Simplifying Energy Efficiency for Homeowners – Results from a California Utility's Pilot Study of a Scalable Solution to Assess Retrofit and Solar Opportunities

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Simplifying Energy Efficiency for Homeowners – Results from a California Utility's Pilot Study of a Scalable Solution to Assess Retrofit and Solar Opportunities

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ABSTRACT

For homeowners, typical choices to reduce net energy use in their homes include: upgrading their home with a tailored efficiency retrofit or investing in roof-top solar. Determining the unique combination of these options that will provide the most cost-effective solution requires analysis for each home. This analysis needs to be presented in a simple and actionable way to homeowners. The solution should also be easily scalable to thousands of homes to enable utilities to better target efficiency program options and support solar installations.

Sacramento Municipal Utility District (SMUD) piloted a new tool developed by Vistar Energy called XeroHome™ which automates the assessment of energy efficiency and solar opportunities in existing homes. XeroHome demonstrates an approach to using building energy modeling, energy use data analytics and homeowner engagement to identify and target energy efficiency opportunities at scale.

XeroHome uses automation to build an EnergyPlus™ model for each home, based on information from public data sources such as property assessment records, building permit records, aerial/satellite photography, and template models derived from ResStock™. Utilizing cloud computing, machine learning and optimization algorithms, energy upgrade packages are ranked by cost-effectiveness for each home and presented over an interactive web-portal.

This paper discusses SMUD's pilot project using XeroHome to conduct analysis for 1,500 existing homes in Sacramento, CA. Development of XeroHome's advanced analytics capabilities are discussed in the context of applicability for utility programs.

Opportunities and Obstacles in Residential Energy Retrofits

According to a recent study on the U.S. building energy efficiency market size (Rockefeller Foundation and Deutsche Bank CCA 2012), existing residential buildings represent a staggering 80% of the total U.S. building floor area. Further, about 50% of the energy savings potential from the entire building sector can come from single-family residential buildings alone (Figure 1). Another study by NREL (Wilson, et al. 2017) estimates the economically achievable energy savings potential from single-family residential buildings in U.S. to be 245 terawatt-hours (TWh), which amounts to 6.3% of total U.S. electricity consumption. This makes single-family homes a prime opportunity for energy efficiency programs nationwide. However, the diversity and fragmentation in the single-family residential segment makes it difficult to develop and promote energy efficiency programs at scale.

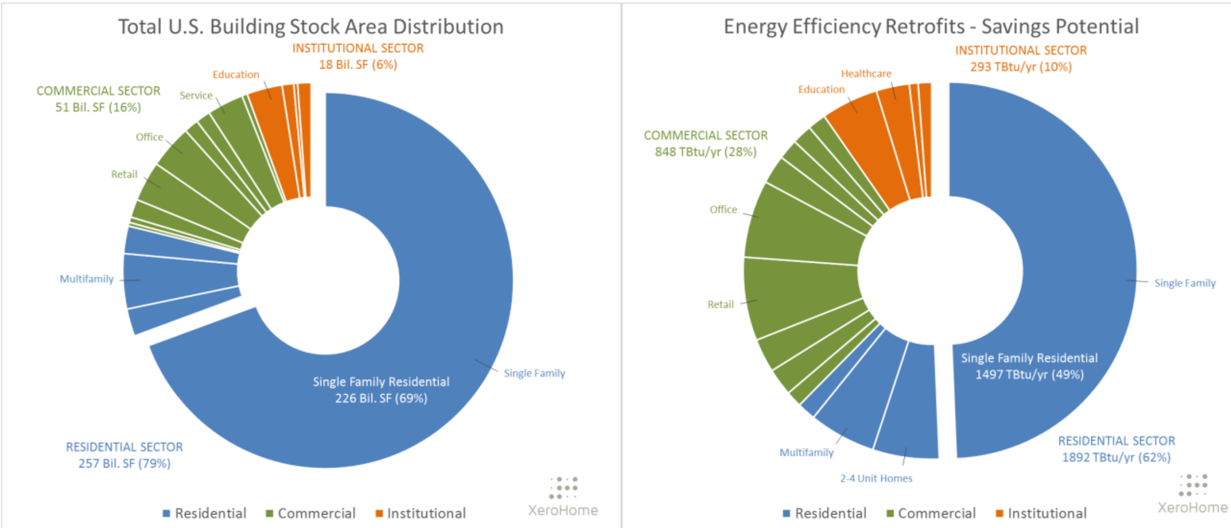

Figure 1: US Building Stock Analysis (Rockefeller Foundation and Deutsche Bank CCA 2012)

Understanding which energy efficiency measures will be effective for a specific home, or for groups of homes, can take time, and requires detailed analysis. Whole-house energy improvement programs have traditionally relied on detailed on-site energy audits to identify energy upgrade opportunities. However, that approach takes time, requires specialized skills, and importantly – cannot be scaled quickly to large geographical areas. A simpler but much less accurate alternative that is sometimes used, is to rely on crude assumptions based on home age and location for identifying retrofit opportunities. Utilities, local governments, and technology vendors that need this targeting information for their programs and products are left with essentially two unappealing alternatives. One provides sufficient rigor in analysis, but is expensive, labor-intensive and does not scale well, while the other is defeated by the lack of detail in oversimplified assumptions.

Building Energy Modeling Based Assessments for Existing Homes

Building energy modeling (BEM), using a whole building energy simulation tool like EnergyPlus, can be an effective approach to providing accurate and reliable assessment of energy retrofit and solar opportunities for existing homes, provided that quality information is used to construct the models (avoiding “garbage in, garbage out”). In the past, this proviso has generally required on-site energy audits to inform the modeling. However, we are now entering an age of data availability that makes the process plausibly automated.

An alternate approach has been to use utility billing analysis and data analytics with smart meter (or AMI) data to gain insights into existing energy use patterns. This approach can provide some degree of end-use data disaggregation and is relatively easier to scale for the existing building stock. While the approach has been shown to be useful in detecting certain end-uses with high energy use, with varying degrees of certainty, its usefulness in evaluating cost-effective energy efficiency retrofit and solar alternatives is notably limited (Kupser, et al. 2016). This is mainly due to the lack of an energy model in which alternate efficiency measures and packages of measures can be simulated. The approach is most suited to development of behavioral programs and providing measurement and verification applications that track changes in pre and post-retrofit performance.

BEM tools such as BEopt™ and more recently OpenStudio®, from National Renewable Energy Laboratory (NREL), have simplified and expanded usability of EnergyPlus as a simulation tool for existing buildings. More recently NREL developed a large-scale simulation-based residential energy analysis tool called ResStock, that provides highly granular modeling of the U.S. housing stock. Using advanced statistical sampling techniques, the ResStock team developed a comprehensive set of EnergyPlus template models that represent the vast variety of age, size, construction practices, and equipment in the U.S. housing stock. The resulting data set has provided deep insights into potential savings opportunities across multiple states and regions in the U.S. (Wilson, et al. 2017). This dataset can be used by policy makers, program designers and manufacturers to identify cost-effective improvements in a particular state or region, as well as help identify customer segments for targeted marketing and deployment.

XeroHome

The recent developments in batch processing and parametric analysis using EnergyPlus, OpenStudio, and ResStock's development of template models, have opened many possibilities for BEM-based analysis of existing homes. XeroHome is a targeting and outreach tool developed by Vistar Energy that leverages these advances to address the needs of targeting and engagement for utility programs.

XeroHome uses automation to build EnergyPlus models for individual homes and find the most cost-effective way to reduce energy use for a home. The energy models are developed based on information about a home from public data sources, supplemented initially by reasoned assumptions. Data sources such as property assessment and building permit records provide key data on when the home was built and dates when major components of the home were upgraded. These are then cross-referenced with expected efficiencies of various components of the home, based on historic energy codes, which form the inputs for the base energy model. Further, aerial/satellite photography and remote sensing data is used to develop a 3D model, complete with attributes such as tree shading and window areas. Utility bill data, if available, is used to calibrate the energy model. Energy model annual simulation outputs and energy efficiency measure (EEM) cost data are then used to find the most cost-effective way to use retrofits and solar PV installations to lower energy use and ultimately reach annual zero-net energy (ZNE). This information is presented as a "Path to Zero-Net Energy" that starts with the current building and ends with a zero-net energy version of the building. Homeowners can pick any point in-between as their ending point.

This whole process is completely automated, which allows XeroHome to scale the development of energy models for homes rapidly. XeroHome employs a number of innovative techniques such as machine learning to perform the EEM-selection optimization in a computationally tractable and scalable manner. XeroHome also extensively uses distributed cloud computing that compresses the time required to return results. Analysis using the energy models provides the preliminary – also called "white-level" – results, which are presented over an interactive web-portal to a homeowner.

Leveraging Homeowner Engagement to Increase XeroHome's Analysis Accuracy

A central feature of XeroHome's design is its engagement with the homeowner. Through XeroHome's web-based interface, a homeowner will initially be able to access their home's 'white-level' analysis results using just their home address. The entire set of upgrade recommendations are provided to them in the form of an easy-to-follow “Path to Zero-Net Energy”. The path is a visually engaging and interactive way to convey key information to homeowners about which energy retrofit options maximize their home energy improvement investment.

Leveraging this engagement with the homeowner, XeroHome provides a way to incrementally increase accuracy and reduce the uncertainty of its analysis. It provides homeowners, as well as professional energy auditors, a means to enter on-site observations and energy audit data for a home. As users enter this data, it is used internally to replace most of the assumed inputs in the home’s ‘white level’ analysis energy model. The energy simulations are then re-run to update results. As more on-site observed or measured data is provided, uncertainty around the initial ‘white level’ analysis decreases. This is conveyed to the homeowner in terms of progressing colored badges associated with the analysis. The colors indicate increasing level of accuracy – going from an initial ‘white level’, to ‘green level’ and ultimately a ‘blue level’ analysis. To achieve a ‘blue badge’ would require detailed data on multiple inputs, which will likely require a professional energy audit in most homes.

To aid this process, XeroHome creates a prioritized list of questions, based on the relative ease of collection and value of that piece of information in decreasing the uncertainty in the results. This unique step allows users to focus data collection efforts on the information that is more likely to impact the EEM recommendations. The questions and badges also introduce a level of “gamification” to the process of data collection and survey, which otherwise is thought of as a barrier for such applications.

Achieving this interaction and engagement from homeowners is an important attribute of the XeroHome tool. As a tool for utilities that want to increase program participation and connect with customers, XeroHome provides a platform for finding and engaging with those customers. Since these are homeowners that are already well-informed and engaged, they are also more likely to act.

SMUD Pilot with XeroHome

Sacramento Municipal Utility District (SMUD) piloted XeroHome’s approach to assessing energy retrofit and solar opportunities for 1,500 single-family residential customers in the North Franklin community in Sacramento, CA. For these customers, which represent a disadvantaged, low-income community, SMUD needed energy evaluations to determine which of its program offerings were best suited to individual homes. SMUD offers rebate programs for several energy upgrades as well as a whole-house bundled approach with its Home Performance Program. SMUD also offers a community solar program called SolarShares that offers its customers the opportunity to access solar power without upfront costs or equipment installation.

SMUD had a particular goal to determine which energy efficiency opportunities were most cost effective for these homes, and the best opportunities to reduce customer bills while increasing access to solar energy, particularly participation in the SolarShares program.

Utilizing the XeroHome tool, the analysis focused on answering these two key research questions:

1. What is the potential energy savings from cost-effective energy efficiency measures (EEMs) offered by SMUD residential programs for these 1,500 homes?
2. Within the 1,500 homes, which EEMs show up most often as being cost effective? Are there EEMs that SMUD’s Programs should be offering that they currently do not?

Data Acquisition for North Franklin Community

The area of North Franklin in Sacramento is a 2.3 square mile stretch of residential area, located south of downtown Sacramento. To begin the process of analyzing these homes, XeroHome acquired property assessment data from the Sacramento County assessor's office and building permit records from the City of Sacramento for the 1,500 single-family homes.

From the county records two key pieces of information obtained were: Each home's year of construction (year built) and size (area in square feet). A distribution of the homes' year built and home size is provided in Figure 2. The distribution shows that most homes in this community were built between 1940 – 1960, and are between 750 sf to 1,500 sf.

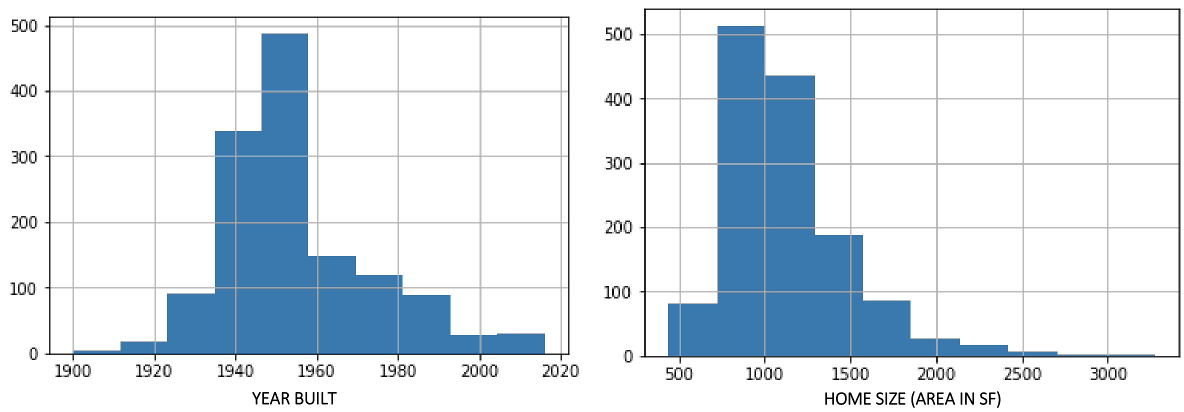

Figure 2: Distribution of Homes - Year Built and Home Size Area

Building permit records provide a unique insight into major changes that a home has undergone such as re-roofing, window replacement, HVAC or water heater change outs, etc. Of the 1,500 homes in North Franklin community, about 70% of the homes had at least one building permit on record. The building permit data was divided into 11 categories. Figure 3 shows the percent of homes with building permits for each category.

The property assessment data from county records and building permits were then used to look up expected efficiencies of various components of each home, based on historic California Title 24 energy codes. The expected efficiency provides a close approximation of what may have been installed when the home was built or when its components changed.

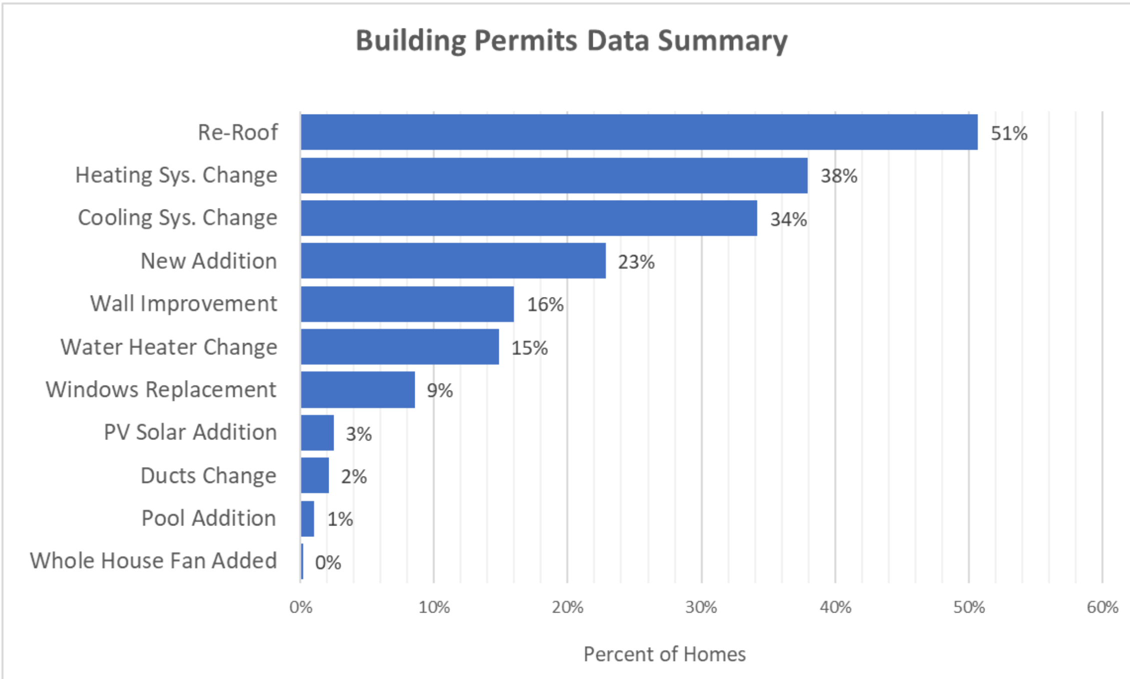

Figure 3: Percent of Homes with Building Permits for Each Category

The energy models were refined using 3D geometry and local shading from aerial/satellite imagery and 3D remote sensing tools acquired from various commercial data sources. As shown in Figure 4, the extracted home models have a high enough level of detail to determine wall and roof areas and their orientations. XeroHome uses this data to generate a 3D model in EnergyPlus for each home, adding contextual shading from trees, as shown in Figure 5.

Figure 4: 3D Geometry for Homes from Remote Sensing and Satellite/Aerial Imagery Datasets

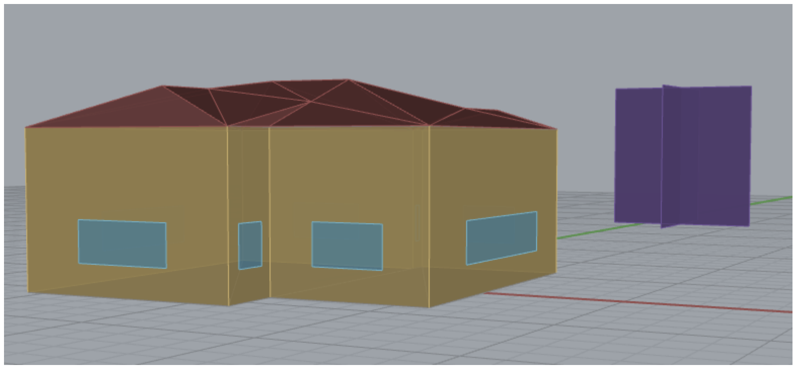

Figure 5: 3D Model in EnergyPlus - Tree as Shade Element Modeled Behind the Home

Base Model Development and Parametric Simulation

With the 3D geometry and various component efficiencies in place, XeroHome completes the EnergyPlus model using reasoned assumptions for the remaining inputs. A well-thought out set of default assumptions have been developed for any input parameter that does not have a reliable data source, such as occupant schedules, plug load profiles, equipment set points etc. For this XeroHome leverages the extensive work done by NREL on the development of ResStock and its residential template EnergyPlus models, that are designed to represent homes of certain vintages and geographical locations (Wilson, et al. 2017).

Given a base building model and a set of possible EEMs, XeroHome then runs parametric simulations and optimization to develop a "Path to Zero-Net Energy" for each of the 1,500 homes. The optimization problem is similar to that faced by NREL's BEopt tool. The BEopt model (Horowitz, et al. 2008) provides some precedence and grounding to that of XeroHome's. However, there are two constraints that are unique to XeroHome: The need for fast (almost real-time) execution of the optimization step to support homeowner engagement over its web-portal, and scalability to present analysis for multiple homes. To accomplish this, several innovations have been applied including the use of machine learning to develop a fast-running approximation to the EnergyPlus model for each building. This approach has shown to increase computational efficiency, providing near-real-time capabilities, and is more effective at rapid scaling of the optimization process from one to multiple homes.

Parametric Analysis

In the parametric analysis step, XeroHome applies various combinations of 12 EEMs and one Roof-Top Solar measure to the energy models. These 12 measures represent typical single-family retrofit options available to homeowners. They covered measures offered by SMUD's Home Performance Program, as well as a few not currently provided by SMUD's program.

For each EEM, XeroHome models a range of efficiency options that cover products available in the market (see Table 1). XeroHome is unique in its use of EnergyPlus for its base model simulations, which allows it to model EEMs with a high level of accuracy to represent the differences in efficiencies of actual products. For example, XeroHome models the EEM of 'Improve Ceiling Insulation' for a range from U-factor 0.227 to 0.016 Btu/hr-sf-F. Within this range are 8 efficiency options ranging from R-0 un-insulated wood frame attic to R-60 with fiberglass insulation. The parametric analysis considers all possible options for a home - going from its initial base condition, to higher efficiency option for each component.

Table 1: Summary of Energy Efficiency Measures Modeled

Energy Efficiency Measure (EEM)	Efficiency Range (Min-Max)	Number of Efficiency Options Modeled
Replace Lighting	Avg. lm/Watt - Range (15 - 80)	7
Replace Water Heater	Energy Factor - Range (0.59 - 0.95)	5
Weatherization	ACH at 50Pa. Pressure (25-1)	12
Install Whole House Fan	(Yes/No)	1
Improve Ceiling Ins.	U-Factor Range (0.227 - 0.016)	8
Replace Furnace	AFUE - Range (0.6 - 0.98)	12
Install Radiant Barrier	(Yes/No)	1
Seal Ducts	Duct leakage % - Range (30% - 7.5%	5
Replace Central AC	SEER - Range (8 - 24.5)	11
Insulate Ducts	R-Value - Range (0 - 8)	4
Improve Wall Ins.	U-Factor Range (0.25 - 0.065)	8
Replace Windows	U-Factor Range (1.16 - 0.17)	25

U-Factor (Btu/hr.sf.F)	R Value (hr.sf.F/Btu)	Improve Ceiling Ins. Efficiency Options
0.227	4.4	Uninsulated, Vented
0.091	11	Ceiling R-7 Fiberglass, Gr-1, Vented
0.059	16.9	Ceiling R-13 Fiberglass, Gr-1, Vented
0.044	22.9	Ceiling R-19 Fiberglass, Gr-1, Vented
0.029	33.9	Ceiling R-30 Fiberglass, Gr-1, Vented
0.024	41.9	Ceiling R-38 Fiberglass, Gr-1, Vented
0.019	52.9	Ceiling R-49 Fiberglass, Gr-1, Vented
0.016	63.9	Ceiling R-60 Fiberglass, Gr-1, Vented

Results from XeroHome Analysis of North Franklin Community

The analysis form XeroHome provides insight into the retrofit opportunities for homes in the North Franklin community. In this phase of the work, the analysis completed for the 1,500 homes, was a "white-level" analysis, in that the analysis was not updated for individual homes with audit data or on-site observations. Rather, the models were developed based on data acquired from county records of property assessments, building permits and 3D geometry as described earlier. The goal of the analysis was to answer key research questions for SMUD, as discussed earlier.

Most Common Cost-Effective EEMs

From the full set of analysis for all 1,500 homes, EEMs and roof-top solar recommendations from each home's "Path to Zero-Net Energy" were ranked by pay-back period. EEMs with a payback period of less than or equal to 5 years were identified and the frequency with which they appear in our analysis set of 1,500 homes is shown in Figure 6. While analysis was done for other payback periods (of 10 and 15 years), for sake of brevity only results from payback period less than or equal to 5 years is presented in this section. To calculate payback, the cost, including purchase and installation of the measures, is divided by the first year of savings, both in present dollars. Costs for all the EEMs and the cost of energy were developed in close collaboration with SMUD to represent the cost for SMUD customers and the Sacramento, CA region.

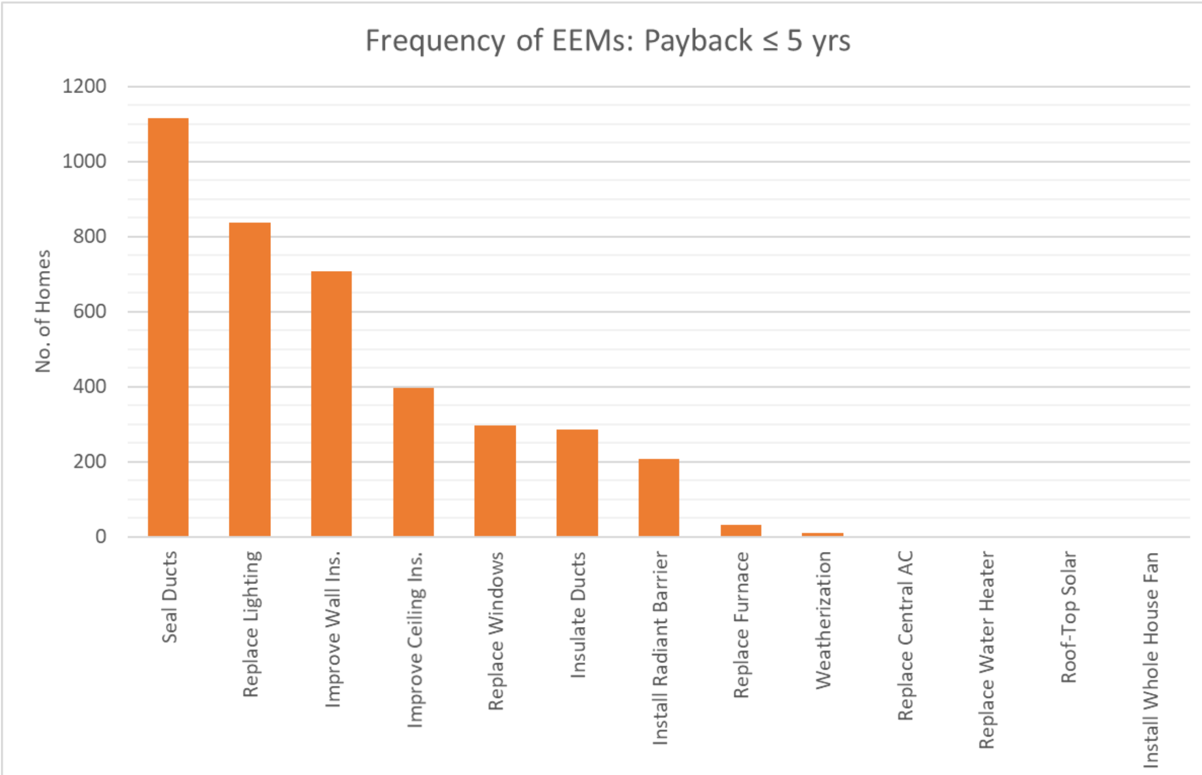

Figure 6: Frequency of Occurrence of Cost Effective EEMs

Figure 6 shows that 9 of the 13 measures considered were cost effective in at least one home in the analysis set. Four measures, namely 'Replace Central AC', 'Replace Water Heater' and 'Install Whole House Fan' and 'Roof-Top Solar' did not show a payback ≤ 5 years. For most homes, more than one measure that had a payback ≤ 5 years.

The analysis showed that the 'Seal Ducts' measure appeared more often than any other measure in the homes with payback ≤ 5 years. This is not surprising, since duct sealing can be relatively cheap, and can have sizable savings. This is followed by 'Replace Lighting', which like the seal ducts measure, is relatively low cost as it does not include labor costs for installation (as it is assumed to be done by the homeowner). These are followed by envelope measures of 'Improve Wall Insulation', "Improve Ceiling Insulation' and 'Replace Windows'. Since most of the homes in this analysis set are older homes, with the majority built before energy codes existed in California (between 1940-1960 - see Figure 2), the initial conditions assume thermally inefficient walls, ceilings, and windows. The few exceptions were homes that had building permits showing upgraded envelope components. Thus, improving these components to even slightly better efficiency, results in substantial energy savings, giving them a payback ≤ 5 years.

Interestingly, 'Install Whole-House Fan' measure did not show up in homes as having payback ≤ 5 years, and 'Weatherization' only for a few homes. This is a result of very low energy savings from these two measures (as discussed in the next section). 'Roof-Top Solar' also does not show up in homes having payback ≤ 5 years, as the high cost pushes its payback closer to 10 and 15 years.

Energy Cost Savings from All EEMs

Figure 7 shows the annual energy savings range for all EEM across all 1,500 homes. This graphs represents energy savings regardless of the EEM's payback. The bars represent 1st and 3rd quartile results while the end of the lines show Min and Max savings. Note that while Figure 7 shows energy savings from each EEM, the order in which the EEMs appear on the X-axis is taken from Figure 6. Together the two graphs can provide insight into the which EEMs will provide high savings and be cost effective for most homes in the analysis set.

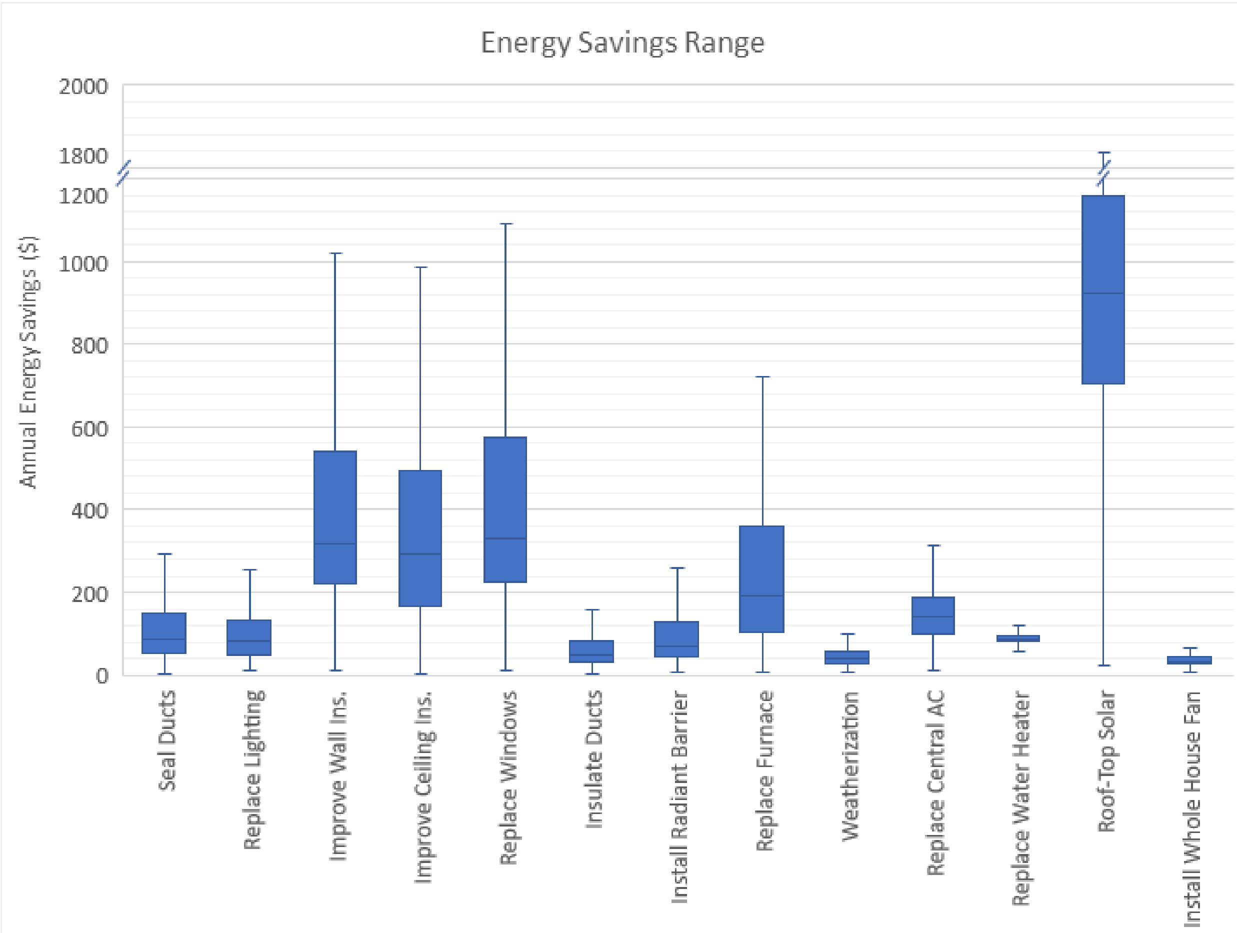

Figure 7: Savings Range for Each EEM

Figure 7 shows that besides 'Roof-Top Solar', the three envelope measures of 'Improve Wall Insulation', "Improve Ceiling Insulation' and 'Replace Windows' show relatively high savings. As explained earlier, this result is indicative of low insulation levels for envelope components as the initial condition for the older (pre-energy code) homes that make up the majority of our analysis set. Also, the savings graph shows the low savings from 'Weatherization' and 'Install Whole House Fan' measures, which result in those measures having Payback greater than 5 years.

Ability to Drill-Down to Individual Home Analysis

While these macro-visualizations of frequency and savings range of cost-effective EEMs provides valuable insights that a utility program can use to focus outreach efforts and customize program offerings, XeroHome offers a unique opportunity to go deeper beyond this level of analysis. Since XeroHome's analysis is done at the individual home level, results can be examined down to the individual home. This ability to drill down, gives a lot of power to a user to customize the analysis of that home. Through XeroHome's web interface, a homeowner can access information about their home using just their home address. Here they can inform themselves about which measures make most sense for them to invest in, by reviewing their customized "Path to Zero-Net Energy". Using the same interface, a homeowner (or an energy auditor) can tap into the energy model for that home and provide site-observed and measured data to make the assessment more accurate. As these changes are made to individual homes, the resulting macro-level analysis is automatically updated, to present more accurate data.

Conclusion

The SMUD XeroHome Pilot project demonstrated the ability of a BEM-based analytical tool to generate energy retrofit recommendations at scale, with speed and accuracy. XeroHome's EnergyPlus based analysis approach, which can be rapidly scaled through innovative use of cloud computing, machine learning and optimization algorithms, provides a solution for tackling the diversity and fragmentation in the single-family residential sector. It provides utilities with a tool to address this barrier to the large-scale development and success of whole-home improvement and energy upgrade programs.

XeroHome's ability to generate analysis for multiple homes, and then drill down to an individual home to access its custom recommendations using a simple, easy-to-use interface is finally how XeroHome can simplify energy efficiency for homeowners. The platform also gives market actors in the home energy retrofit industry – utility program administrators, technology vendors, and home energy audit professionals – access to the same data, which gives them a platform for finding and engaging with potential program participants and customers. As accurate data on energy efficiency opportunities becomes available freely for ALL homes, and to ALL market actors and decision makers, a self-sustaining residential energy efficiency marketplace can develop, which is needed to achieve the eventual goal to a lower-carbon and low-energy residential sector.

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