

Advantages of Implementing a Scalable Building Energy Model (BEM)-Based Approach vs. Traditional Energy Audits

*Mudit Saxena, Inderdeep Dhir, Vistar Energy / XeroHome
Andres Fergadiotti, Jerine Ahmed, Southern California Edison (SCE)*

ABSTRACT

Replacing natural gas water/space heating equipment in existing homes, with high-efficiency appliances including heat pumps, are critical to achieving large-scale building decarbonization goals. However, to achieve this, a compelling analysis of savings and costs must be provided for every home. The challenge is gathering information about the unique conditions of each home. Small differences, such as location and efficiency of current equipment, from one home to another can result in large variations in costs and energy savings.

Traditional energy audits with a trained professional have provided reliable estimates until now. However, this approach has resource constraints such as, cost, time, and reliance on the availability of trained professionals. To overcome resource challenges and achieve large-scale adoption, an innovative web-based, scalable, building energy modeling (BEM) based approach was evaluated that replaces the need for a traditional energy audit in most cases. Homeowners use an online portal to interact with a cloud-based building energy model of their home that can be calibrated with inputs through a virtual energy audit and recommendations updated in real-time.

This paper describes the new approach and discusses the results of its deployment in a city in Southern California. The outcomes from the BEM-based approach are compared against those by a trained energy auditor and the impacts of those differences are explained. Key advantages of a scalable BEM-based approach in providing targeting insights for utility programs, engaging homeowners, and providing guidance with actionable steps are discussed. A strategy to scale this approach for the home energy retrofit market is examined.

Need for Customized Analysis

Existing single-family homes are the largest consumers of energy among all building types and represent one of the largest opportunities to reduce GHG emissions from the built environment (Saxena, Coffey, et al. 2018). In a state like California, greenhouse gas (GHG) emissions attributable to buildings represent about a quarter (25%) of the total emissions, with more than half of those emissions coming from burning gas or propane in furnaces and water heaters in California homes (Hopkins, et al. 2018). It hence becomes imperative to switch fossil fuel-based equipment to higher-efficiency alternatives such as heat pumps powered by low-carbon electricity. Much of this can be provided in cost-effective energy upgrade packages that save the homeowner money every month on their utility bills.

However, without information about which efficiency upgrades work for their home, homeowners cannot be expected to act, leaving cost-effective energy and carbon savings unrealized. As each home is unique, home energy audits have been the only practical way to identify these opportunities and inform homeowners. However, traditional energy audits cost money, require scheduling, and cannot be scaled up quickly. Most programs nationwide have

struggled to justify the cost of energy audits weighed against the potential savings from efficiency measures (LBNL 2018), except in a small number of cases where a home undergoes deep energy retrofits. Professional energy audits performed remotely can make this process easier and cheaper, but they do not solve the bigger problem with this approach – that it is impractical to conduct an energy audit for every home.

Limitations of Existing Home Energy Assessment Options

Apart from requesting a home energy audit, homeowners have a few self-help options to obtaining customized guidance on home energy upgrades. These options and their limitations are discussed here.

- DIY energy audit tools such as Universal Audit Tool from OPower¹, have been used by several utilities to help their customers better understand energy consumption (DNV-GL 2017). These tools typically require answers to an exhaustive set of questions, before they provide energy efficiency tips based on those inputs. The main limitation of this approach is that it relies on the user (homeowner) to provide all inputs. Additionally, these tools lack the complexity and detailed energy calculation basis needed to provide larger energy upgrade recommendations, such as electrification upgrades. So they are limited to providing only simple behavior-based energy efficiency tips.
- Tools based on building energy modeling (BEM) such as DOE's Home Energy Saver² (Pinckard, et al. 2005) can estimate energy savings from various potential upgrade options for a home. While this approach has the necessary calculation basis to recommend deep energy retrofits and electrification upgrades, it requires that the user describes the home in detail and hence relies entirely on the knowledge and ability of the user to provide accurate input. Homeowners, by themselves, may not have the technical know-how to provide all inputs accurately. Home Energy Saver will use defaults for any missing input, but the tool's interface does not communicate if defaults have been used instead of user inputs, and for how many fields. This leaves the user with a high level of uncertainty on the accuracy of the output from the tool. Another limitation of this approach is that large-scale analysis for all homes in a city/region is not possible with current BEM-based tools. This is because running building energy simulations can be compute-time intensive and running a batch of thousands of homes can be prohibitively expensive.
- Lastly, using energy consumption as the basis, tools like HEA's HomeIntel³ allow users to understand where their energy is being used and how to reduce it. These tools can provide a detailed understanding of home energy use and can be a great tool for consumer education. However, they lack an energy calculation basis to estimate energy saving scenarios and cannot be used to develop estimates for large energy upgrades such as electrification upgrades.

To truly accelerate the adoption of clean and efficient energy retrofits we need a radically scalable, yet capable and cost-effective solution.

¹ Oracle Utilities (OPower): <https://www.oracle.com/industries/utilities/opower-energy-efficiency/>

² LBNL Home Energy Saver: <https://homeenergysaver.lbl.gov/consumer/>

³ Home Energy Analytics (HomeIntel): <https://corp.hea.com/hintel>

A New Scalable BEM-Based Approach

A new scalable BEM-based approach addresses many of the limitations of existing approaches discussed in the last section. Like prior BEM-based tools, this approach also uses a building energy model as the calculation basis for energy upgrade recommendations. However, three key innovations set it apart.

- Publicly available data on homes is used to make assumptions about all inputs needed to build a unique building energy model for each home. This process is automated and repeatable for all homes across an entire region such as a city or a utility territory.
- A web-based interface is used to engage with a homeowner, where they confirm some of the key assumptions in their home's energy model. This helps achieve a higher level of accuracy. Also, importantly, the homeowner is not burdened with technical questions upfront. Instead, they are asked to confirm inputs already populated, which makes it easier to use the tool.
- A cloud-based platform hosts the building energy model which is updated in real-time with homeowner input. All computations including running hourly energy simulations are performed on the cloud platform. This solves the problem of computational expense of running parametric energy simulations for a large number of homes, making it possible to provide recommendations at the scale of an entire city or utility region.

This approach provides a scalable solution with a calculation basis capable of developing savings estimate with a high level of accuracy, and recommend large retrofits like electrification upgrades. The approach was recently evaluated by Southern California Edison's (SCE) Emerging Technologies (ET) program. It's ability to leverage a rich layer of publicly available data about homes, the homeowner's ability to confirm assumptions via a web-based virtual energy audit, and the scalability with cloud computing were evaluated in the program. The approach was of interest to Southern California Edison, as it promises to:

- Eliminate the need to conduct a traditional home energy audit to develop energy upgrade recommendations.
- Generate recommendations at scale for homes across an entire city or a large region
- Provide actionable information to homeowners on energy upgrades online, so it is available when they need it.
- Engage homeowners in the development of their home's recommendations.

Santa Monica Pilot with XeroHome™

SCE's ET program evaluated this new approach by piloting the residential retrofit recommendation tool, XeroHome™ in the city of Santa Monica, California. XeroHome is a web-based tool developed by Vistar Energy (Saxena, Coffey, et al. 2018) that pioneered the new scalable BEM-based approach described in the prior section. It develops EnergyPlus™ building energy models for individual homes, which can be scaled rapidly to cover all homes in a city or larger region. XeroHome also uniquely employs a machine learning method known as surrogate modeling, that enables the tool to perform large number of building energy simulations at a fraction of the run time of EnergyPlus. This innovation makes it possible to run analysis with

these energy models across a large parametric space to find and recommend the optimal energy upgrade option or package for each home.

Figure 1 provides a graphical description of XeroHome's building energy model development process. A base EnergyPlus home energy model is developed by inferring information from public data sources about the home.

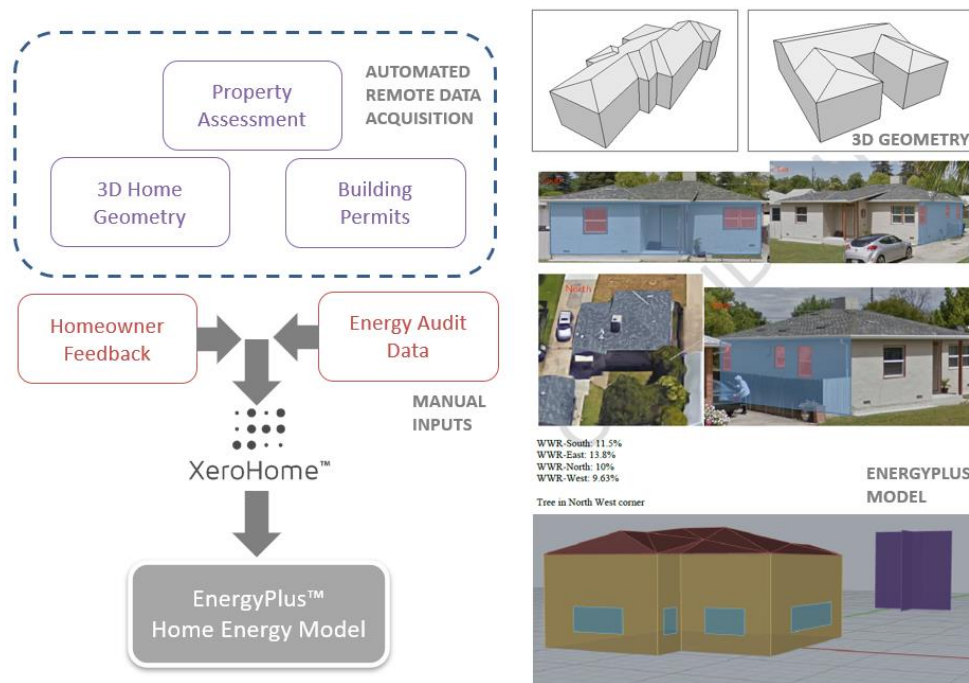


Figure 1: XeroHome's building energy model development process and example

At a minimum, the following data sources are required to build the initial energy model for a home, and they are available for most homes and cities in the U.S.:

- **Property Assessments** – Typically collected and maintained by local counties, data include year built, building area, physical characteristics like the number of bedrooms, stories, and occasionally, heating fuel type. For Santa Monica this data was obtained from the county⁴. The year built was used to infer various efficiencies of the building energy model's envelope and system component, albeit with limited certainty.
- **Building Permits** – Typically collected by the city or county planning/inspection office, the data includes the date and description of any major renovation or retrofit to the home such as rooftop solar installation, or envelope / HVAC upgrades. For Santa Monica, this data was obtained from the city⁵. Using this information, the efficiencies assigned to the envelope and system components of the energy model can be updated. Not all upgrades require a building permit, so this information is by no means comprehensive, but is incremental in improving the energy model's accurate representation of the home's actual condition.

⁴ Santa Monica Property Records Search: <https://www.countyoffice.org/santa-monica-ca-property-records/>

⁵ Santa Monica Building Permit Document Archive Search: <https://publicdocs.smgov.net/WebLink/Welcome.aspx>

- **3D Geometry** – GIS companies can provide detailed 3D geometries for buildings that they derive from satellite and aerial photography and LiDAR (Light Detection and Ranging). This data provides surface areas and orientations to the home’s energy model, as well as an estimate of the roof areas available for solar energy production.

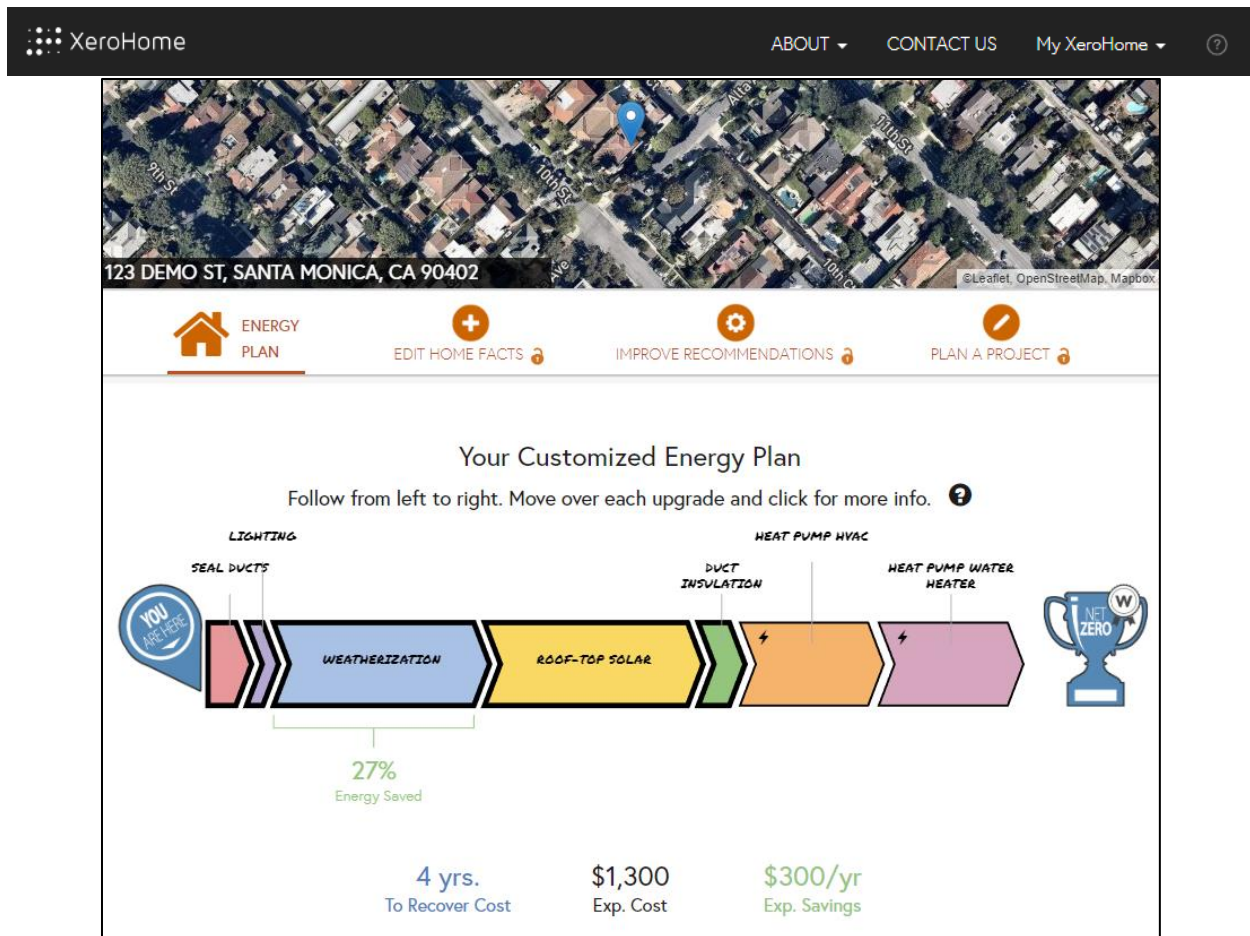


Figure 2: XeroHome’s homeowner facing user interface (<https://my.xerohome.com/>)

XeroHome provides a homeowner-facing web-based front end (Figure 2) – <https://my.xerohome.com/> where a homeowner can access their home’s recommendations by providing their home address. XeroHome also provides a dashboard designed to be used by a utility program, where the results from all homes can be accessed over a geographical map and filtered to identify targeting opportunities for specific program offerings or electrification opportunities.

A unique aspect of XeroHome is that it clearly represents model input uncertainty using a 3-stage, colored badge system. The badges serve as incentives to encourage homeowners to update certain key inputs about their home that improves the overall accuracy of the results:



Figure 3 Colored badges (White Green and Blue) to indicate the level of analysis

- **White Badge** – Represents analysis from an energy model where all inputs are based on inferences from property assessment and building permit data.
- **Green Badge** – Represents analysis from the energy model where the model inputs have been updated based on the homeowner confirming them through a virtual home energy audit. The audit is a set of 16 questions that confirm the main inputs to the energy model.
- **Blue Badge** – Represents analysis from the energy model updated with detailed inputs after the home receives a professional home energy assessment.

With these three badges, XeroHome provides homeowners with gradually increasing accuracy and certainty on the results, giving them the choice to stop anywhere on the scale from White to Blue. For example, as a homeowner confirms inputs through the virtual home energy audit, the white badge progressively changes to a green badge. The audit consists of 16 questions and once all have been answered by the homeowner, the badge turns fully green. A homeowner may choose to act on the recommendations at the White Badge level, while another may choose to take the virtual energy audit and get the Green Badge, while another may want to call a traditional home energy audit to get the Blue Badge.

XeroHome's Santa Monica Deployment and Results

XeroHome's homeowner portal was deployed in Santa Monica starting October 2020. The following metrics were tracked for the first year (Oct 2020 to Sept 2021):

- **Site Visits:** The site was visited by about 800 unique visitors. About 1,400 individual sessions indicated that many of the visitors came back to the site.
- **Engagement:** Visitors spent on average 6.5 minutes on the site exploring various energy upgrades recommended to them. This engagement is significant when compared to the average time spent by utility customers interacting online with a utility of 40 seconds (GreenTechMedia 2016).
- **Virtual Energy Audits Completed:** A feature of the virtual energy audit is that a homeowner can quit after any number of questions are answered. 80% of all homeowners that started the Virtual Energy Audit completed at least 4 of 16 questions, 50% of the homeowners completed 13 of 16 questions, and 28% completed the entire audit questionnaire. Figure 4 shows this information graphed by questions answered.
- **Traditional Energy Audits Requested:** 7 homeowners requested and completed a traditional home energy audit – which was being offered free of charge to the homeowners as part of SCE's program.

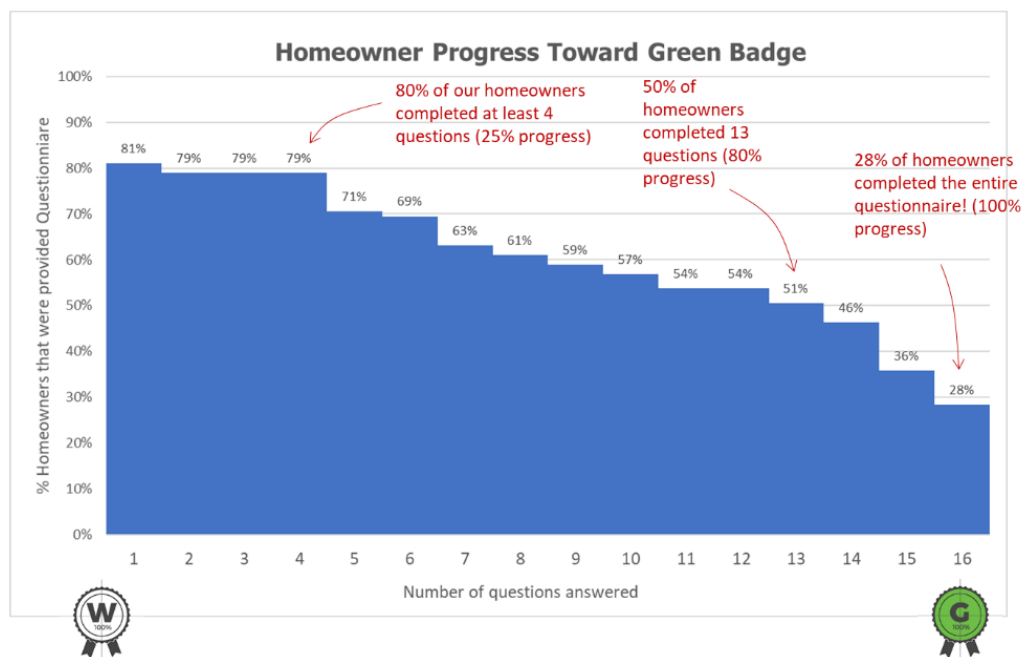


Figure 4: Virtual Energy Audit – How many Homeowners Completed the Questionnaire?

This indicates that the BEM-based approach was more actively being pursued by homeowners – with over 100 homeowners claiming and engaging with the web portal – compared to only 7 homeowners that request a traditional home energy audit, even when it was being offered for free. It makes sense that the convenience of reviewing home energy recommendations on their own time was seen as a more attractive proposition, compared to the alternative.

Comparing BEM-Based Approach to Traditional Energy Audits

The project team then compared the results from the energy models for homes that took the virtual home energy audit (green badge homes), and those that took the traditional energy audit (blue badge homes). The 7 homes that took the traditional energy audit had data at white badge, green badge, and blue badge levels. This allowed the team to establish an initial value of accuracy to XeroHome’s energy modeling-based approach compared to that of a traditional energy audit.

Figure 5 shows the 7 homes (Homes A through G) for which data from the traditional home energy audits were available. The graph plots the energy model’s energy use intensity (EUI in kBtu/sf-yr.). The initial model developed by XeroHome’s automated modeling method is represented as the white dot (white badge). The same model with the homeowner’s virtual energy audit completed is represented as the green dot (green badge) and finally, the energy assessor’s energy model output is represented as the blue dot (blue badge).

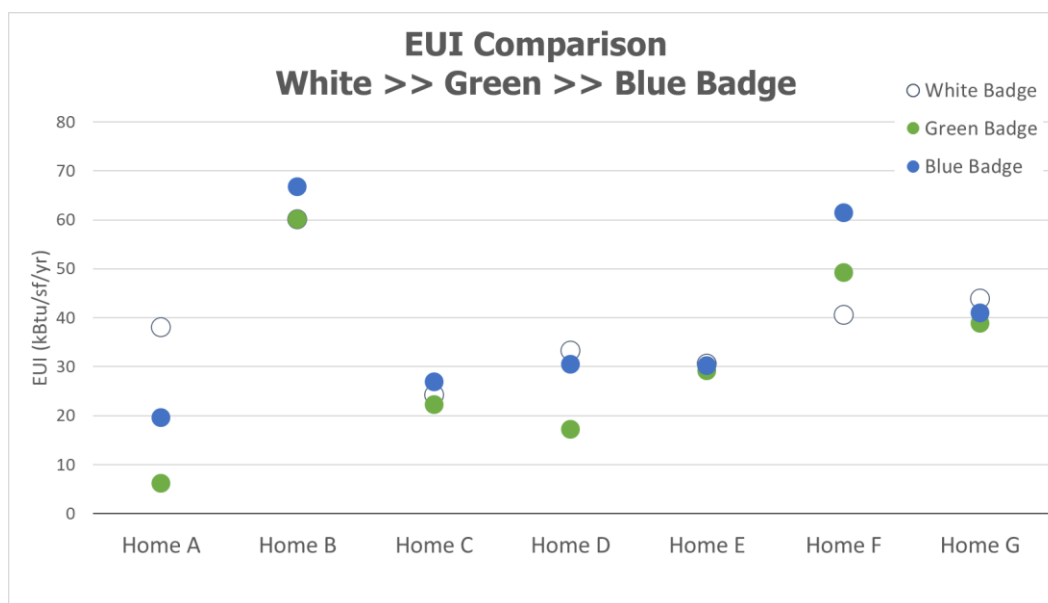


Figure 5: Comparing modeling results of White Badge analysis against Green and Blue Badge.

Considering the blue dot's EUI to be the standard to meet, as it consists of on-site data collected by a professional energy assessor, we first compare the blue to the white dot's EUI.

In **5 out of the 7 homes**, the difference between the white and blue EUIs was **within 10%**. In 2 out of the 7 homes, the difference exceeded 10%. Differences in % EUI between white and blue EUIs and green and blue EUIs are noted in the table below:

Home	Difference in EUI	
	Blue to White	Blue to Green
A	-49%	-84%
B	10%	0%
C	10%	-8%
D	-8%	-48%
E	-1%	-5%
F	52%	21%
G	-7%	-7%

Figure 6: Difference in EUI between Blue, White, and Green EUIs

By exploring the results in more detail, the large discrepancies in homes A and F were revealed.

- In home A, the XeroHome white badge analysis modeled the home without solar, but the home has a solar. XeroHome uses building permit data to determine if a home has solar, and this was likely due to an error in that data. When the error was fixed, i.e., when we modeled the home again but this time with solar, the white EUI came to within 6% different compared to the blue EUI

- In home F, the XeroHome white badge analysis incorrectly assigned a higher efficiency heating system, based on the date of a permit for HVAC for that home. The actual efficiency of the heating system was lower, as reported by the energy auditor.

Notwithstanding the two homes (A and F), the overall results indicate that the BEM-based approach with an automated energy model and a virtual home energy audit is providing reliable results for many of the homes. Future improvements in XeroHome's assumptions on HVAC efficiency defaults and better building permit data can even bring in the two outlier homes.

It should also be noted that since this study is limited to only 7 homes, the results should not be considered as statistically indicative. Instead, they are a qualitative assessment of the XeroHome tool and its scalable BEM-based approach and should be treated as such.

The project team made another comparison to determine how the homeowners completing a virtual home energy audit changed the EUI of the energy model. Figure 7 shows the EUI for about 87 homes where homeowners answered at least one of the virtual energy audit questions. White badge EUI is from the energy model built with all assumptions based on public data, and green badge EUI is from the same energy model, but with inputs changes based on responses from the homeowner from the virtual energy audit. The data shows that there was overall good agreement with an R-square of 69% and a trend showing that completing the virtual energy audit tended to reduce the modeled energy use in most homes.

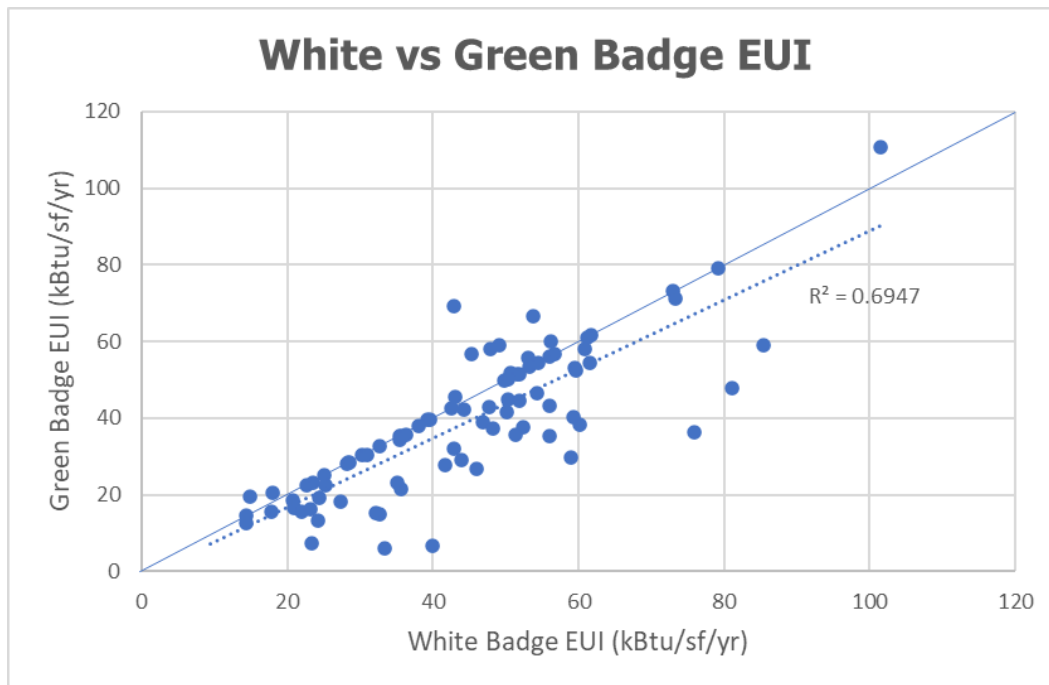


Figure 7: How did homeowners that completed the Virtual Energy Audit impact resulting home EUI?

Applications and Advantages of The Scalable BEM-based Approach

Since the SCE ET evaluation of XeroHome's scalable BEM-based approach in Santa Monica, the XeroHome platform has been deployed in several utility research and homeowner

engagement pilot projects. These projects demonstrate the approach's versatility and advantages over prior analysis and outreach methods in providing program-level insights and engaging with residential customers.

A key advantage of XeroHome's BEM-based approach is its **scalability** – analysis performed for one home can be performed for thousands of homes in a city or a region using a cloud-computing for computational efficiency. XeroHome uses a cloud platform and a unique machine-learning technique that speeds up energy calculation at scale. This capability was used to develop analysis for the California Statewide Codes and Standards team to support developing of a potential electrification reach code for existing buildings (Saxena, May-Ostendorp, et al. 2020). Analysis for reach codes in the past have used a small number of residential prototypes (typically based on building vintage) to represent residential building stock diversity. XeroHome's approach to model every home, not just a typical or representative set captured the true variation in energy savings that can be expected in the real world. This resulted in insights that informed the development of a robust reach code and appropriate exceptions, which would not have been possible with a prototype-based analysis.

Another unique advantage of this approach is its ability to provide **engagement** – homeowners can interact with an energy model of their home, making changes to it in real-time, to determine the best course of action for them. In a recent project, discussed in an accompanying paper presented at this conference (Saxena, Dhir, et al. 2022) XeroHome was deployed in the city of San Luis Obispo, CA, to give its residents the option to evaluate potential electrification options and determine which ones are cost effective. This deployment gives homeowners the ability to understand and act on the opportunity of reducing carbon emissions from their homes without the need to conduct energy audits upfront, promoting building decarbonization retrofits at scale. Other similar deployments of XeroHome to promote homeowner engagement are currently underway with the cities of Petaluma, CA, Sacramento, CA, Richmond Heights, MO, and Atlanta, GA.

Conclusion

This paper explored data collected from the deployment of XeroHome, a new scalable BEM-based approach that uses publicly available data on homes, and a virtual home energy audit conducted by homeowners to quickly develop custom recommendations for home energy upgrades. The approach has promising potential to make home energy upgrade recommendations accessible to a large number of households, eliminating the labor-intensive traditional home energy audit step for most homes.

Existing virtual energy audit and other DIY home energy assessment tools have limitations related to insufficient calculation basis and accuracy, which XeroHome's scalable approach incorporating building energy modeling and homeowner interaction successfully bridges. XeroHome provides an interactive solution where a homeowner can directly interact with their own home's building energy model. Using automation, cloud computing, machine learning, and access to a rich layer of publicly available data on homes, it provides a scalable process in which accuracy can be improved incrementally through homeowner action. XeroHome's colored badge system communicates this level of analysis accuracy to the user, while also encouraging them improve it.

Since this evaluation was limited to only 7 homes with detailed energy audit data, the results cannot be considered as statistically indicative, but more as a qualitative assessment of the XeroHome tool and its scalable BEM-based approach. The results indicate that XeroHome's

modeling approach has the capability to provide reliable energy models that can be used to develop energy upgrade recommendations. Future work on this approach could incorporate flags that indicate poor data input quality for certain homes that may be relegated to the traditional energy audit.

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