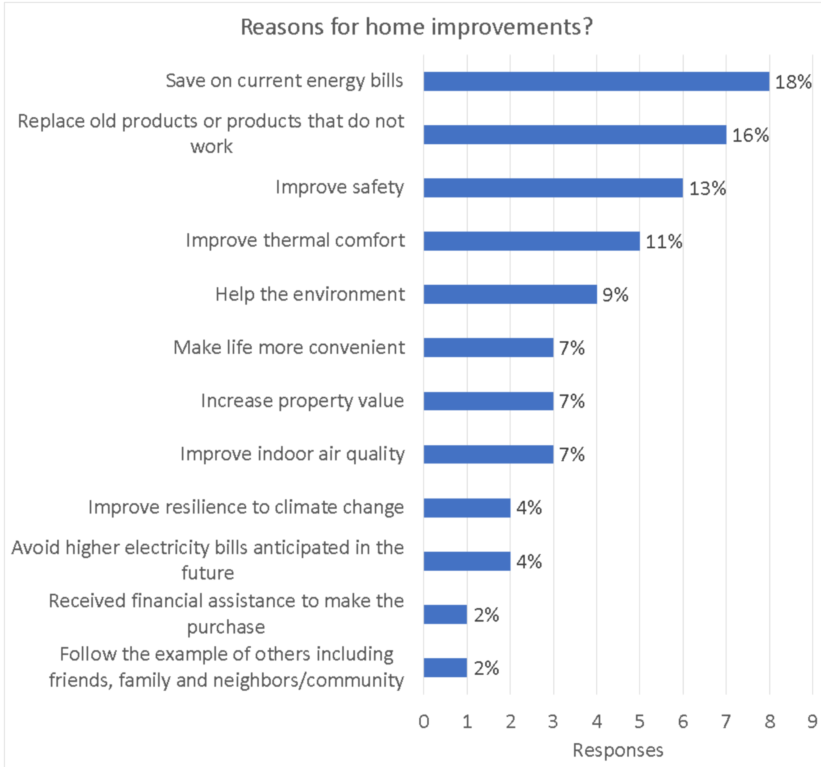


Figure 7. General favorability regarding and likelihood to adopt home energy upgrades.

When specifically asked about factors that influence decisions to make home energy upgrades (see Figure 8), residents cite saving on energy bills (18%), need to replace broken appliances (16%), improving safety (13%), and improving thermal comfort levels (11%) as the top reasons. On the other hand, the top 4 factors that reportedly prevent home improvements are cost (27%), feeling no need for replacement (22%), too time-consuming (13%), and having other people outside the household (e.g., landlord) prevent them from making a replacement (11%).



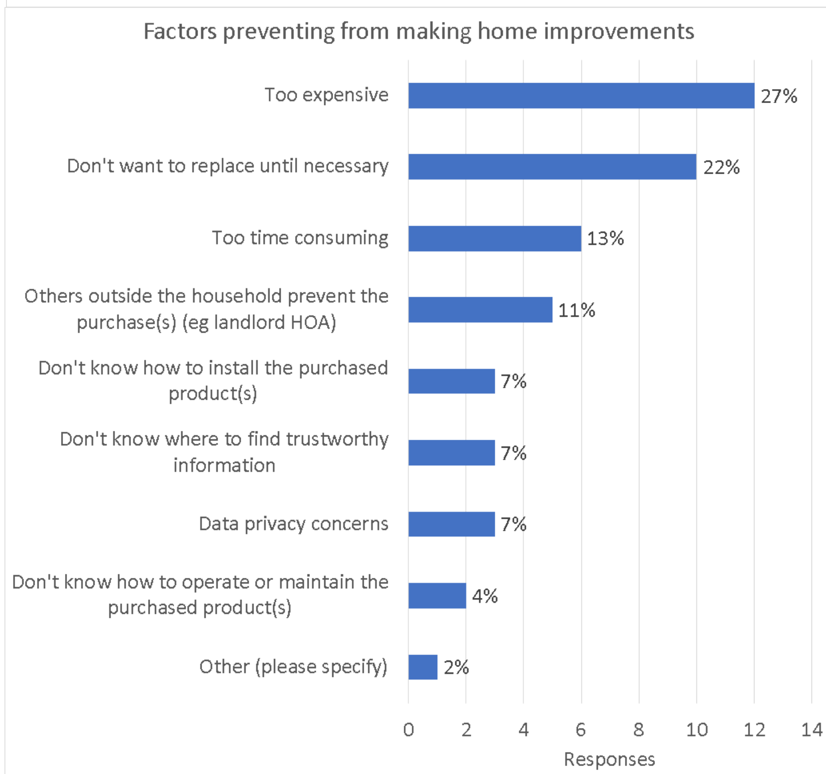


Figure 8. Factors influencing home improvement decision-making.

Gaps in experience with home energy upgrades that are key components of building decarbonization plans are evident in the survey data (see Figure 9). In particular, none of the residents have direct experience with heat pump heating/cooling or water heating installations, and just 7% report knowing others who have experience with these upgrades. While a strong majority (80%) have at least heard about these upgrade options, substantial portions (33-40%) don't know how they first heard about them. Heat pump clothes dryers emerge as the least familiar option, with the largest percentage of residents (27%) having never heard of this upgrade. Of the upgrades that residents are most familiar with – adding insulating, installing efficient windows, installing lighting, and upgrading to a new refrigerator (60-80% have done the upgrade or know others who have) – the single most prominent source of information is consistently a friend, family, or neighbor (20-33% across those upgrades). Results suggest that only lighting upgrades have achieved substantial penetration, with 33% of respondents reporting that many or most of their close acquaintances having reportedly done this upgrade (no other upgrade exceeds 13%).

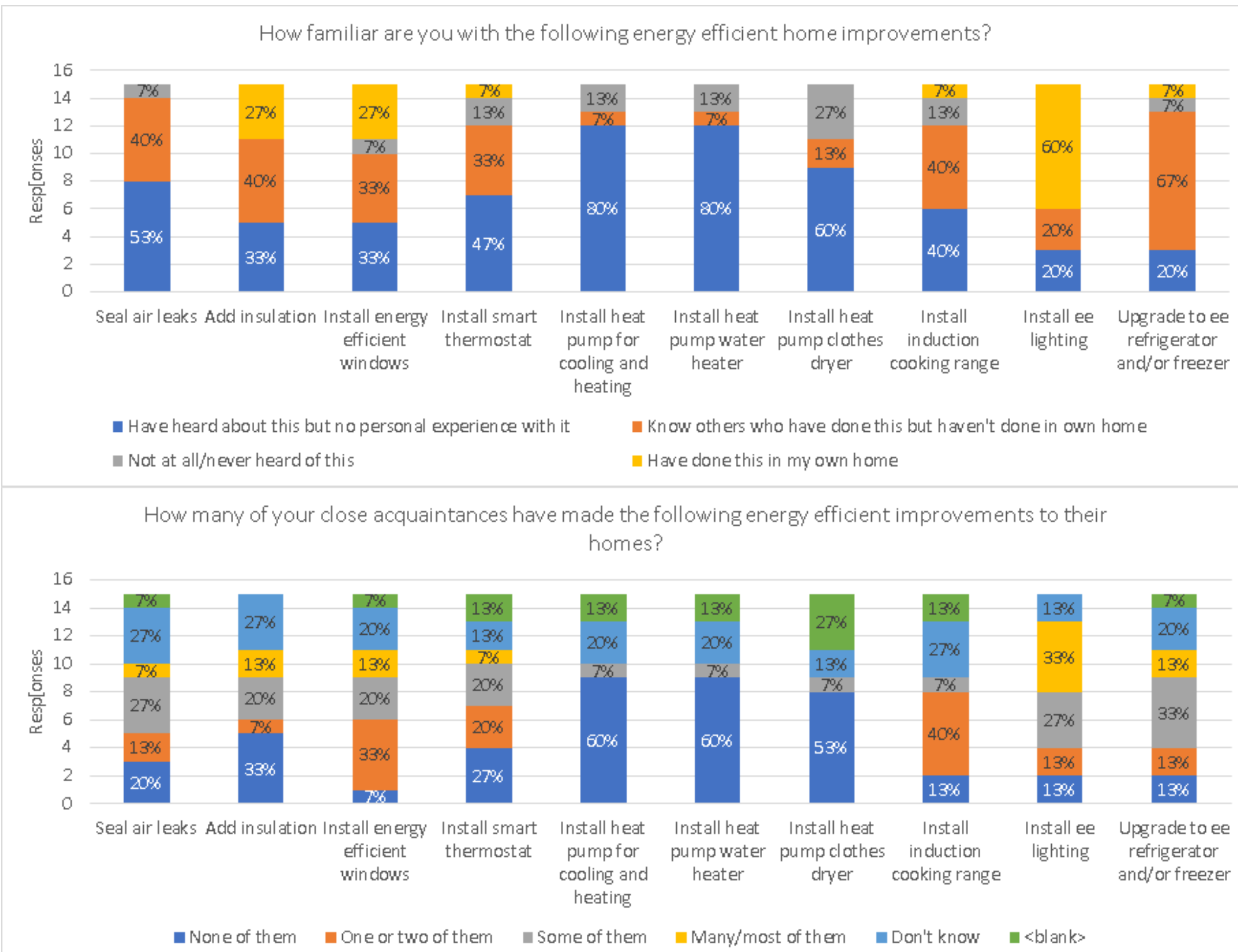


Figure 9. Familiarity with home energy upgrades.

Given the importance of upgrade cost and bill savings as factors that constrain and motivate home improvements, resident perceptions of these upgrade attributes are of particular interest (see Figure 10). Regarding cost, residents view efficient lighting as the least expensive upgrade (53% inexpensive/very inexpensive) but also view it as one of the least impactful upgrades for bill savings (46% very small/small impact) together with induction cooking (47%). On the other end of the perceived cost spectrum, adding insulation and installing efficient windows are viewed as two of the most expensive upgrades (53% and 67% expensive/very expensive, respectively) with the largest impacts on energy bills (74% and 47% large/very large, respectively). While installing heat pumps for heating/cooling and water heating are also perceived as among the most costly upgrades (60% and 53% expensive/very expensive, respectively), a wide range of perceptions is evident on the potential bill savings from these upgrades and from smart thermostats, including substantial portions of residents who believe the savings levels are very small to neutral. Sealing air leaks and upgrading refrigerators appear most favorable in terms of perceived cost and bill savings, as both have relatively low perceived costs (20% expensive/very expensive, respectively) with relatively high perceived bill savings (40% and 46% large/very large, respectively). These two measures and smart thermostats show relatively higher uncertainties regarding costs, however, with one third of residents reporting that they don't know their cost.

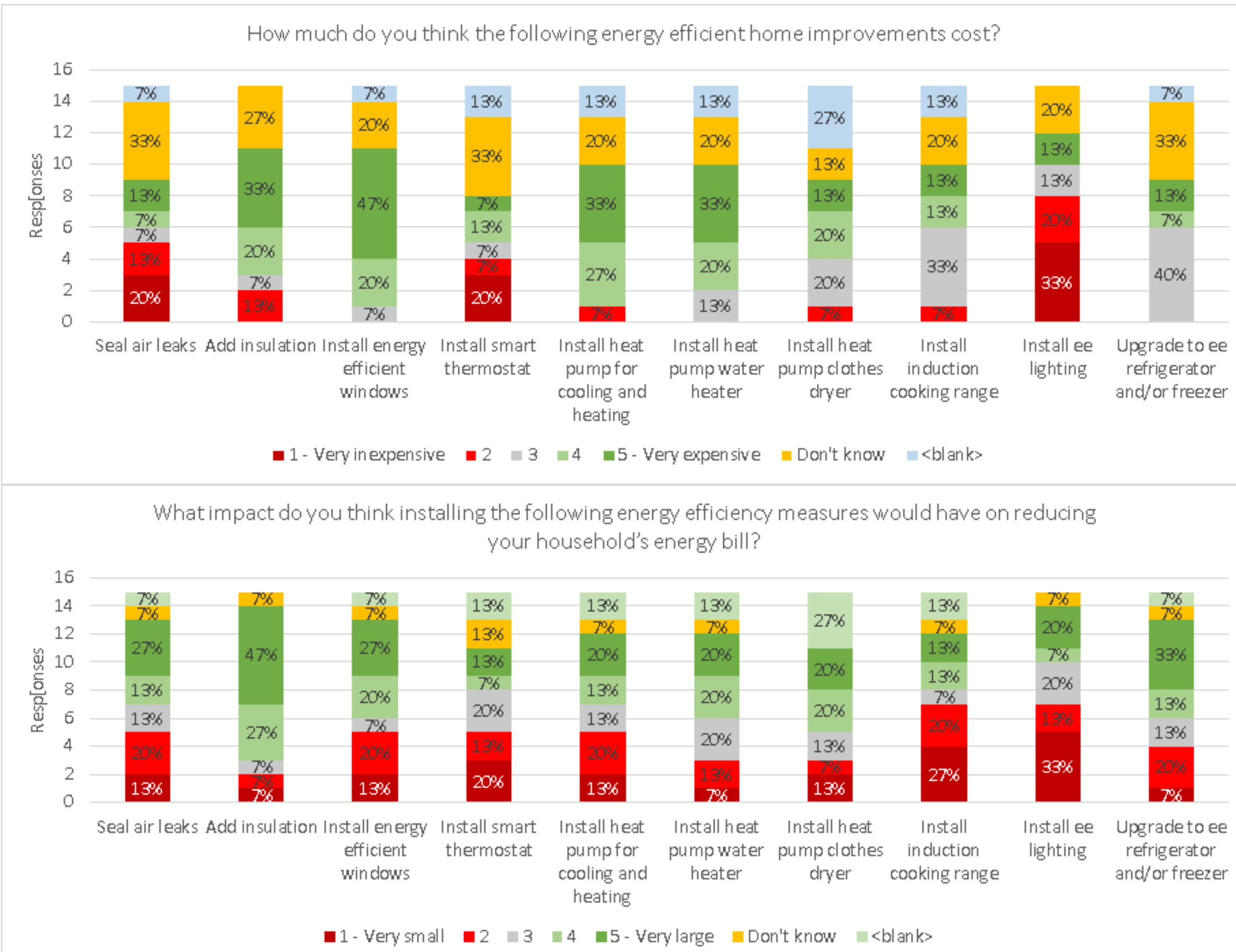


Figure 10. Perceived cost and bill savings of home energy upgrades.

Notably, respondents are generally unaware of financial incentives that could reduce the cost of making efficient upgrades – at best, 27% are aware of incentives for installing efficient lighting and refrigerators, and 20% are aware of incentives for efficient windows. Just 7% of respondents are aware of incentives for installing a heat pump for heating/cooling, and no respondents are aware of incentives for installing a heat pump water heater, heat pump clothes dryer, or induction cooking range. See Figure 11 for more detail.

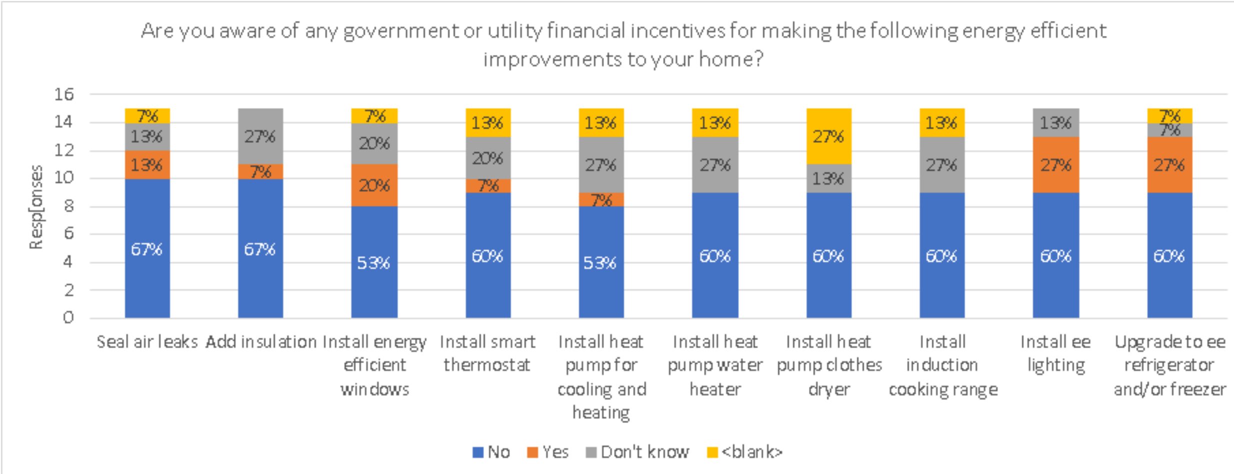


Figure 11. Resident awareness of financial incentives for home energy upgrades.

In addition to cost and bill savings, the perceived effort to install and operate/maintain efficient upgrades is another key attribute of interest (see Figure 12), given that lack of time or need of replacement are cited as among the top barriers for making home improvements. The same upgrades that residents perceive as the most expensive emerge as having the highest perceived effort to install – adding insulation, installing efficient windows, and installing heat pumps for heating/cooling and water heating (40-67% high/very high across these upgrades). On the other hand, lighting and smart thermostats, which are among the upgrades with the lowest perceived installation costs, also have the lowest perceived installation effort (73% and 53% low/very low effort, respectively). Regarding upgrade operations and maintenance, residents believe that heat pumps for heating/cooling, water heating, and drying will require relatively more effort to operate and maintain than other upgrades: while 54-67% of residents believe non-heat pump upgrades will require low to very low effort to operate, notably lower shares believe this for the heat pump upgrades (34-53%).

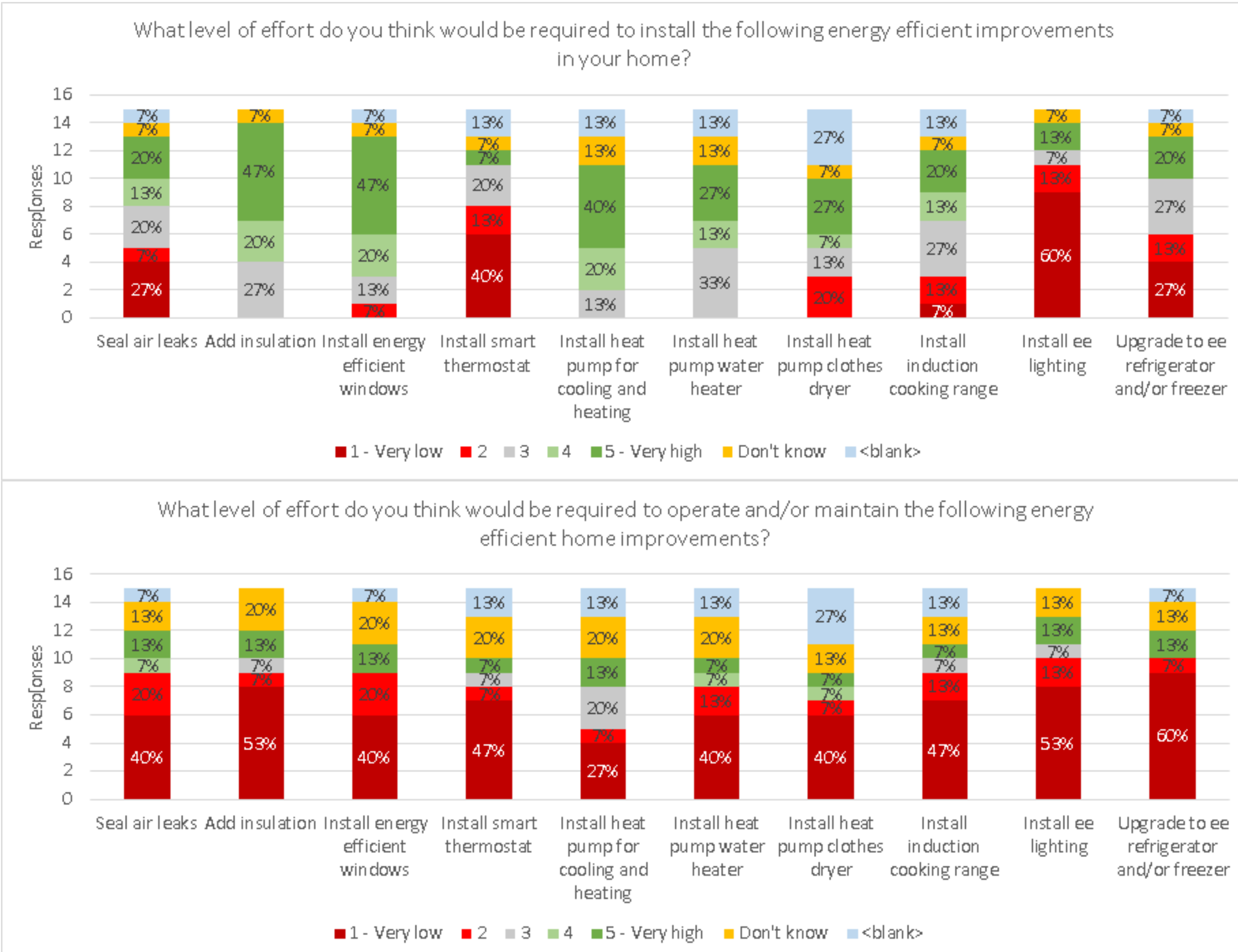


Figure 12. Perceived effort to install/operate various home energy upgrades.

Questions on resident perceptions in the choice survey cover several additional benefits that might be expected of home energy upgrades (see Figure 13):

- **Improving day-to-day quality of life, health, and or comfort.** Measures that affect thermal comfort (sealing air leaks, adding insulation, installing efficient windows, installing heat pump for heating/cooling) have notably higher perceived benefits on this metric than other upgrades, ranging from 53-73% who believe it would have large to very large impacts, vs. 20-40% for other upgrades. Notably, just 20% believe that smart thermostats will benefit this metric, despite their potential impacts on thermal comfort.
- **Benefitting the environment.** Installing efficient lighting, adding insulation, and installing heat pump water heating are the upgrades with the largest perceived benefits to the environment (53-54% assign these upgrades the top two levels of benefits). While most other upgrades also have relatively high perceived benefits to the environment (40-47% in the top two levels), smart thermostats are a notable exception with just 27% assigning this upgrade the top two levels of environmental benefit.
- **Increasing home value and/or rents.** Two upgrades stand out on the home value metric: installing efficient windows, which has the highest perceived potential to raise home value (33% yes/definitely yes); and installing efficient lighting, which has the lowest perceived potential to raise home value (33% no/definitely not). Installing induction cooking, sealing air leaks, adding

insulation, and installing smart thermostats are also substantially perceived to have no effect on home value (20-27% no/definitely not). Responses from renters generally display high uncertainty about the impacts of home energy upgrades on rents, with strong majorities reporting that they don't know the impact on rent across upgrade options.

- **Getting attention from friends, family, or neighbors.** Residents believe the most attention would be received for installing efficient windows (67% yes/definitely yes) and, to a lesser degree, for installing induction cooking (53% yes/definitely yes). The least perceived attention is reported for sealing air leaks (54% no/definitely not) and installing heat pump water heating (53% no/definitely not).
- **Connectivity and ability for remote control via phone, computer, or tablet.** For the upgrades where this feature is relevant, residents are overwhelmingly positive about it, with 60-74% perceiving it as favorable or very favorable across upgrades, and just 7% perceiving it as unfavorable or very unfavorable.

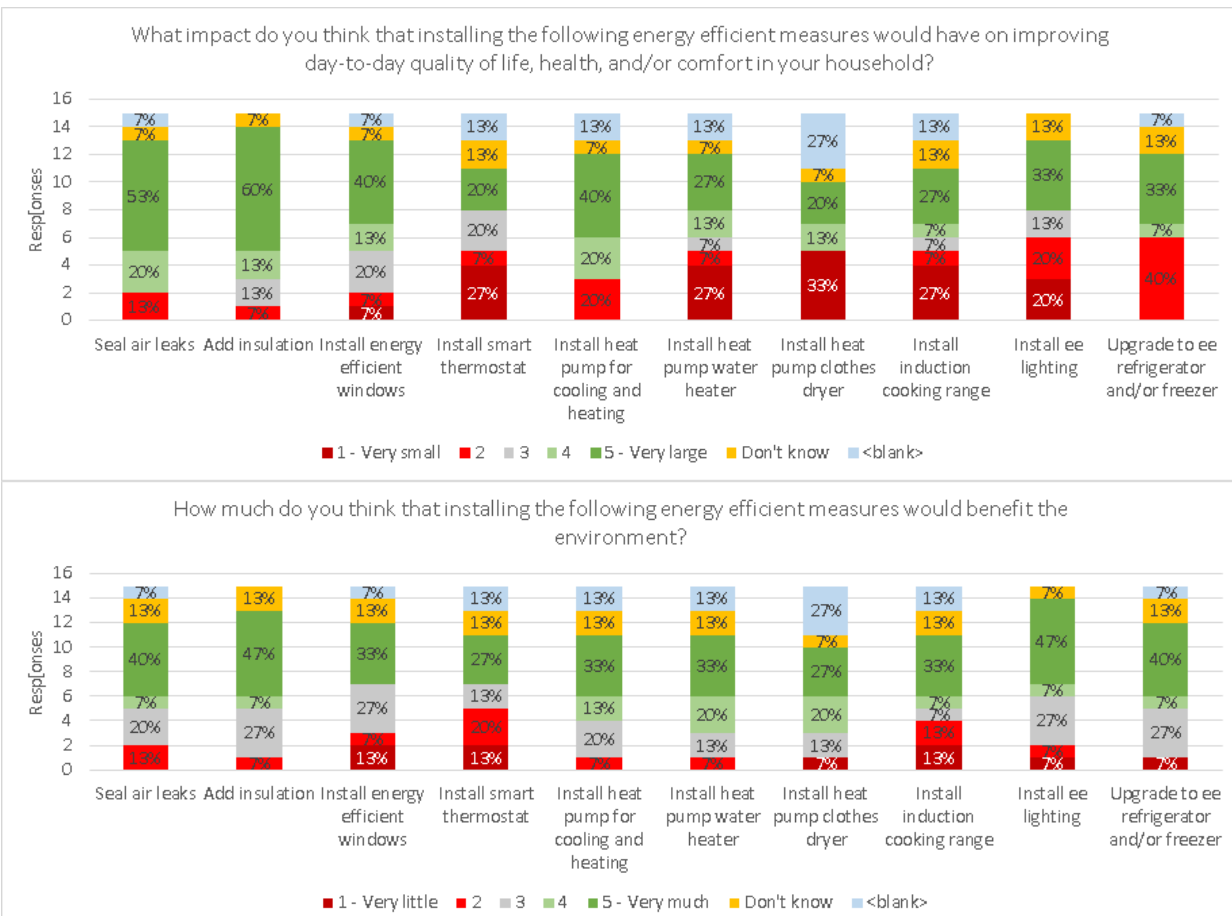


Figure 13. Perceived quality of life and environmental benefits of home energy upgrades.

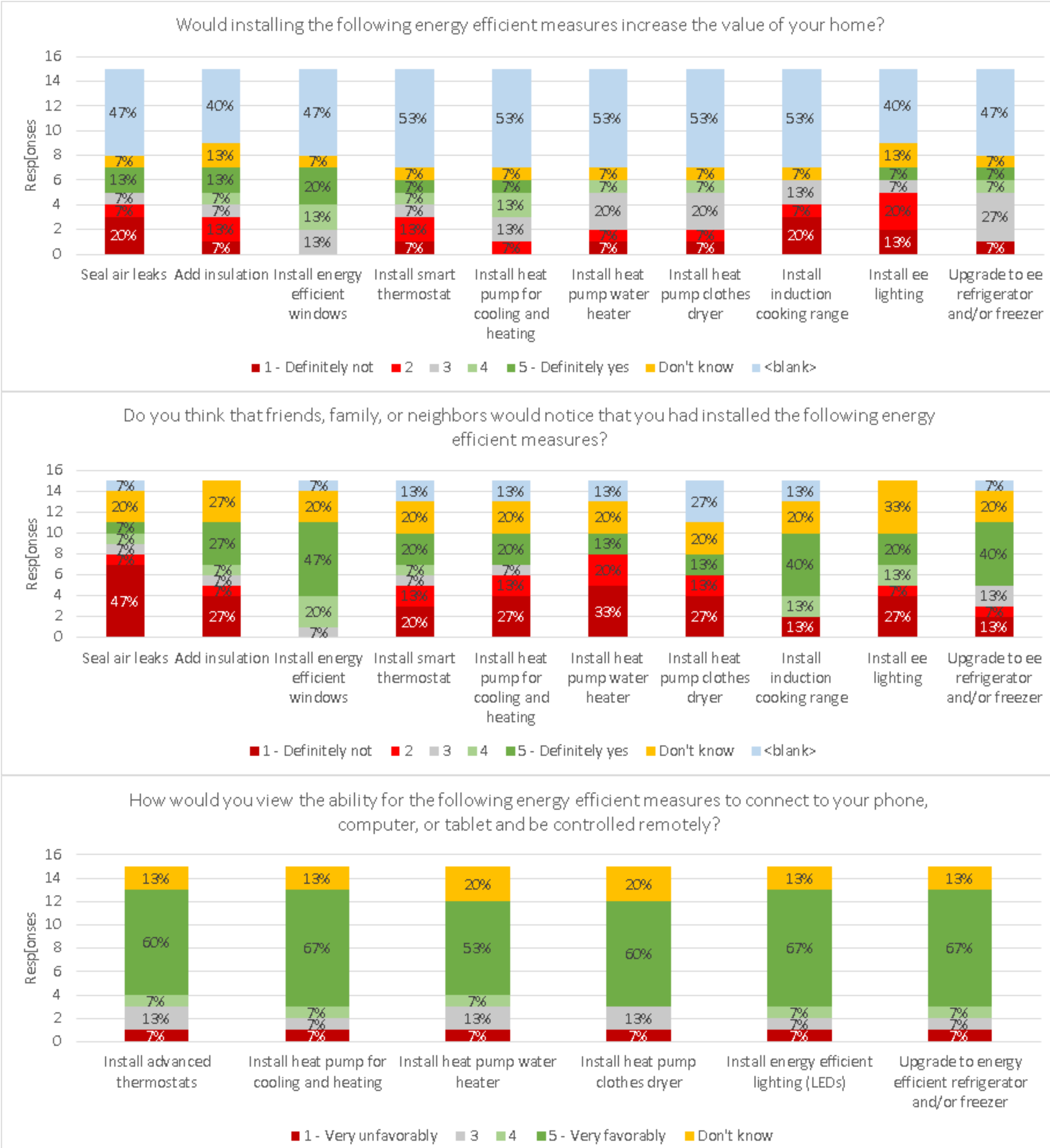


Figure 13 (continued). Perceived home value impacts, attention, and connectivity benefits of home energy upgrades.

Finally, we note that a regression analysis was conducted to attempt to quantitatively investigate key correlations between adoption likelihood and the perceived upgrade attributes covered above. Due to the small number of households covered by the data, however, we are unable to draw meaningful conclusions from this exercise. We expect that follow-on research efforts that deploy this survey with larger samples of residents will facilitate such quantitative modeling efforts.

4.2. Operational behavior surveys

A total of 38 responses were received for the operational behavior surveys across three distribution periods: Nov 2 - Dec 1, 2021 (14 responses), Jan 18 - Feb 22, 2022 (11 responses), and Jun 28 - Aug 2, 2022 (13 responses). Outdoor temperatures registered at the times of responses were generally moderate: 63ºF (54-67ºF min./max. range) in the November distribution; 52ºF (43-66ºF range) in the January distribution; and 64ºF (56-78ºF range) in the June distribution.

Figure 14 shows that respondent demographics largely mirror those of the choice survey, with an even split on gender (50% male, 47% female, 3% non-binary), respondent ages typically in the 30s to mid-40s, and a majority of White respondents (55%) followed by Asians (13%) and Multi-racial (11%). As in the choice survey results, the majority of respondents (58%) have a Bachelor's degree, and there is a relatively even split between homeowners and renters, with slightly more owners than renters (53% vs. 47%).

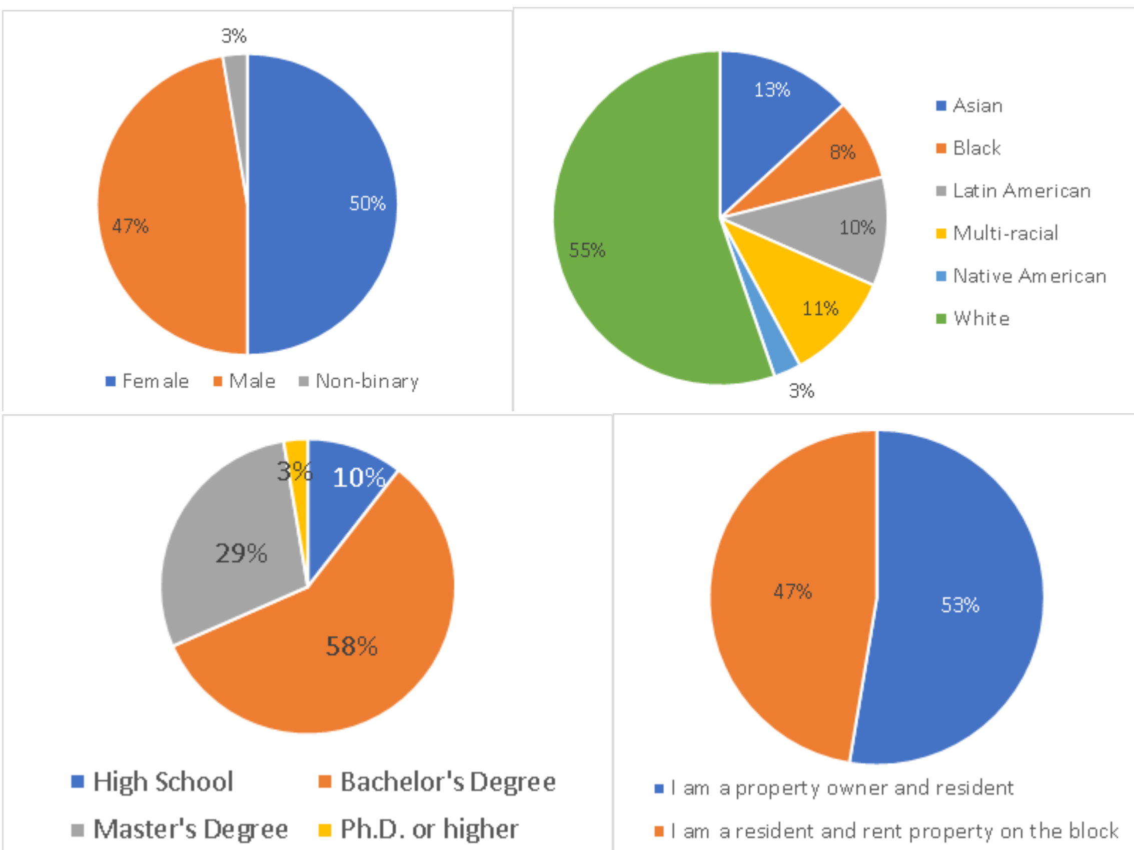


Figure 14. Demographic profiles and homeownership/renter profiles.

Respondent building characteristics are also mostly consistent with those observed in the choice survey results (see Figure 15). Most residents (58%) live in apartments in 2-4 unit buildings constructed before 1980 (86%), and most homes have 3-6 rooms with floor areas between 750-1500 square feet. Per Figure 16, Respondents mostly use natural gas for heating (76%), water heating (79%), and cooking (50%); the operational survey additionally asks about fuel source for clothes drying, which is mostly electricity (71%). A strong majority (87%) of residents pay utility bills, and most (56%) split the bill with others in their household. Energy bills average $85 and $145 in the winter and summer months, somewhat lower than what was reported for bills on the choice survey.

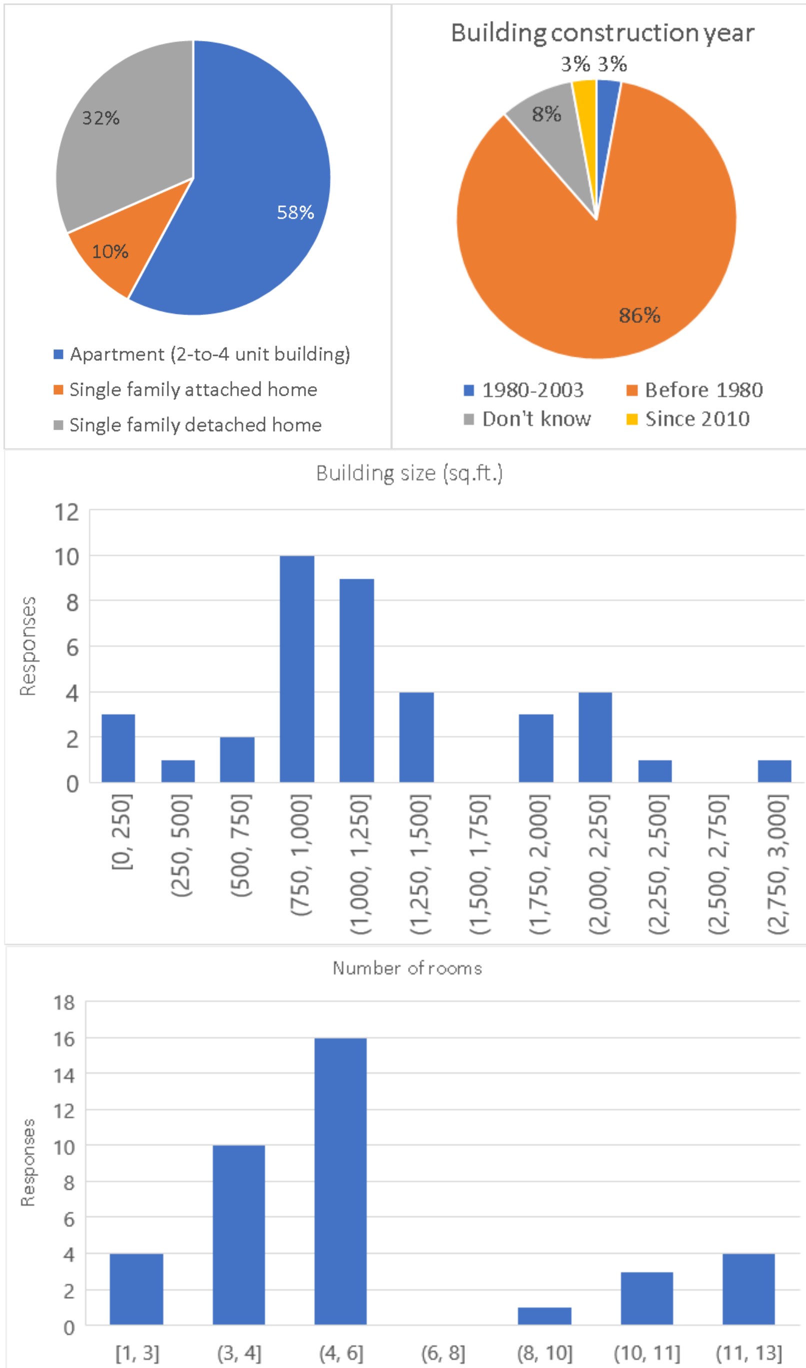


Figure 15. Operational survey respondent building characteristics.

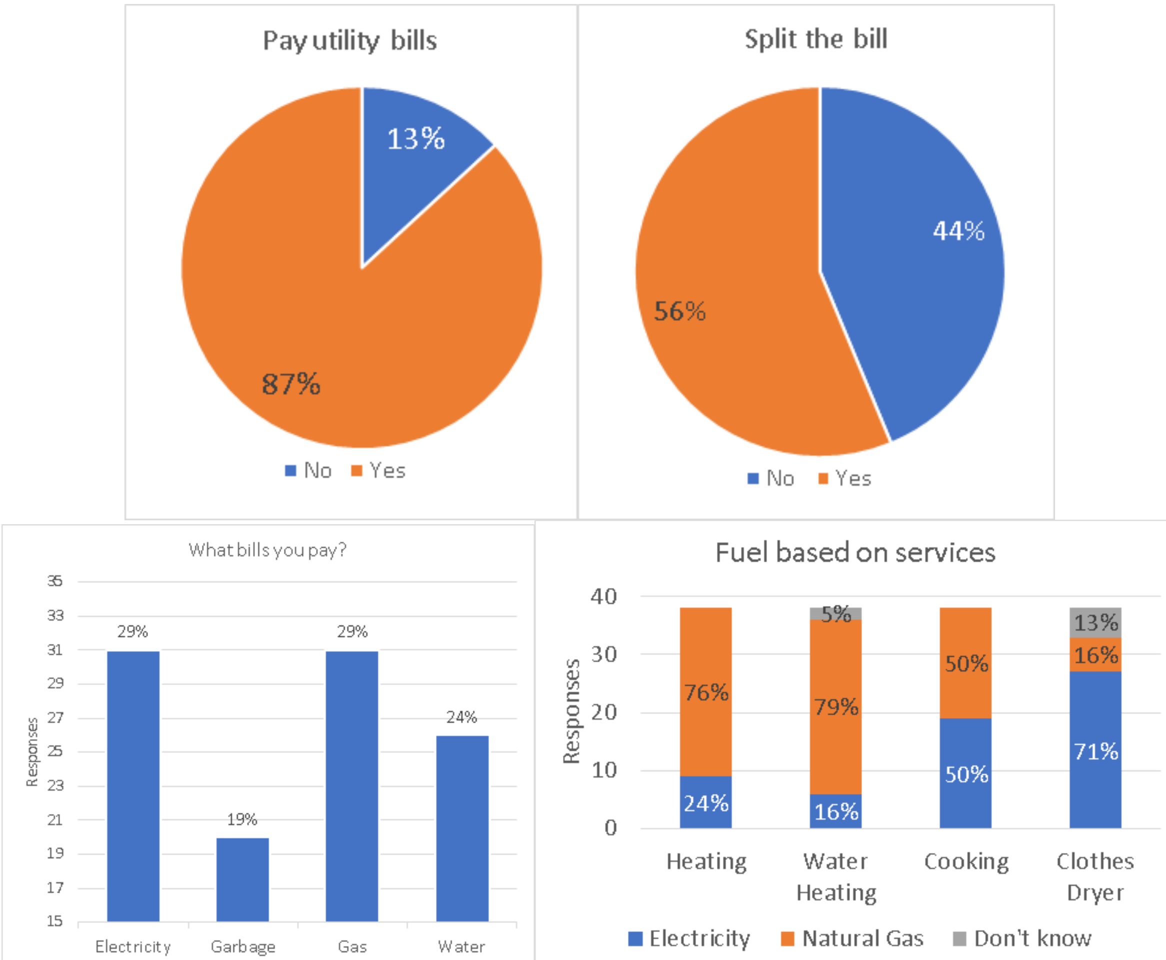


Figure 16. Utility bills and fuel types.

Typical occupancy patterns shown in Figure 17 likely reflect the influence of the COVID-19 pandemic, with a large portion of respondents (58%) reportedly at home for more than 10 hours on weekdays and just 10% of respondents home for less than 3 hours on weekdays. Respondents are also mostly at home on the weekends, when 84% indicate they spend more than 6 hours at home per day. When at home, virtually all respondents (97%) share their space with at least one other person.

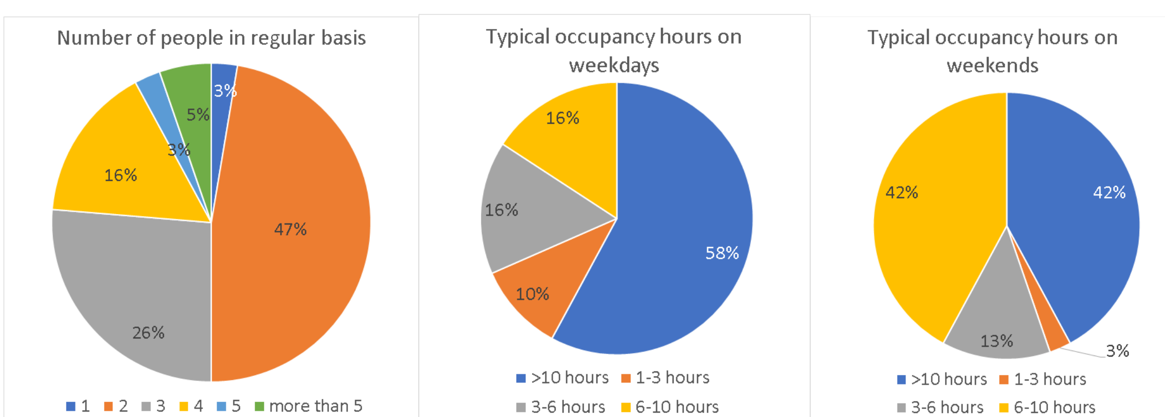


Figure 17. Number of people and typical occupancy during weekdays and weekends.

The operational surveys include additional questions about the equipment and envelope features in respondents' homes that are related to environmentally adaptive behaviors (see Figure 18). For HVAC equipment, just 3% of respondents have central air-conditioning, but most do have central heating equipment – 58% have furnaces, 13% have boilers, and 3% have baseboard heat. HVAC systems are rarely maintained (47% report never having performed maintenance on this equipment), but when maintenance is reported it mostly occurs once every few years (29%). To control the HVAC equipment, a plurality of respondents (34%) use a smart thermostat, which is more than expected given the choice survey results, where just 7% indicated a smart thermostat was installed in their home. Another 29% of respondents report that a thermostat is unavailable or that they don't know which type of thermostat is used. Regarding building envelopes, all respondents have operable windows, and 82% have more than 5 of them. Most respondents also have some sort of shading device, with the majority (53%) using curtains, another 27% using horizontal or vertical blinds, and 13% using shades.

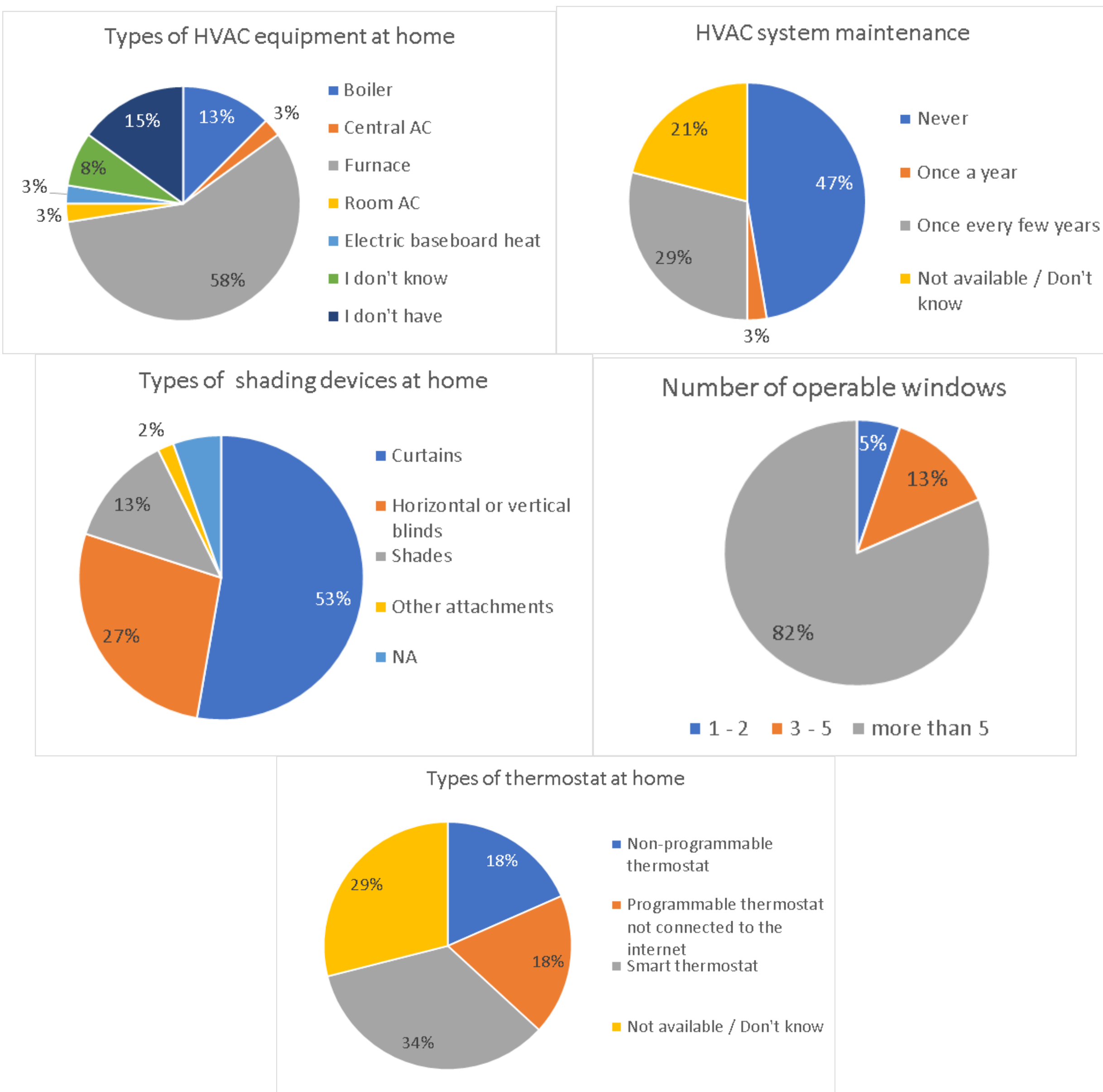


Figure 18. HVAC types and maintenance, windows, shading devices, and thermostat types.

Rates of equipment and appliance replacement in respondents' homes vary widely by equipment type, as might be expected given differences in equipment/appliance lifetimes and in levels of ability/effort to make a replacement (see Figure 19). Equipment and appliances with shorter lifetimes that residents are able to replace easily, such as light bulbs, space heaters, and fans, tend to have been replaced relatively more recently (77% have replaced lighting in the last 5 years, while 37% have done so for space heaters and fans). While substantial percentages of respondents (40-48%) also report having replaced larger appliances such as refrigerators, clothes washer/dryers, stoves/ovens, and water heaters within the last 10 years, this still suggests that such appliances are aging for the majority of those who responded to the survey. Central heating equipment, which as mentioned is infrequently maintained, is also the least frequently replaced equipment, or else its replacement history is uncertain – just 30% report heating equipment having been replaced at all, with another 24% reporting that it has never been replaced and a further 39% unsure of when it was replaced.

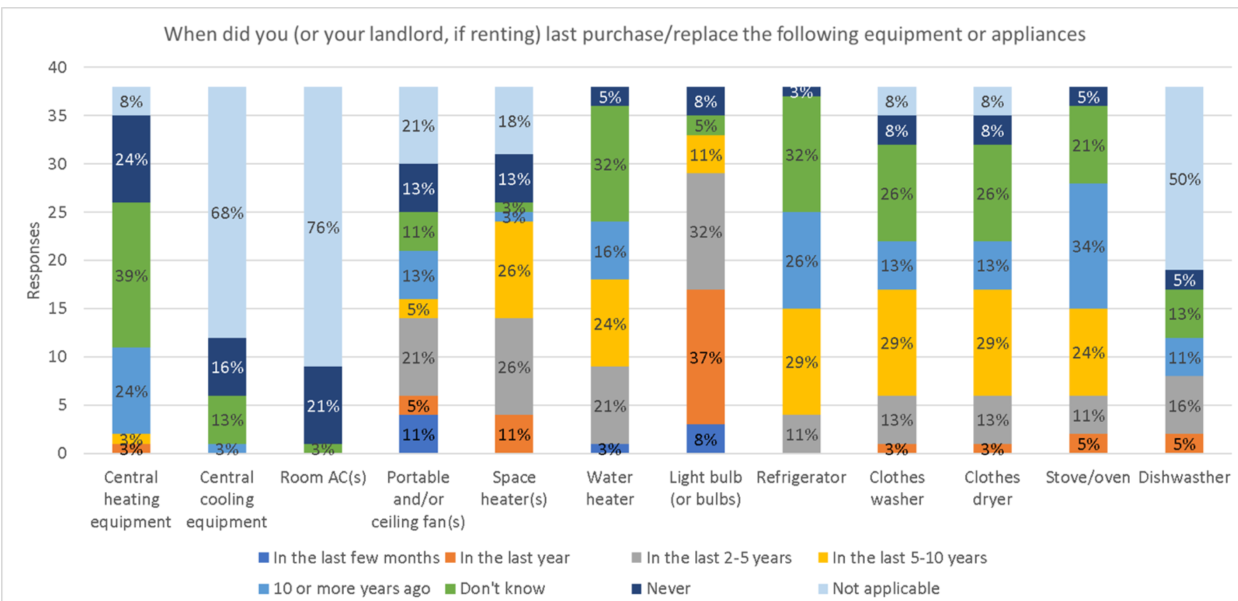


Figure 19. Recent equipment/appliances upgrades.

Despite potential issues with aging equipment and appliances, respondents are generally satisfied with the functioning of most devices that they use regularly (see Figure 20) – less than 20% of respondents report dissatisfaction with the functioning of their water heaters, light bulbs, clothes washers/dryers, and dishwashers. Refrigerators and stoves/ovens are notable exceptions, with roughly 1/3 of residents reporting dissatisfaction with the functioning of these appliances and less than half reporting at least some degree of satisfaction with their functioning (vs. well over half for other regularly utilized equipment/appliances). Perhaps relatedly, these two appliances have not been replaced in the last 10 years for 60-61% of respondents.

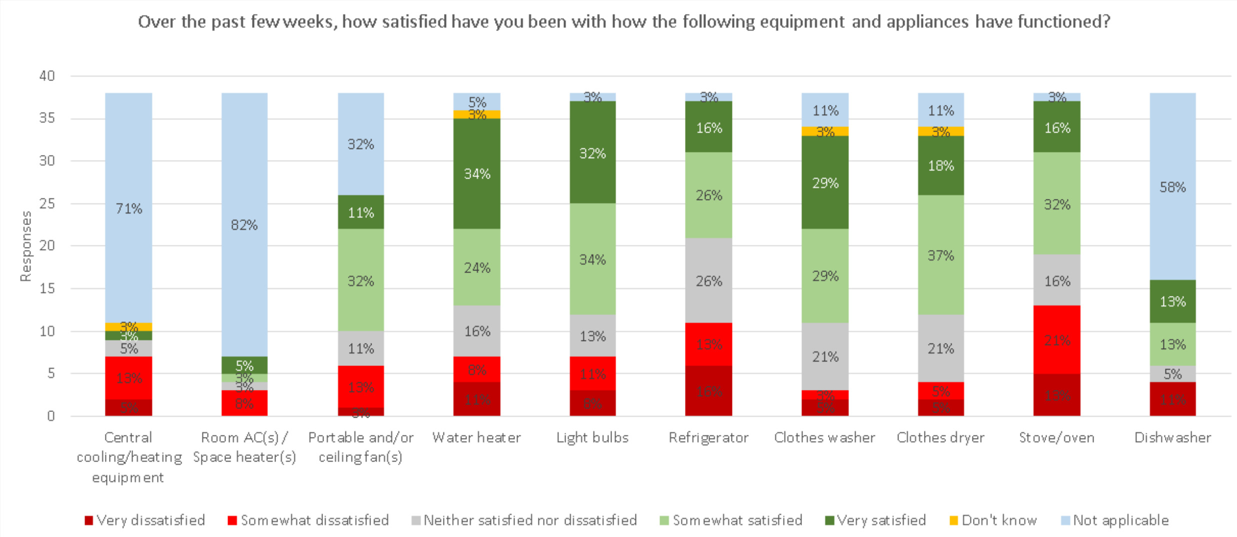


Figure 20. Satisfaction with appliance functioning.

Household appliance use varies widely across appliances: 98% and 87% of respondents use their computers and ovens/stove tops once per day or more, for example, while clothes washers and dryers are only used once or twice a week for most respondents (58%). Time of use is also variable (see Figure 21): while computers are used across all hours of the day, use of ovens/stove tops is more concentrated around the morning and evening hours. Across all options, evening hours are the most commonly cited time of day for appliance use.

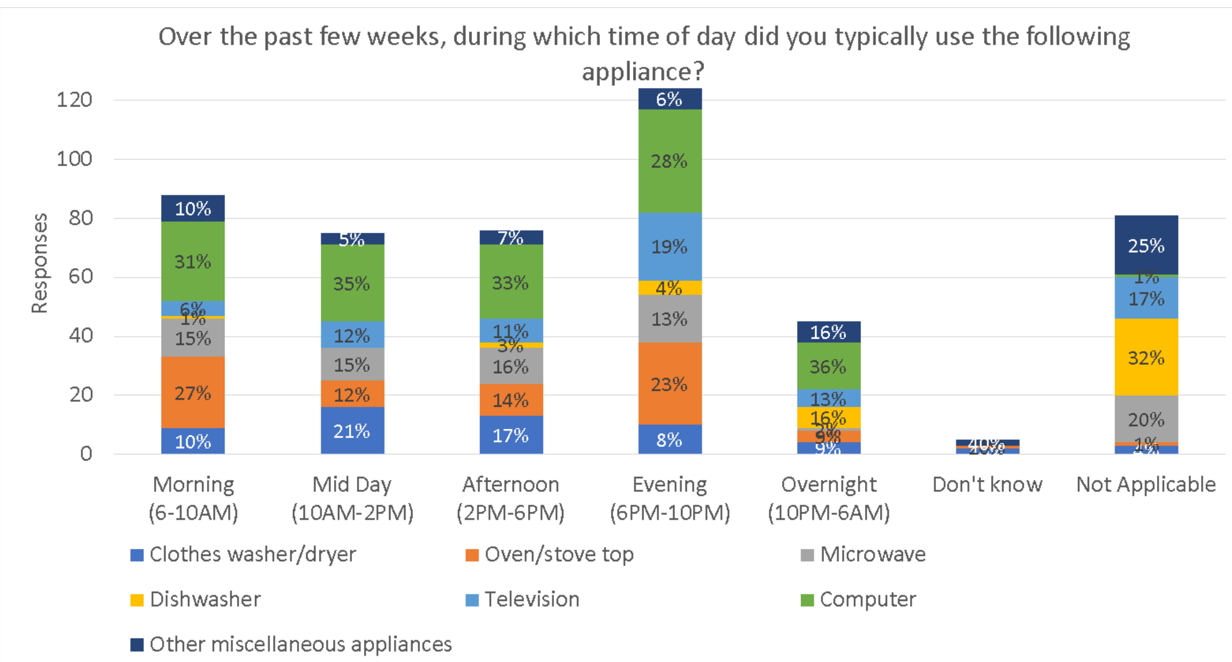


Figure 21. Typical time of day for appliance use.

Equipment and appliances related to thermal comfort provision – central HVAC equipment, room ACs/space heaters, and portable/ceiling fans – were largely either unavailable or not used in the weeks before the surveys. For those who did use central HVAC equipment in particular, however, there was a high degree of dissatisfaction with functionality: 18% report dissatisfaction, out of a total of 29% for whom recent central HVAC use was applicable. Potential issues with equipment thermal comfort provision are echoed by responses about satisfaction with indoor environmental conditions (see Figure 22): temperature has the highest percentage of somewhat to very dissatisfied scores (55%), together with noise levels (50%) and indoor air quality/cleanliness (39%). Conversely, natural lighting and amount of privacy have high satisfaction marks (89% and 85% somewhat/very satisfied, respectively) and 85% of respondents were somewhat to very satisfied with general quality of life, despite the clear issues with temperature and noise levels.

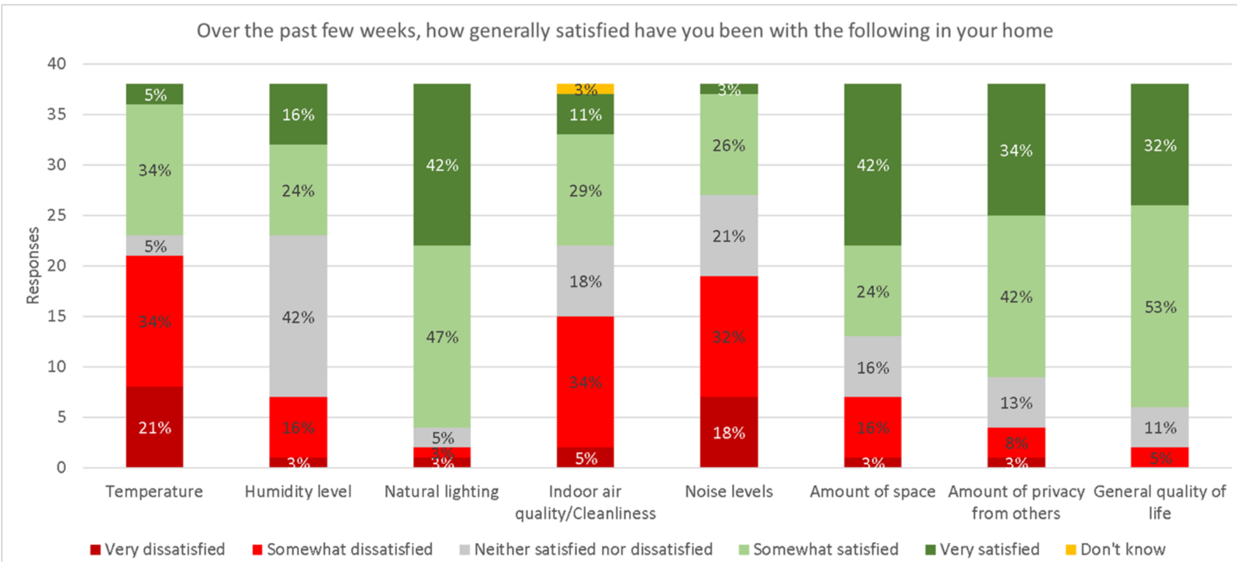


Figure 22. Occupant's satisfaction with indoor environmental conditions.

Regarding environmentally adaptive actions, Figure 23 shows that respondents report having frequently adjusted the lights and opening/closing windows, blinds or attachments (95%, 63%, and 74% took these actions at least once per day). On the other hand, respondents infrequently adjusted thermostats (16% did this at least once per day, and 44% did this rarely or never) and only 8% of renter respondents indicated that they regularly reported issues with equipment to their landlord. Figure 24 shows that lighting actions and adjustments to window blinds or other attachments were concentrated strongly in the morning and evening/overnight hours, while adjustments to windows were more evenly spread across the day and substantially occurred in the afternoon, as well as in the evening and morning hours. Figure 25 shows that comfort is the reason most frequently given for taking adaptive actions – 47% of responses to this question list addressing the comfort of others in the home (31%) or personal comfort (16%) as a reason for having taken adaptive actions. Saving on energy bills is the second most commonly cited reason for taking actions, indicated in 20% of the responses to this question. Respondents link lighting actions most strongly to an energy savings motivation, including opening blinds for more natural light and using minimal artificial light, followed by thermally adaptive actions such as closing blinds or shades to reduce heat gain and opening windows to take advantage of cooler outdoor air.

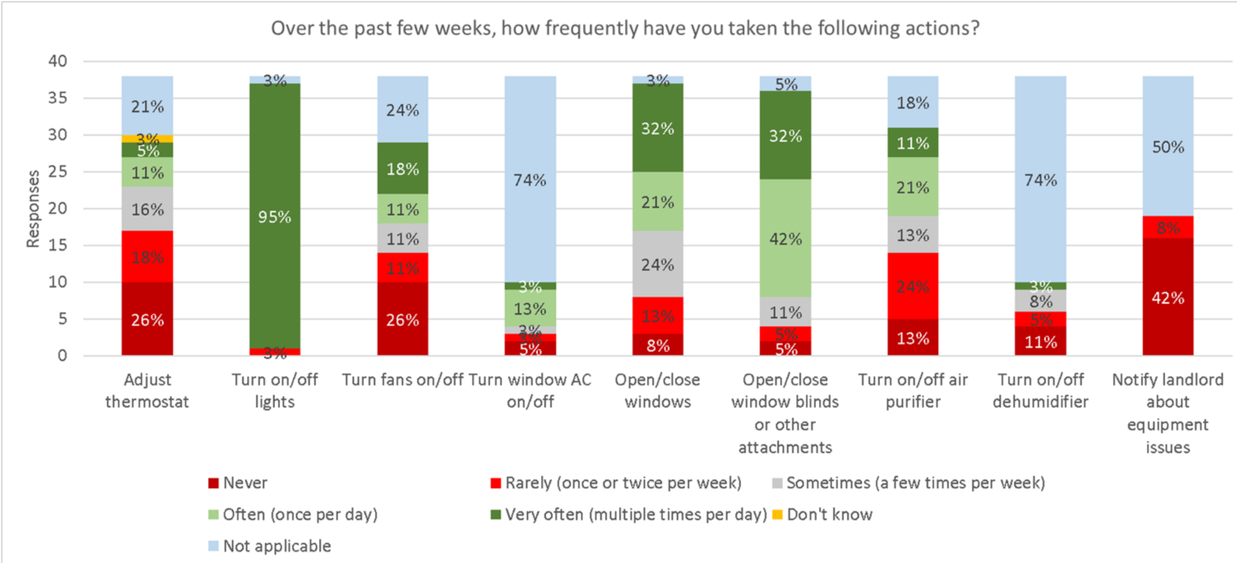


Figure 23. Frequency of adaptive actions..

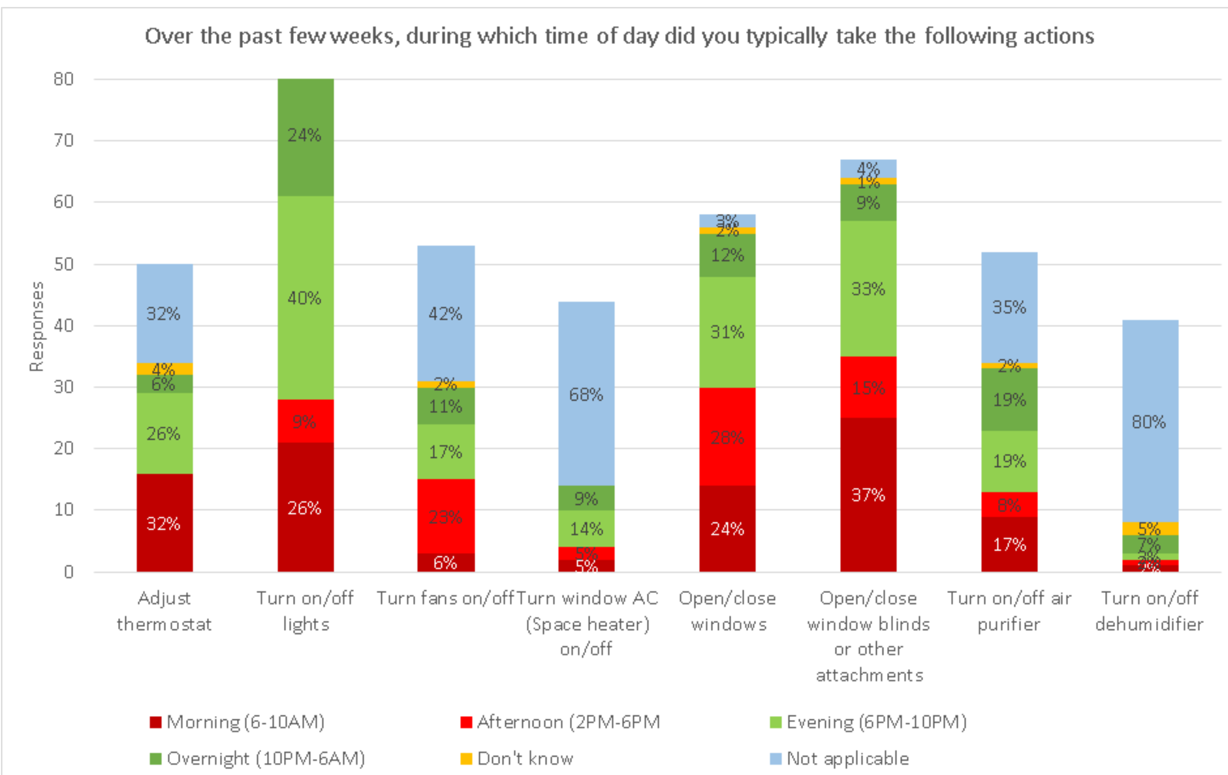


Figure 24. Time of day for adaptive actions.

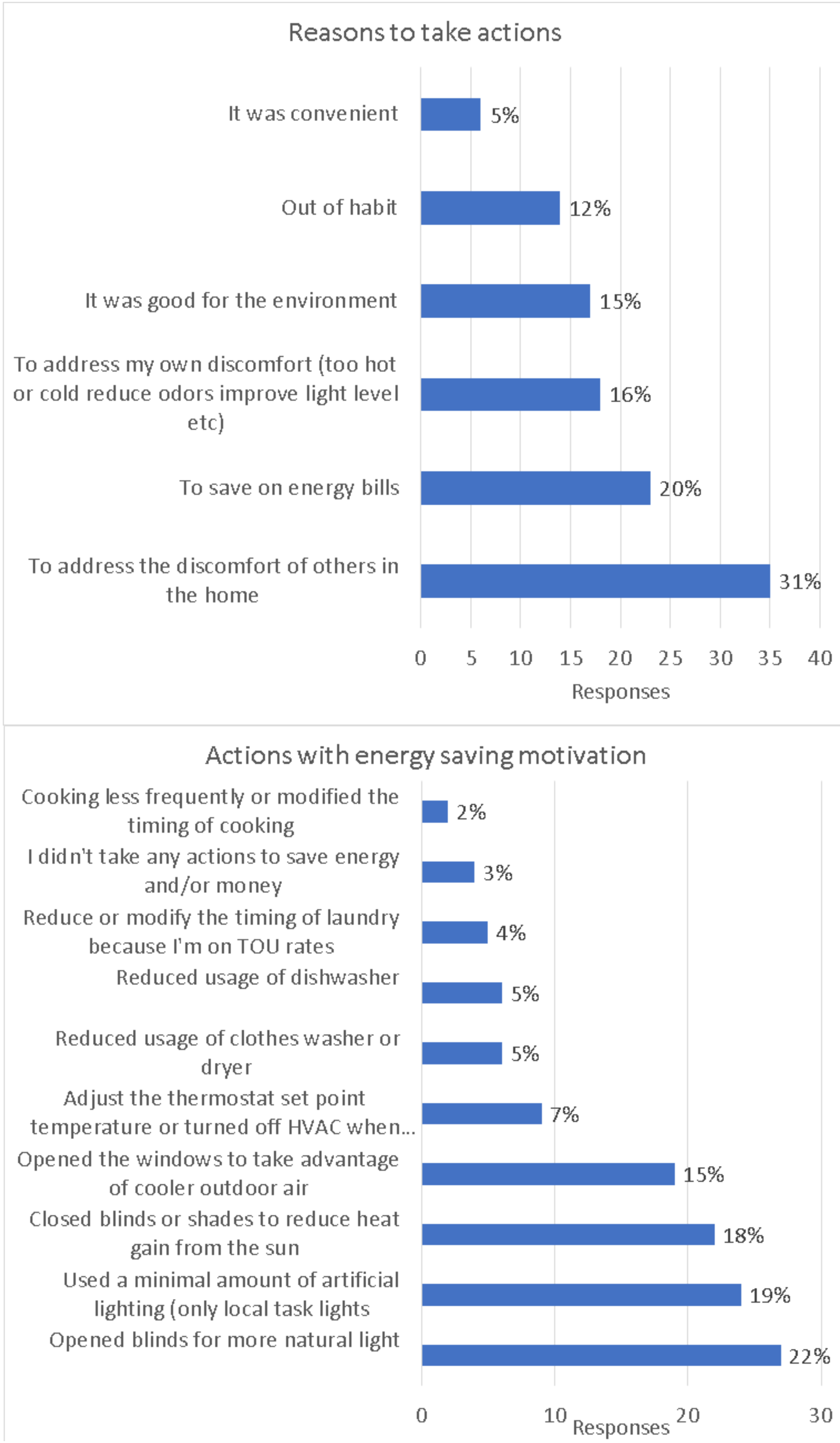


Figure 25. Reasons for adaptive actions and actions with energy saving motivation.

When asked about willingness to temporarily reduce energy use during certain times of day given a 10% utility bill credit (see Figure 26), residents express the greatest willingness to adjust clothes washing and drying schedules (65% likely/very likely), followed by cleaning schedules (58%) and thermostat set point (47%). Residents are particularly unwilling to adjust their use of TVs, computers, and other electronics (53% not likely/very unlikely), cooking (45%), and lighting (34%). Interestingly, these results map well to the responses about the frequency of appliance use and adaptive actions – behaviors that residents appear most willing to modify (washing/drying, thermostats), are reportedly taken less frequently, while behaviors that residents are least willing to modify (computers, lighting) are reportedly a frequent part of daily life.

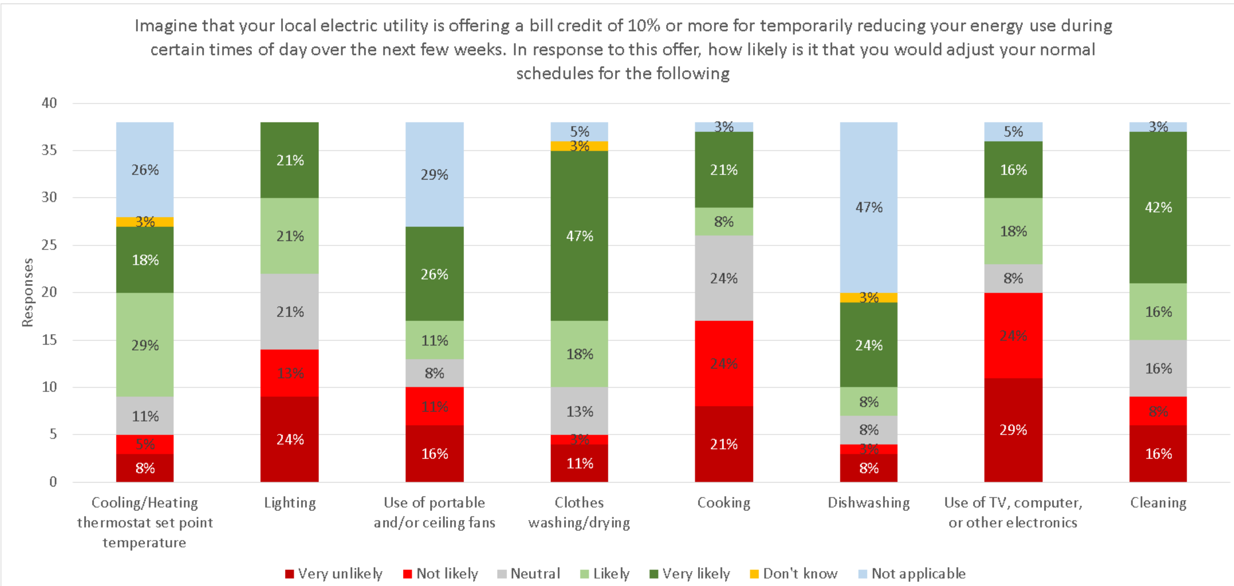


Figure 26. **Willingness to adjust schedules in response to utility incentives**.

5. Discussion

5.1. Key survey insights and implications

Technology choice survey

Residents are pragmatic in their consideration of whether to make home energy upgrades, citing cost, equipment functionality and need of replacement, safety, and comfort implications as key factors in their decision-making. Efforts to increase the deployment and acceptance of energy efficiency upgrades should therefore focus on innovative ways of reducing first costs (for example, through financing schemes, credits and rebates, or reduction of "soft costs" associated with equipment installation) while highlighting the benefits that upgrades offer on improved comfort, functionality, and household safety/health. For renters, additional constraints on the ability to install equipment must be considered: in total, 40% of respondents to our choice survey are renters and cite their landlord as the person who decides about home improvements. In these cases, deployment programs should accordingly focus on the landlord as the primary decision-maker while highlighting the general favorability of energy upgrades amongst tenants and emphasizing the potential for installation of energy upgrades to help attract new tenants.

Across the energy upgrades surveyed, lighting upgrades are the best-regarded by residents and already appear to enjoy widespread adoption, with most residents reporting having done this in their own home and expressing a high likelihood of doing this in the future. Lighting upgrades are generally perceived as low cost and low effort to install and maintain, with solid benefits to the environment – a favorable combination of perceived attributes that is unmatched by other upgrades in the list considered by our survey respondents.

Envelope improvements – in particular, adding insulation and installing efficient windows – are relatively familiar to residents, some of whom have friends, family members, or neighbors who have done these upgrades and others who have done this in their own home. These upgrades also have relatively high perceived benefits to utility bills and day-to-day quality of life, health, and/or comfort. Moreover, relative to other upgrades, efficient windows have high perceived impacts on home value, and they are the upgrade that residents think would be most noticeable to their friends, family, or neighbors. Nevertheless, envelope upgrades are among the highest in terms of perceived cost and effort to install, which is likely a significant barrier to adoption given the strong weight assigned to these attributes in residents' decision-making about home energy upgrades. Implementing envelope efficiency upgrades is critical to lowering household energy consumption and facilitating electrification measures[2]; therefore, efforts should be focused on bringing down the high first cost that residents correctly perceive for such envelope measures and on reducing the degree to which envelope replacements are disruptive to residents, while emphasizing the multiple benefits that residents already acknowledge for these upgrades.

Strong majorities of residents use gas for heating, water heating, and responses suggest that the electrification measures often cited as critical for decarbonization of the buildings sector will face significant challenges with consumer adoption. In particular, heat pumps for heating/cooling and water heating both tend to be perceived as having relatively high costs and high effort to install/operate, and resident perceptions of their utility bill benefits are mixed. Few residents have direct experience with these technologies or know others who do, and very few residents know of available incentives that would offset the upfront costs of heat pumps. These results suggest that unlike envelope, where residents are largely already familiar with the upgrades and simply need more assistance in paying for and installing them, an initial focus for heat pump deployment should be on educating about typical costs, level of effort/disruption to install, and operational tendencies, which may be more favorable than residents expect. This educational effort should also highlight the growing number of state and federal incentives that are available to offset the upfront costs of heat pump technologies, and should confirm the benefits that many residents already perceive for these technologies – for example, that installing heat pumps for heating and cooling would improve quality of life, health, and comfort.

For cooking, installing an induction range is the least favorably viewed upgrade we surveyed, and while it is not among the upgrades with the highest perceived upfront costs, it has particularly small perceived benefits to utility bills and a smaller perceived impacts on quality of life, health, and comfort than most other upgrades. Indeed, residents may not expect significant enough benefits from switching to induction cooking to justify the effort to replace existing cooking equipment. Yet, the operational survey results do indicate substantial dissatisfaction with the functionality of existing cooking equipment, and induction emerges in the choice survey results as one of two upgrades (along with efficient windows) that many residents believe that others will notice. Again, resident education efforts could increase the deployment potential for this upgrade. In this case, such efforts could highlight the improved

[2] For example, by reducing the required heating/cooling capacity of heat pumps and mitigating potential energy cost increases from fuel switching away from gas

functionality of induction stoves vs. aging existing cooking equipment, and promote the sleeker design characteristics of new induction cooking products.

Smart thermostats are another upgrade that a notable percentage of residents perceive unfavorably, and together with induction, are the upgrade that respondents are least likely to install in their homes in the future. This is surprising given that respondents generally believe smart thermostats to be low-cost measures that require little effort to install and overwhelmingly view internet connectivity and remote control of equipment – which smart thermostats would allow for HVAC – as a favorable capability. Similar to induction cooking, smart thermostats have relatively low perceived benefits to utility bills, and few believe smart thermostats would unlock additional benefits such as improving quality of life/comfort, increasing home value, or being noticed by others. Efforts to educate residents about the benefits of installing smart thermostats could therefore focus primarily on their ability to enable connectivity/remote control of HVAC equipment. Additionally, given the issues with temperature uncovered by the operational behavior survey, education efforts could also emphasize the benefits of smart thermostats in improving thermal comfort through control schedules that are tailored to occupancy patterns and thermal preferences.

Operational behavioral survey

In the operational survey results, residents report making operational adjustments primarily to address comfort issues, and addressing the comfort of others is cited above personal comfort as a reason to take actions (virtually all respondents share their space with at least one other person). Energy bill savings is also cited as a top reason for making operational adjustments, and commonly-cited adjustments with an energy saving motivation tend to relate to use of windows and window attachments (e.g., opening blinds to maximize natural light, close blinds or shades to reduce heat gains, or opening windows to bring in outdoor air). These results suggest that programs intended to promote energy saving operational behavior should address concerns about comfort impacts first, in addition to prioritizing measures with relatively lower risks of compromising comfort – for example, those that replace active energy services with passive measures for providing thermal and visual comfort.

The operational survey also reveals that a large share of residents have aging equipment and appliances in their homes, though equipment functionality is generally assessed as satisfactory with the notable exceptions of cooking and refrigeration equipment. HVAC equipment is both the least commonly replaced equipment type and is infrequently maintained. While our survey distributions may have failed to capture periods of more extreme weather conditions and frequent use of HVAC equipment, significant dissatisfaction with HVAC equipment functioning is observed for those who reported using it, and respondent dissatisfaction with temperature is greater than that of any other indoor environmental condition. This result underscores a potential opportunity to frame the replacement of existing HVAC with efficient heat pumps and smart thermostat controls as a measure to significantly improve the quality of thermal comfort provision in residents' homes that would also carry benefits to energy bills and the environment.

The frequency and temporal patterns of adaptive actions and use of appliances/equipment vary widely across the items we surveyed. With the exception of use of computers, however, actions do tend to be concentrated around the morning or evening hours, and are reported most commonly in the evening hours bin. Additionally, schedules for actions that residents engage in most frequently, such as lighting, cooking, and computer usage, are also those that they are the least willing to temporarily adjust in response to utility incentives, while more willingness is observed for temporarily adjusting schedules of infrequent actions such as clothes washing/drying and thermostat set point adjustments. These results suggest two implications for the potential use of residential building load management as a grid resource. First, it's clear that there is a high degree of coincidence between residential energy use patterns and the evening hours of day when utility system demand tends to peak, and that therefore management of residential building loads could provide large benefits in peak load reduction. Second, there may be significant resident pushback on rescheduling actions and/or use of equipment/appliances that are critical to residents' daily functioning, even on a temporary basis – for example, turning on the lights when it's dark outside, cooking dinner at a normal hour, or using the computer to complete tasks for a job. Accordingly, utilities should seek to target flexible management of loads such as heating/cooling and washing/drying that may be easier to reschedule without major disruptions to residents, and should ensure that incentives for modifying behaviors are commensurate with the potential risks of disruption that residents would need to absorb.

5.2. Key limitations and areas for future work

Our insights regarding decision-making about home energy upgrades and patterns of residential equipment operation are preliminary and not broadly generalizable due to the small sample of respondents in this study. Despite our best efforts to incentivize high response rates, including the use of $25 gift cards to encourage survey participation, our choice survey data cover slightly less than half of the total EcoBlock households, and the operational behavior surveys likely cover an even smaller portion of potential respondents. Due to the COVID-19 pandemic, our ability to conduct in-person engagements on survey participation was limited, and this reduced our primary information channels to e-mail and the community newsletters that were published by the UC Berkeley EcoBlock team. Further in-person engagement may have helped to garner additional responses from residents who are not actively engaged through these two information channels, for example because they don't have access to a computer or smart phone or are not native English speakers and do not read the EcoBlock publications.

Future development of this project will focus on adapting and deploying the surveys with a larger pool of respondents to enable more robust exploration of initial insights and quantitative modeling of the key associations targeted by this study's research questions. Given larger datasets of responses, more sophisticated analysis techniques could be used; for example, discrete choice experiments could be added that elicit quantitative relationships between key technology attributes and the likelihood of technology adoption. Accessing a larger sample of residents would require expanding the geographic scope of the research, for example to the city, state, or even regional and national levels, which would also open up interesting comparisons of responses by location. While greater geographic scope challenges the ability to do in-person recruitment, recruitment risks could be mitigated by the use of third-party market research services that would ensure access to a sufficiently large pool of respondents.

Finally, the scope of our surveys is limited to upgrades and operational actions that relate primarily to building energy efficiency and, to a lesser degree, load flexibility; other distributed energy resources that may be important to the energy transition such as onsite PV generation, electric vehicles, and behind-the-meter batteries were not covered by this research. Moreover, broader operational metrics of interest that are related to energy use, such as resilience, were not within the scope of this study. Future survey iterations could therefore also conduct a deeper investigation of the adoption, operation, and potential benefits of load flexibility technologies and other distributed energy resources, particularly in the context of times of high stress on the power grid.

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Appendix

A.1 Technology choice survey instrument

1. Has anyone else in your household already participated in this survey?
   Yes [exit survey]/No [survey process]
2. Are you eighteen years or older? Yes/No
3. Are you currently a resident or homeowner with an address on Blossom Street or Fruitvale Avenue (referred to subsequently as the "EcoBlock")? Yes/No
4. Before you start the survey, please reference the Informed Consent Form and save it for your records. Please click to proceed to the next page of the online survey as an indication of your consent.
5. Address(es) on Blossom or Fruitvale Avenue
6. Age
7. Gender:
   a. Male
   b. Female
   c. Non-binary
   d. Prefer to self-describe
8. Ethnicity
   a. American Indian or Alaska Native
   b. Asian
   c. Black or African American
   d. Native Hawaiian or Other Pacific Islander
   e. White
   f. Other (please specify)
9. What was your total household income before taxes during the past 12 months?
   a. Less than $25,000
   b. $25,000 to $49,999
   c. $50,000 to $74,999
   d. $75,000 to $99,999
   e. $100,000 to $149,999
   f. $150,000 to $199,999
   g. $200,000 or more
10. Education level
    a. Some High School
    b. High School
    c. Bachelor's Degree
    d. Master's Degree
    e. Ph.D. or higher
    f. Trade School
    g. Other (please explain)
11. Which of the following best describes you?
    a. I am a property owner and resident
    b. I am a property owner but do not live on the block
    c. I am a resident and rent property on the block
    d. Other (please explain)

12. Note: please answer the questions in the following screens for your EcoBlock property only. If you own multiple properties on the EcoBlock, please choose only one as the basis for your responses.
13. How many properties do you own on the block in total?
14. How long have you been living in your current residence (in years or months)?
15. How long have you owned your property (in years or months)?
16. How many people including yourself live or stay in your dwelling on a regular basis (More than 2-3 days/week, including family, roommates)?
    a. 1
    b. 2
    c. 3
    d. 4
    e. 5
    f. More than 5
17. Do you pay your utility bills? Yes/No
18. Which bills do you pay?
    a. Water
    b. Garbage
    c. Gas
    d. Electricity
19. What is your average monthly energy bill ($/month) in summer (total of gas, electricity, and any other fuels):
20. What is your average monthly energy bill ($/month) in winter (total of gas, electricity, and any other fuels):
21. Who pays the bill?
    a. Other household members
    b. My landlord
    c. Other (please explain)
22. Do you split your bill with any other household members? Yes/No
23. When do you estimate your building was constructed?
    a. Before 1980
    b. 1980-2003
    c. 2004-2010
    d. Since 2010
    e. Don't know
24. What type of building do you currently live in or own?
    a. Single family detached home
    b. Single family attached home
    c. Apartment (2-to-4 unit building)
    d. Apartment (5 or more unit building)
    e. Other (please specify)
25. What is the size of your home in square feet?
26. How many rooms do you have in your home? Please include your kitchen and bathroom
27. What is the floor area of your residence?
28. What is the main fuel used for the following services

	Electricity	Natural Gas	Propane	Fuel oil	Renewable source	Don’t know
Heating						

Water heating						
Cooking						

29. How much money do you budget or spend each year on home improvements like those listed in the examples provided below?
Example home improvement options include upgrading heating, cooling, or water heating equipment; improving the building's envelope by installing new windows, adding insulation, or sealing air leaks; replacing appliances such as refrigerators or clothes washers/dryers and dishwashers; or switching to new, longer-lasting light bulbs.
    a. Less than $100
    b. $100 - $999
    c. $1000 - $4999
    d. $5000 - $10,000
    e. Above $10,000
30. Who primarily makes decisions about purchasing home improvements like those listed in the example provided below?
Example home improvement options include upgrading heating, cooling, or water heating equipment; improving the building's envelope by installing new windows, adding insulation, or sealing air leaks; replacing appliances such as refrigerators or clothes washers/dryers and dishwashers; or switching to new, longer-lasting light bulbs.
    a. Me alone
    b. Me together with others in my household
    c. Others in my household
    d. My landlord
    e. Other (please specify)
31. In general, what are the primary reasons that you might consider making home improvements such as those listed in the examples provided below? Example home improvement options include upgrading heating, cooling, or water heating equipment; improving the building's envelope by installing new windows, adding insulation, or sealing air leaks; replacing appliances such as refrigerators or clothes washers/dryers and dishwashers; or switching to new, longer-lasting light bulbs. Please select the top three reasons in the following list. If you are not involved in the purchasing decisions, please provide your best guess.
    a. Save on current energy bills
    b. Increase property value
    c. Low purchase price
    d. Improve indoor air quality
    e. Improve thermal comfort
    f. Make life more convenient
    g. Improve safety
    h. More control over home operation
    i. Help the environment
    j. Replace old products or products that do not work
    k. Improve resilience to climate change
    l. Avoid higher electricity bills anticipated in the future
    m. Received financial assistance to make the purchase
    n. Follow the example of others, including friends/family, and neighbors/community
    o. Other (please specify)

32. In general, what are the primary factors that would prevent you from making home improvements such as those listed in the examples provided below?
Example home improvement options include upgrading heating, cooling, or water heating equipment; improving the building's envelope by installing new windows, adding insulation, or sealing air leaks; replacing appliances such as refrigerators or clothes washers/dryers and dishwashers; or switching to new, longer-lasting light bulbs.
Please select the top three reasons in the following list. If you are not involved in the purchasing decisions, please provide your best guess.
    a. Too expensive
    b. Don't want to replace until necessary
    c. Don't know where to find trustworthy information
    d. Don't know how to install the purchased product(s)
    e. Don't know how to operate or maintain the purchased product(s)
    f. Energy efficiency is not my top concern
    g. Too time consuming
    h. Data privacy concerns
    i. Disagreement among household members about purchase(s)
    j. Others outside the household prevent the purchase(s) (e.g., landlord, HOA)
    k. Other (please specify)
33. How familiar are you with the following energy efficient home improvements?

	Not at all/never heard of this	Have heard about this but no personal experience with it	Know others who have done this but haven't done in own home	Have done this in my own home
Seal air leaks				
Add insulation material to walls, attic/ceiling, and/or floors				
Install energy efficient windows				
Install internet-connected smart thermostats				
Install heat pump for cooling and heating				
Install heat pump water heater				
Install heat pump clothes dryer				
Install induction cooking range				
Install energy efficient lighting (LED)				

Upgrade to energy efficient refrigerator and/or freezer				

34. How did you first hear about or encounter each of the following energy efficient home improvements?

	TV or Radio	Social media	Friend, family or neighbor	Local officials	Local utility	Local store or vendor	Other	Don't know
[Insert subset of measures that they've heard of]								

35. How many of your close acquaintances (e.g., friends, family, or neighbors) have made the following energy efficient improvements to their homes?

	None of them	One or two of them	Some of them	Many/most of them	Don't know
[Insert subset of measures that they've heard of]					

36. Are you aware of any government or utility financial incentives (e.g., tax credits, cost rebates, or similar) for making the following energy efficient improvements to your home?

	Yes	No	Don't know
[Insert subset of measures that they've heard of]			

37. Overall, how do you view the following energy efficient home improvements?

	1 - Very unfavorably	2	3	4	5 - Very favorably	Don't know
[Insert subset of measures that they've heard of]						

38. How likely is it that you will purchase and/or install the following energy efficient home improvements for your Blossom St. or Fruitvale Ave. property at some point in the future? If you have already recently purchased and/or installed any of these options in your home, please indicate how likely you would be to recommend the option to a friend or family member.

	1 - Very unlikely	2	3	4	5 - Very likely	Cannot do this	Don't know
[Insert subset of measures that they've heard of]							

39. How much do you think the following energy efficient home improvements cost?

	1 - Very inexpensive	2	3	4	5 - Very expensive	Don't know
[Insert subset of measures that they've heard of]						

40. What impact do you think installing the following energy efficiency measures would have on reducing your household's energy bill?

	1 - Very small	2	3	4	5 - Very large	Don't know
[Insert subset of measures that they've heard of]						

41. What level of effort do you think would be required to install the following energy efficient improvements in your home?

	1 - Very low	2	3	4	5 - Very high	Don't know
[Insert subset of measures that they've heard of]						

42. What level of effort do you think would be required to operate and/or maintain the following energy efficient home improvements?

	1 - Very low	2	3	4	5 - Very high	Don't know
[Insert subset of measures that they've heard of]						

43. What impact do you think that installing the following energy efficient measures would have on improving day-to-day quality of life, health, and/or comfort in your household?

	1 - Very small	2	3	4	5 - Very large	Don't know
[Insert subset of measures that they've heard of]						

44. How much do you think that installing the following energy efficient measures would benefit the environment?

	1 - Very little	2	3	4	5 - Very much	Don't know
[Insert subset of measures that they've heard of]						

45. Would installing the following energy efficient measures increase the value of your home?

	1 – Definitely not	2	3	4	5 – Definitely yes	Don't know
[Insert subset of measures that they've heard of]						

46. Would installing the following energy efficient measures increase your rent?

	1 – Definitely not	2	3	4	5 – Definitely yes	Don't know
[Insert subset of measures that they've heard of]						

47. Do you think that friends, family, or neighbors would notice that you had installed the following energy efficient measures?

	1 – Definitely not	2	3	4	5 – Definitely yes	Don't know
[Insert subset of						

measures that they've heard of]						

48. How would you view the ability for the following energy efficient measures to connect to your phone, computer, or tablet and be controlled remotely?

	1 - Very unfavorably	2	3	4	5 - Very favorably	Don't know
Install advanced thermostats						
Install heat pump for cooling and heating						
Install heat pump water heater						
Install heat pump clothes dryer						
Install energy efficient lighting (LEDs)						
Upgrade to energy efficient refrigerator and/or freezer						

49. Do you have final thoughts you would like to share with us?

A.2 Operational behavior survey instrument

1. Are you eighteen years or older? Yes/No
2. Are you currently a resident or homeowner with an address on Blossom Street or Fruitvale Avenue (referred to subsequently as the "EcoBlock")? Yes/No
3. Before you start the survey, please reference the Informed Consent Form and save it for your records. Please click to proceed to the next page of the online survey as an indication of your consent.
4. Address(es) on Blossom or Fruitvale Avenue
5. Age

6. Gender:
    a. Male
    b. Female
    c. Non-binary
    d. Prefer to self-describe
7. Ethnicity
    a. American Indian or Alaska Native
    b. Asian
    c. Black or African American
    d. Native Hawaiian or Other Pacific Islander
    e. White
    f. Other (please specify)
8. What was your total household income before taxes during the past 12 months?
    a. Less than $25,000
    b. $25,000 to $49,999
    c. $50,000 to $74,999
    d. $75,000 to $99,999
    e. $100,000 to $149,999
    f. $150,000 to $199,999
    g. $200,000 or more
9. Education level
    a. Some High School
    b. High School
    c. Bachelor's Degree
    d. Master's Degree
    e. Ph.D. or higher
    f. Trade School
    g. Other (please explain)
10. Which of the following best describes you?
    a. I am a property owner and resident
    b. I am a property owner but do not live on the block
    c. I am a resident and rent property on the block
    d. Other (please explain)
11. Note: please answer the questions in the following screens for your EcoBlock property only. If you own multiple properties on the EcoBlock, please choose only one as the basis for your responses.
12. How many properties do you own on the block in total?
13. How long have you been living in your current residence (in years or months)?
14. How long have you owned your property (in years or months)?
15. How many people including yourself live or stay in your dwelling on a regular basis (More than 2-3 days/week, including family, roommates)?
    a. 1
    b. 2
    c. 3
    d. 4
    e. 5
    f. More than 5
16. Do you pay your utility bills? Yes/No

17. Which bills do you pay?
    a. Water
    b. Garbage
    c. Gas
    d. Electricity
18. What is your average monthly energy bill ($/month) in summer (total of gas, electricity, and any other fuels):
19. What is your average monthly energy bill ($/month) in winter (total of gas, electricity, and any other fuels):
20. Who pays the bill?
    a. Other household members
    b. My landlord
    c. Other (please explain)
21. Do you split your bill with any other household members? Yes/No
22. When do you estimate your building was constructed?
    a. Before 1980
    b. 1980-2003
    c. 2004-2010
    d. Since 2010
    e. Don't know
23. What type of building do you currently live in or own?
    a. Single family detached home
    b. Single family attached home
    c. Apartment (2-to-4 unit building)
    d. Apartment (5 or more unit building)
    e. Other (please specify)
24. What is the size of your home in square feet?
25. How many rooms do you have in your home? Please include your kitchen and bathroom
26. What is the floor of your residence?
27. What is the main fuel used for the following services

	Electricity	Natural Gas	Propane	Fuel oil	Renewable source	Don't know
Heating						
Water heating						
Cooking						
Clothes Dryer						

28. What type of HVAC equipment does your home have (check all that apply)?
    a. Furnace
    b. Central AC
    c. Room AC(s)
    d. Heat pump
    e. Boiler
    f. Electric baseboard heat
    g. I don't know
    h. Other (please specify)

29. What type of thermostat do you use to control your HVAC system?
    a. Smart thermostat that "learns" your schedule to help save energy (e.g., Nest, Ecobee, Lyric)
    b. Programmable thermostat connected to the internet
    c. Programmable thermostat not connected to the internet
    d. Non-programmable thermostat
    e. Not available / Don't know
30. What type of shading devices do you have on your windows (check all that apply)?
    a. Horizontal or vertical blinds
    b. Shades
    c. Curtains
    d. Other attachments
    e. Not available
    f. Not applicable
31. How many operable windows (e.g. windows you can open or close) does your home have?
    a. 1-2
    b. 2-3
    c. 3-5
    d. More than 5
32. When did you (or your landlord, if renting) last purchase/replace the following equipment or appliances:

	In the last few months	In the last year	In the last 2-5 years	In the last 5-10 years	10 or more years ago	Never	Not applicable	Don't know
Central heating equipment								
Central cooling equipment								
Room AC(s)								
Portable and/or ceiling fan(s)								
Space heater(s)								
Water heater								
Light bulb (or bulbs)								
Refrigerator								
Clothes washer								
Clothes dryer								

Stove/oven								
Dishwasher								

33. How regularly is your central HVAC system maintained? This refers to cleaning, replacing filters, and cleaning debris, and making minor repairs, for example.
    a. Multiple times a year
    b. Once a year
    c. Once every few years
    d. Never
    e. Not available / Don't know
34. On an average weekday over the past few weeks, how many hours between 8 AM - 8 PM was the house occupied (one or more people)?
    a. <1 hour
    b. 1-3 hours
    c. 3-6 hours
    d. 6-10 hours
    e. >10 hours
35. On an average weekend over the past few weeks, how many hours between 8 AM - 8 PM was the house occupied (one or more people)?
    a. <1 hour
    b. 1-3 hours
    c. 3-6 hours
    d. 6-10 hours
    e. >10 hours
36. Over the past few weeks, how generally satisfied have you been with the following in your home.

	Very dissatisfied	Somewhat dissatisfied	Neither satisfied nor dissatisfied	Somewhat satisfied	Very satisfied	Don't know
Temperature						
Humidity Level						
Natural Lighting						
Indoor air quality/Cleanliness						
Noise levels						
Amount of space						
Amount of privacy from others						
General quality of life						

37. Over the past few weeks, how generally satisfied have you been with the following in your home.

	Very dissatisfied	Somewhat dissatisfied	Neither satisfied	Somewhat satisfied	Very satisfied	Not applicable	Don't know

			nor dissatisfied				
Central heating/ cooling equipment							
Space heater/ Room AC(s)							
Portable and/or ceiling fan(s)							
Water heater							
Light bulbs							
Refrigerator							
Clothes washer							
Clothes dryer							
Stove/oven							
Dishwasher							

38. Over the past few weeks, how frequently have you taken the following actions?

	Never	Rarely (once or twice per week)	Sometimes (a few times per week)	Often (once per day)	Very often (multiple times per day)	Not applicable	Don't know
Adjust thermostat							
Turn on/off lights							
Turn fans (ceiling or portable) on/off							
Turn space heater/window AC on/off							
Open/close windows							
Open/close window blinds or other attachments							
Turn on/off air purifier							
Turn on/off dehumidifier							

Notify landlord/association about problems with equipment operation							

39. Over the past few weeks, during which time of day did you typically take the following actions

	Morning (6-10AM)	Mid Day (10AM-2PM)	Afternoon (2PM-6PM	Evening (6PM-10PM)	Overnight (10PM-6AM)	Not applicable	Don't know
Adjust thermostat							
Turn on/off lights							
Turn fans (ceiling or portable) on/off							
Turn space heater/window AC on/off							
Open/close windows							
Open/close window blinds or other attachments							
Turn on/off air purifier							
Turn on/off dehumidifier							

40. Generally speaking, why did you take the actions listed in the previous question (check all that apply)?
    a. To address my own discomfort (too hot or cold; reduce odors; improve light level, etc.)
    b. To address the discomfort of others in the home
    c. To save on energy bills
    d. It was convenient
    e. It was good for the environment
    f. Out of habit
    g. I don't know
    h. Other (please specify)
41. Over the past few weeks, how frequently have you and members of household used the following appliances

	Never	Rarely (once or	Sometimes (a few	Often (once per day)	Very often (multiple	Not applicable	Don't know

		twice per week)	times per week)		times per day)		
Clothes washer/dryer							
Oven/stovetop							
Microwave							
Dishwasher							
Television							
Computer							
Other miscellaneous appliances (e.g., medical equipment, humidifiers, etc.)							

42. Over the past few weeks, during which time of day did you typically use the following appliances (check all that apply)?

	Morning (6-10AM)	Mid Day (10AM-2PM)	Afternoon (2PM-6PM	Evening (6PM-10PM)	Overnight (10PM-6AM)	Not applicable	Don't know
Clothes washer/dryer							
Oven/stovetop							
Microwave							
Dishwasher							
Television							
Computer							
Other miscellaneous appliances (e.g., medical equipment, humidifiers, etc.)							

43. Over the past few weeks, which of the following actions have you taken specifically to save energy and/or money on your utility bill (check all that apply)?
    a. Raised the thermostat cooling set point temperature or turned off HVAC when the home was occupied
    b. Raised the thermostat cooling set point temperature when the home was unoccupied
    c. Opened the windows to take advantage of cooler outdoor air
    d. Closed blinds or shades to reduce heat gain from the sun
    e. Opened blinds for more natural light
    f. Used a minimal amount of artificial lighting (e.g., only local task lights, turn off lights in unoccupied rooms)

g. Reduced usage of clothes washer or dryer
h. Reduced usage of dishwasher
i. Cooking less frequently or modified the timing of cooking
j. I didn't take any actions to save energy and/or money
k. Reduce or modify the timing of laundry because I'm on TOU rates
l. Other (please specify)

44. Imagine that your local electric utility is offering a bill credit of 10% or more for temporarily reducing your energy use during certain times of day over the next few weeks. In response to this offer, how likely is it that you would adjust your normal schedules for the following:

	Very unlikely	Not likely	Neutral	Likely	Very likely	Not applicable	Don't know
Heating/Cooling thermostat set point temperature							
Lighting							
Use of portable and/or ceiling fans							
Clothes washing/drying							
Cooking							
Dishwashing							
Use of TV, computer, or other electronics							
Cleaning (e.g., vaccuming							

A.3 Summary of reviewer comments on EcoBlock survey drafts

In early March 2021, the survey drafts were distributed to five subject matter experts for review and feedback. The reviewers were also provided with a general description of the project, key research questions, and plans for deploying the surveys, and were instructed to assess the survey instruments with that broader project context in mind.

Here we provide information about the reviewers that were included in this exercise and list specific points of feedback. Additional edits were made to the survey drafts themselves, which are found here and here.

Name: Elizabeth Hewitt
Title: Assistant Professor
Institution: Stony Brook University
Email: elizabeth.hewitt@stonybrook.edu

Bio: Dr. Elizabeth L. Hewitt is an Assistant Professor of Energy Policy at Stony Brook University. Her research focuses on the technological, social, and policy-based challenges surrounding energy consumption in the built environment. In particular, she teaches, publishes, and conducts research on occupant behavior in green and conventional buildings, the role of values and norms in shaping energy and environmental behavior, and the technological and policy approaches to addressing demand-side energy consumption in buildings and cities. Dr. Hewitt is trained as an urban planner and social scientist, and received her PhD from the Bloustein School of Planning & Public Policy at Rutgers University. Her doctoral studies were funded by a National Science Foundation (NSF) IGERT fellowship for interdisciplinary energy research. Prior to her doctoral studies, she worked for a number of years as an urban planning practitioner, and has been involved with various policy and planning projects in New York City. From 2006-2010 she worked at the Alliance for Downtown New York, the largest business improvement district in North America, where she led the organization's green building research and policy initiatives.

She is LEED-accredited by the United States Green Building Council. Dr. Hewitt also holds a Master of Urban Planning (MUP) degree from New York University and a Bachelor of Fine Arts degree in Interior Design from the State University of New York.

Comments:

Technology choice survey

- Welcome page: These should be swapped (e.g. if no one else in the household has participated yet, they should proceed, not exit the survey.
- Question 11:This sounds too similar to choice (a). I would differentiate the wording of (a) to make it clear one is regarding current costs and the other is regarding potential future costs OR they could be combined into a single measure.
- Question 24: Might also be useful to include a question or two that asks solely about environmental attitudes/values. That would allow you to see if there are divergences between respondents' concern for the environment and their willingness to make improvements.
- Question 26: Same comment as above -- and do they care if friends/family notice?

Operational behavior survey

- Question 10h: I would separate N/A and don't know. Perhaps put "NA/None" for people who have no window treatments and "don't know" for people who are unsure. It might be important for energy purposes to be able to differentiate those respondents who have nothing in the windows.
- Question 13: I added some language to (a) because choices a & b could be seen as the same/very similar to people who are unfamiliar.

Name: MaryAnn Sorensen Allacci
Title: Director for Projects for Environmental Health, Knowledge, & Action, Inc., Instructor
Institution: NYU and FIT

Email: maryannsa@optonline.net

Bio: MaryAnn earned her Ph.D. in Environmental Psychology from the Graduate School and University Center at CUNY. With a specific focus on environmental health concerns, affordable housing, and social equity, she has published work on neighborhood asthma triggers, community based research, and green buildings, among other topics. She currently leads up Projects for Environmental Health, Knowledge, & Action, Inc., a non-profit research and education organization. She received her MA from Hunter College.

Comments:

General

Interesting study, Jared. I responded to the survey links and a few thoughts on the overview description:

- Block level housing types & socio-economic characteristics will be important to characterize completely, e.g., will these be renters, homeowners, co-op, SFH, multifamily buildings. Also condition of the neighborhood, e.g., density, in-transition, older, gentrified.
- It may be important to know if the individual household characteristics and variable properties are relevant to block-level features to avoid threats to validity such as ecological fallacy and atomistic fallacy.
- I appreciate the protocol allows for multi-methods of interviewing.
- Pre- and post covid reflections will be important, as you probably recognize, as well as neighborhood retail access.

Technology choice survey

- Welcome page: This assumes purchases are made. Someone with very low income or who is a renter may not see the term "home improvement" as relevant to them. it's a catch word. perhaps break it down to something like, 'The questions below are about what residents do or purchase to improve the function and comfort of their homes'. I saw your note about 'pop-up explanation', so you don't want to lose their interest in the first paragraph. OR, eliminate the first paragraph altogether, maybe add 'energy efficient AND home improvement...' and if the person does not see themselves purchasing items they think a intended by the term EE? you might provide some examples, LED or fluorescent lamps, appliances, solar panels, insulation, etc.
- Question 9: Again, this is a loaded social construction - break down the term into what you really mean.
- Question 13: I don't know all of what dimensions of EE purchases you're considering, but most of these are biased toward building owners. Renters might consider heavy window treatments, EPA Energy Star microwaves, AC / fans (ceiling?), space heaters, etc. Are all windows assumed to be operable?

- Question 15: This Q begins to get at some measure of social norm, but maybe also include a question that asks if they care if their neighbors know/see what improvements they make, or if they are influenced by what their friends/family do (not just how many acquaintances).
- Question 25: probably not relevant to renters...or maybe in a negative way if rent increases.

Name: Jennifer Senick
Title: Executive Director
Institution: Rutgers Center for Green Building
Email: jsenick@rutgers.edu

Bio: Jennifer Senick, PhD, is Executive Director of the Rutgers Center for Green Building at the Edward J. Bloustein School of Urban Planning and Policy Development, Rutgers University, and an instructor in the department. An experienced urban planner, Dr. Senick received her PhD. in Planning and Public Policy from Rutgers, her M.A. in Political Science from UCLA, and her A.B. in Government from Bowdoin College. Areas of expertise include sustainable development, green building and environmental behavior. Current appointments include Environmental Design Research Association (EDRA), co-chair Sustainable Planning Design and Behavior Network; coordinator International Health Planning and Impact Assessment Initiatives, American Planning Association (APA) International Division; executive committee, American Planning Association-NJ Chapter; facilitator, NJ Health Impact Collaborative; invited member, Rutgers Sustainability Committee and Rutgers Energy Institute.

Comments:

Technology choice survey

- Welcome page: If your IRB permits, I would move this sentence to top - see above.
- Welcome page: Rewrote this paragraph but guessing too late per IRB approval
- Welcome page: “issues related to” with “more information on”Since you are conducting surveys seasonally maybe ask for average monthly energy bill in winter/summer. Not the same difference as in NJ of course but to better match your research design.
- Welcome page: Is "Oakland EcoBlock" already an identifier for participants in this survey?
- Question 6:Since you are conducting surveys seasonally maybe ask for average monthly energy bill in winter/summer. Not the same difference as in NJ of course but to better match your research design.
- Question 11: I'm wondering if it is important that we call the equipment/alliances "energy consuming" in these questions since this is not what what will tell us whether EE characteristics impact decision to buy vs the answers to this question. Ditto other questions.
- Question 11: Long list. Could they first check all that apply and then rank?
- Question 19: A bit of a leading question but I haven't thought of a better alternative yet w/out changing the repeated format of the series.
- Question 19: Well, you could change to how much do you think the following EE home improvements cost?
- Question 20: What impact would installing the following EE have....
- Question 23: What impact would these have…

- Question 24: Same
- Question 25: Same

Operational behavior survey

- Welcome page: Generally we don't need to give participants all the technical details just what to expect on their end. I suspect your participants are well educated, but we are instructed at Rutgers to write for a 4th grade literacy level!
- Welcome page: Does your IRB require the "as possible" qualifier on "confidential". Rutgers does not. It feels ambiguous so if you don't need it suggest to eliminate that phrase here and other survey.
- Question 9: Whoops! I just resolved/deleted Ted's very good comment about seasonability and am not succeeding in getting it back! Agree w/ him that we need to specify the season or something like last 3 months. I was trying to respond to it!
- Question 10f: An option is to use RECS wording for these questions if not too clunky. Another is to use a photo app but that's a complication you may not want to endeavor now and probably doesn't have enough value for you. We are using it in an energy code compliance baseline in NJ (belongs to NMR, consultant). In this case, it matters a lot that the info is accurate.
- Operational Infrastructure and Availability (heading): You may want to consider asking in the 2nd survey if there have been changes, w/o going through the whole series of course.
- Question 14: I recognize the intent - same as the work Handi was involved in at Rutgers re locus of control and negotiated status, albeit in commercial office settings. Not sure what we gain here? It may be possible to eliminate this series and just include a "cannot adjust" in a series below about actual actions taken. Conversely, if we really want to establish the possibly contested or dynamic nature of these settings we need a different mechanism.
- Question 17: May want to define as something like "cleanliness of air" but more typically this would be broken out into whether stuffy, drafty, odors etc. I added Humidity after Temperature (previously thermal comfort). If you will promote electrification, IAQ is important. Especially when we changed to induction stove top we improved IAQ, although frying in oil and cooking meat remain problematic. At least, we got rid of NO_2! Also relevant to weatherization measures.
- Question 18: How will these answers be used?
- Question 19: Suggest adding cannot adjust/operate from earlier series and eliminating that one
- Question 20: For agent based modeling (Handi)?
- Question 24: I can't remember if "set point" is earlier defined? Maybe do so w/ words and an illustration
- Question 25: Admittedly a threshold complicates things, but lack of one creates too much ambiguity and thus makes its difficult to interpret responses.

Name: Angela Sanguinetti

Title: Research Ecological Behaviorist
Institution: UC Davis
Email: asanguinetti@ucdavis.edu

Bio: Dr. Sanguinetti earned a B.S. and M.S. in Psychology, with an emphasis in Behavior Analysis, from CSU Stanislaus, and a Ph.D. in Planning, Policy and Design, with an emphasis in Design-Behavior Research, from UC Irvine's School of Social Ecology in 2013.

Her research interests center on how the design of the built environment, including our communities, homes, and vehicles, impacts our behavior and well-being. She directs the Consumer Energy Interfaces Lab and brings her behavioral expertise to projects with the Plug-in Hybrid Electric Vehicle Research Center, 3 Revolutions Future Mobility Program, Western Cooling Efficiency Center, Center for Water-Energy Efficiency, and Energy & Efficiency Insitute. Dr. Sanguinetti is also Director of the Cohousing Research Network, which seeks to increase the impact of research establishing the personal, societal, and environmental benefits of living in collaborative neighborhoods.

At UC Davis since 2014, she has worked on over 20 research grants and authored over a dozen peer-reviewed journal publications.

Comments:

General

I'll attach a paper based on a survey I did about consumer perceptions of smart home products. It is relevant to the recommendation I made about needing to define the technologies before gauging people's perceptions if they are not familiar with them. We went as far as making infographics for each technology. You might also choose to just not ask about perceptions of technologies that respondents say they've never ever heard of.

Technology choice survey

- Question 8d: Are these select all that apply? What if someone has solar water heating with a gas backup?
- Question 11 and 12: 11 and 12 are going to be tricky for some people to answer for several reasons. First, "energy-consuming equipment and appliances" is very broad and you haven't provided any specific examples to make it concrete, so some people may not know what to be think. Also, since this is such a broad category, you might have some people answering with solar panels in mind and others thinking about a new sound system. I'm assuming you're more interested in the former. Finally, ranking this many items can be tedious and awkward, especially with a question that is not super specific. Possible solutions include providing a list of the types of retrofit measures you want them to be thinking about (this would help provide more context for earlier questions as well so it could be placed near the top). Another possibility is to ask them to select items on that list that they have considered or purchased and then ask about motivations and barriers—this way the questions may be easier for them to answer and you will know what they are thinking about when they answer so your interpretation may be better. Finally, instead of ranking you could consider having them select their top three motivations and barriers.

- Question 11j: This could be more specific—I think you are trying to get at whether someone values having the latest or cutting edge technologies
- Question 12b: Or trustworthy
- Question 13: But haven't done in own home ? Otherwise this would need to be select all that apply
- Question 14: Only for those they've heard about before
- Question 15: Needs a not sure option since insulation and some of these other things are not a common conversation topic even among close relations. Also few v. some doesn't seem like a good distinction. Maybe "one or two" v "some"
- Question 16: Maybe add the term rebates since that could be a more familiar way to talk about it
- Question 18: Hopefully you're doing this with survey logic and not giving two different questions at once

Name: Ted Lamm
Title: Senior Research Fellow
Institution Center for Law, Energy & the Environment
Email: tlamm@law.berkeley.edu

Bio: Ted Lamm is Senior Research Fellow in the Climate Program at CLEE. Ted's research focuses on California climate change law and policy and the relationships between other areas of policy and the achievement of California's climate change-related goals. His recent work has centered on climate change, insurance and financial risk; electrical grid decarbonization and resilience; and electric vehicles and transportation policy.

Prior to joining CLEE, Ted practiced both environmental law and corporate law in New York City. At New York University School of Law, where Ted received his J.D., he was the symposium editor of the Environmental Law Journal and participated in the NYU/NRDC Environmental Law Clinic. Ted received his A.B. in English and Economics from Brown University. He has been admitted to the California, New York, and D.C. Circuit bars.

Comments:

Technology choice survey

- Question 9: For non-resident owners, is this number meant to be per unit?
- Question 11 Assume this should be "major energy consuming-equipment"?
- Question 12: Consider adding an option like "don't need to upgrade at this time" or "don't want to replace until necessary"?
- Question 21: Prior questions use a "do you think" construction - is the shift here intentional?

Operational behavior survey

- Welcome page: Energy Commission?
- Question 1: For non-resident owners, clarify whether asking for home/mailing address or block address?
- Question 3: Should # of housing units be included within this question, or as a separate question?

- Question 7:"in general" seems potentially problematic to answer for a multi-member household. How would you characterize a household with an unwell elderly grandparent and multiple children in fine health? Consider adding an answer to reflect a "some poor, others good" type of possibility?
- Question 8:Could this be better presented with a complete list of options, under question "who pays your utility bills?": a) you, b) another member of household, c) landlord, d) other [explain]
- Question 8: May be worth explicitly spelling out "utility (i.e. electric, gas, and water) bills"
- Question 9:See above: spell out "energy (electric and gas)"?
- Question 10d: Is this meant to include all room types, or just bedrooms? Either way, may be helpful to clarify since some respondents may just give # bedrooms.
- Question 10e: Add clothes dryer?
- Question 10g: Clarify that this includes windows-in-doors, skylights? And excludes interior windows?
- Question 11: or your landlord
- Question 11: Consider splitting these responses, so respondents can be clear about equipment they don't have vs. equipment they have but don't know the age of.
- Question 11: This could be categorically different from the other appliances, since many respondents will likely have a mix of bulb ages and types in their homes and replace them as needed.
- Question 14: Should this include ceiling fans?
- Question 14: Consider adding cooking stove vent/hood?
- Question 15: Consider "one or more people" to clarify that a single occupant qualifies?
- Question 17: Consider moving this question to the end of the list - QoL can encompass a lot more than the quality of indoor home environment, and putting it first might be disorienting. Putting it after thermal comfort, AQ, etc. will help focus respondents on these issues. Or consider being more explicit about something like "overall indoor home environment"
- Question 19: Should this include ceiling fans?
- Question 21: Consider expanding on what is meant by discomfort? Temperature, odors, light level, etc. Some may not consider baseline thermostat adjustment in winter to be a matter of "discomfort"
- Question 22: You or members of your household? Thinking about households with multiple computers/TVs going simultaneously, particularly in the last year.
- Question 22: Consider adding an "other" category for any major energy users that don't fit the main categories? Thinking about medical baseline equipment, possibly others.
- Question 23: Assume this will be a "check all that apply" response.