Clean Power Research

Virtual Energy Audit Case Study – Short Form

Evaluating Building Performance of Single-Family Homes in SMUD's Service Territory

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Executive Summary

Clean Power Research developed the Virtual Energy Audit to help address some of the building electrification challenges that consumers and utilities will encounter as policies to encourage building efficiency improvements and building electrification are enacted.[1]. The Virtual Energy Audit provides a no-touch method for calculating building shell efficiency using a metric that is uniformly comparable across a utility service territory, an entire state and beyond. Utilities can use empirically derived results to examine efficiency program impact or the effect of building electrification on the distribution grid. At the same time, consumers could use this information to determine how their electric bill might change if they replace gas heating with an electric heat pump with some combination of building shell efficiency investments.

In this case study, we performed a Virtual Energy Audit for nearly 350,000 single-family residential homes in SMUD (Sacramento Municipal Utility District) territory. The study:

1) Used only hourly electric usage data.
2) Calculated overall building shell efficiency.
3) Validated electricity consumption model accuracy.
4) Identified building shell efficiency investments and equipment changes.

PLEASE REFER TO THE FULL CASE STUDY FOR MORE DETAILED INFORMATION, CHARTS AND FIGURES.

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[1] Lori Bird and Tyler Clevenger. "2019 Was a Watershed Year for Clean Energy Commitments from U.S. States and Utilities." World Resources Institute, 20 Dec. 2019, https://www.wri.org/blog/2019/12/2019-was-watershed-year-clean-energy-commitments-us-states-and-utilities

Benefits and Challenges of Building Electrification

Building electrification can benefit both utilities and their customers. For utilities, it can help reverse the trend toward declining electricity sales. Consumers, meanwhile, will benefit from improved indoor air quality.[2] Some customers may also experience a reduction in costs,[3] although savings are not a certainty. In any case, these benefits come with several challenges for both utilities and consumers.

Changes in Peak Load

Electrified buildings will consume substantially more electricity than buildings that rely on fossil fuels for space and water heating. Additional load may require utilities to upgrade infrastructure and these costs will most likely be passed on to consumers. Also, with the addition of electric heat pumps for space heating, utilities may experience a shift in peak load, from summer to winter.

Savings for Customers

Although several studies have found that electrification of space and water heating is less expensive than using fossil fuels, the cost savings may be lower than expected. In some cases, costs may even be increased. Customer comfort and safety drives energy usage for heating and cooling, so they are not highly flexible loads. Time-of-use rates, implemented by utilities to shape load curves, can result in higher bills for customers. Similarly, if utilities raise winter electricity prices to incentivize reduced usage, customers with solar PV may find that the economics are no longer as attractive since solar production is not well matched to winter-peaking loads.

Owner Buy-in

Building owners must participate in building electrification. However, electrification can require a non-trivial investment in equipment and/or building efficiency. There are also myriad approaches to electrification and efficiency, some involving multiple technologies, and each with its own trade-offs. A lack of understanding of the costs and benefits of the different approaches can cause confusion, and

[2] California Air Resources Board. "Indoor Air Pollution from Cooking." Viewed March 16, 2021. https://ww2.arb.ca.gov/resources/documents/indoor-air-pollution-cooking; https://ww2.arb.ca.gov/sites/default/files/2018-09/Bibliography-of-US-and-International-Studies-on-Indoor-Air-Pollution-from-Cooking.pdf

[3] Billimoria, Sherri, Mike Henchen, Leia Guccione, and Leah Louis-Prescott. "The Economics of Electrifying Buildings: How Electric Space and Water Heating Supports Decarbonization of Residential Buildings." Rocky Mountain Institute, 2018, rmi.org/insight/the-economics-of-electrifying-buildings.

owners may be reluctant to act – particularly when the building is occupied by a tenant and many of the benefits of electrification would not accrue to the owner.

Balancing Electrification and Efficiency

Performing an assessment of a building's current, or baseline, energy performance can help inform electrification decisions. For owners, an in-depth assessment allows them to minimize up-front and/or long-term costs by optimizing investments in equipment versus building shell efficiency. For utilities, an assessment helps guide owners to avoid choices that might trigger costly distribution system upgrades. However, traditional methods for assessing a building's baseline performance are time consuming, require an on-site visit, and are costly.[4]

[4] According to https://www.homeadvisor.com/cost/energy-efficiency/hire-a-home-energy-auditor/ accessed on Dec. 7, 2021, the average cost of a home energy audit in Sacramento, CA is $246. The national average is $407.

Virtual Energy Audit at SMUD

The Virtual Energy Audit characterizes building energy performance to help utilities and consumers meet some of the challenges of building electrification. It provides an accurate, no-touch, building assessment more quickly and at lower costs than traditional methods.

By identifying buildings where electrification without efficiency improvements might cause occupant discomfort, the Virtual Energy Audit provides owners with the means to prioritize improvements and allows utilities to make more effective use of funds earmarked for decarbonization.

In previous studies, Clean Power Research has shown that the Virtual Energy Audit can be used to accurately model energy consumption by end use as a function of average outdoor temperature. It can also be used to calculate an Effective R-value that provides a uniform metric for overall building shell efficiency.[5, 6]

When consumption measurements are available for all energy sources used in a building, the Virtual Energy Audit can accurately predict all energy consumption. However, when a Virtual Energy Audit is performed on a building heated by natural gas, using only electricity measurements, the energy used for heating is not included in the predicted electricity consumption.

In this study, Clean Power Research explored Virtual Energy Audit scalability for large numbers of buildings, further validated model accuracy and identification of changes to HVAC (Heating Ventilation and Air Conditioning) equipment. There are several unique aspects of this study.

1) Clean Power Research performed Virtual Energy Audits using only electric data.
2) We produced electric consumption models for hundreds of thousands of customers.
3) We examined the correlation between building shell efficiency and several other metrics.
4) We validated heating and cooling equipment changes identified by the Virtual Energy Audit.

The ability to rapidly calculate building shell efficiency for large numbers of customers while identifying changes to equipment and the building shell, provides utilities' efficiency program

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[5] "Virtual Energy Audit: Reducing Barriers to Building Electrification, Validation for the City of Palo Alto Utilities." January 2021.

[6] Hoff, Thomas E., "The Virtual Energy Audit, Validation for Sacramento Municipal Utility District." June 2018.

managers with tools to validate improvements and quantify their effectiveness. Correlation with income and geography can help identify target groups for those programs.

Objectives

The primary goal of this study was to provide SMUD with a consistent measurement of building efficiency for all single-family residential customers and explore the relationship between Effective R-Value and socioeconomic, geographic, and other factors. We also wanted to provide additional validation of the Virtual Energy Audit model and change detection accuracy using large numbers of customers.

Method

In this study, Clean Power Research made use of electric consumption data from buildings within SMUD service territory. We performed the following steps:

1. Collected site information and hourly electric consumption data.
2. Prepared the electric consumption data, including calculating base load, identifying (and excluding) unoccupied days, and calculating the seven-day average hourly electricity consumption.
3. Collected and prepared outdoor temperature data.
4. Ran the Virtual Energy Audit using electric data.
5. Evaluated Effective R-Values across SMUD territory and validated accuracy.

PLEASE REFER TO THE FULL CASE STUDY FOR EXTENSIVE INFORMATION ON EACH OF THESE STEPS AND ON THE VIRTUAL ENERGY AUDIT MODEL VALIDATION AND SAMPLE SITES.

Residential Building Efficiency in SMUD Territory

The Virtual Energy Audit uses Effective R-Value as a measure of building efficiency. This metric expresses the overall efficiency of the building shell, including walls, ceilings, floors, windows, doors, and air infiltration. Effective R-Value is calculated as the exterior surface area divided by the heating or cooling fuel rate times the equipment efficiency of the heating or cooling system, as shown in the formula below.[7]

$$R^{Effective} = \frac{A^{Total}}{FuelRate^{Cooling} * \eta^{Cooling}}$$

Most customers in SMUD territory do not heat their homes with electricity, but they do typically have air conditioning. Since this study used only electric data, Clean Power Research used the cooling fuel rate in calculating Effective R-Value. Detailed information on the efficiency of cooling equipment was not available. Instead, we assumed an equipment efficiency of 13 SEER[8] for all customers.

Clean Power Research based its surface area estimate on the living area and number of floors obtained from the Sacramento County Assessor's Office.

For the surface area calculation, Clean Power Research assumed that buildings are square with walls that are eight feet high per floor.

Cooling fuel rate, another one of the inputs to the Effective R-Value calculation, is one of the results produced by the Virtual Energy Audit. Cooling and heating fuel rates, given in units of energy per hour-°F tell us how the rate of fuel consumption changes as the temperature changes. Higher units indicate greater energy consumption per hour for every degree of temperature change. For example, a cooling fuel rate of 50 Wh per hour-°F means that if consumption is 1,100 Wh per hour at 78° Fahrenheit and the temperature increases one degree to 79°F, electricity consumption would increase by 50 Wh per hour to 1,150 Wh per hour.

[7] This version of the calculation is based on the cooling fuel rate and cooling system efficiency.

[8] According to https://www.eia.gov/todayinenergy/detail.php?id=40232, accessed Dec. 8, 2021, the minimum efficiency in SMUD territory from 2006-2015 was 13 SEER and https://www.energy.gov/energysaver/central-air-conditioning says the lifespan of a central air conditioner is 15-20 years. As of January 2015, the minimum efficiency is 14 SEER. Using higher equipment efficiency results in lower calculated Effective R-Values.

Having examined the characteristics of the inputs to the Effective R-Value calculation, Clean Power Research applied the formula to calculate an Effective R-Value for each home in the study. The distribution of Effective R-Values for single-family residential homes is shown in Figure 1. The mean Effective R-Value was seven and the median was four.

Although only five percent of buildings had an Effective R-Value greater than 15, it's important to note that these high Effective R-Values appear to primarily be due to very low cooling fuel rates. The mean cooling fuel rate for buildings with an Effective R-Value of 15 or lower is 87 Watts per Hour-°F, but for buildings with an Effective R-Value higher than 15 the mean cooling fuel rate is just 10 Watts per Hour-°F. There are several possible explanations for these low fuel rates, but Clean Power Research does not have enough information to draw any firm conclusions. Perhaps these buildings have no air conditioning, or it's only used infrequently.

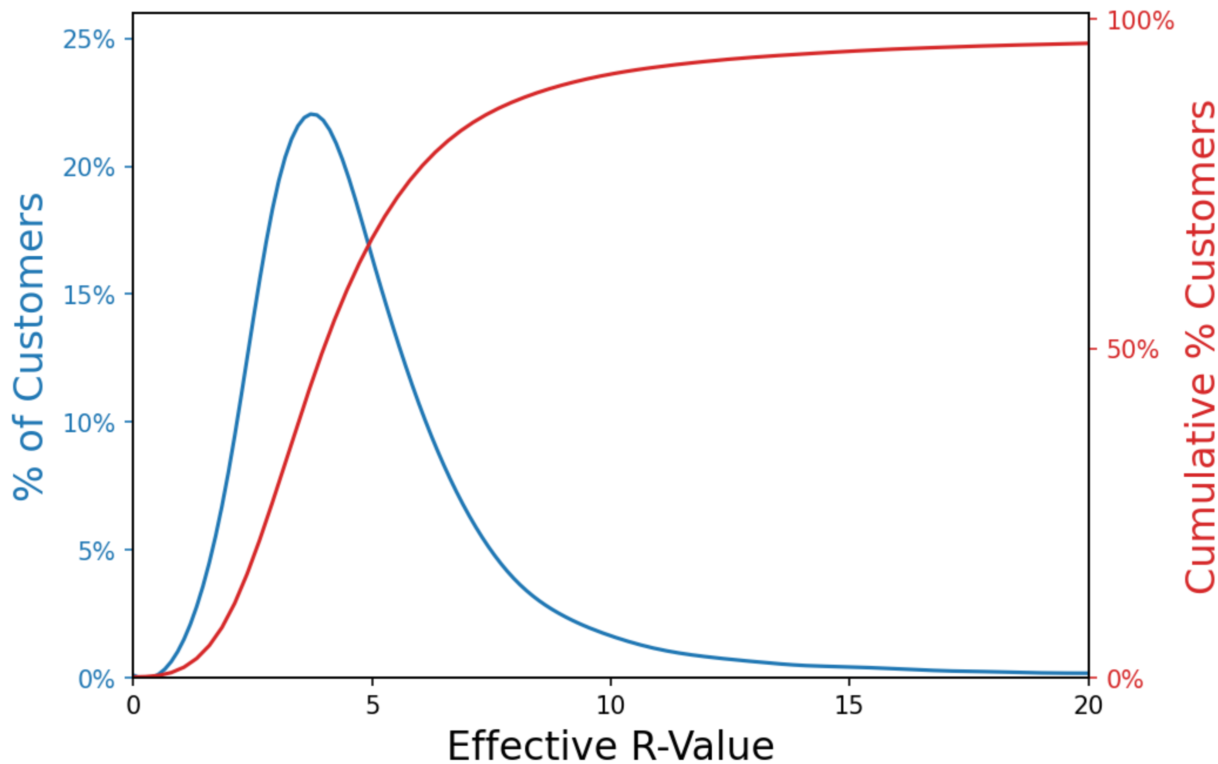

Figure 1 - Distribution of Effective R-Values

Figure 2 shows a map of the median Effective R-Values for each Census Block Group with 100 or more homes, where Effective R-Value is less than 20. Although this map can be useful as a general indicator of areas to examine in more depth, some of the areas with values at the extremes have relatively few homes in them.

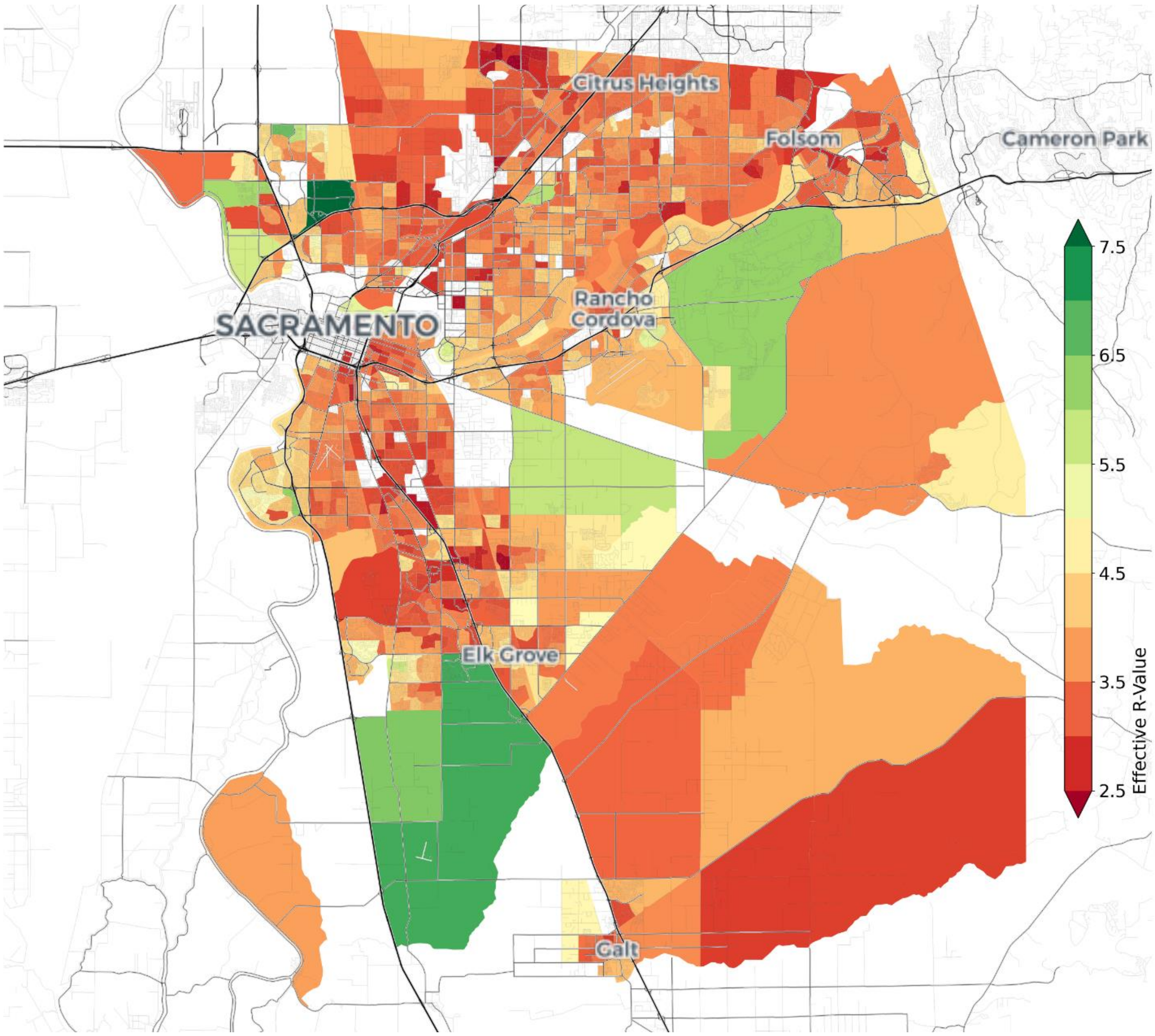

Figure 2 - Median Effective R-Value by Census Block Group

The Effective R-Value calculated by the Virtual Energy Audit provides a consistent metric for comparing building efficiency across a utility territory, an entire state, or nationwide. Where detailed information is available for individual consumers, assumptions about building shape and equipment efficiency can easily be replaced to produce a more accurate estimate.

Please refer to the full case study for detailed information on the Correlation of Effective R-Value with Other Factors, including living area and income level.

Exploring Effective R-Value for Individual Buildings

While it's useful to look at overall results for the entire set of customers, examining results for smaller areas and individual buildings can also provide insight. As we zoom in on smaller areas, it becomes clear that there are, in fact, a range of values in every area. Figure 3 shows the measured and modeled energy for a single building at the lower left. In the middle plot, we see the Effective R-Value for that building in the context of the surrounding buildings in the Census Block Group. Finally, at the upper right, the median value for the Census Block Group is shown in the context of all Census Block Groups in SMUD territory.

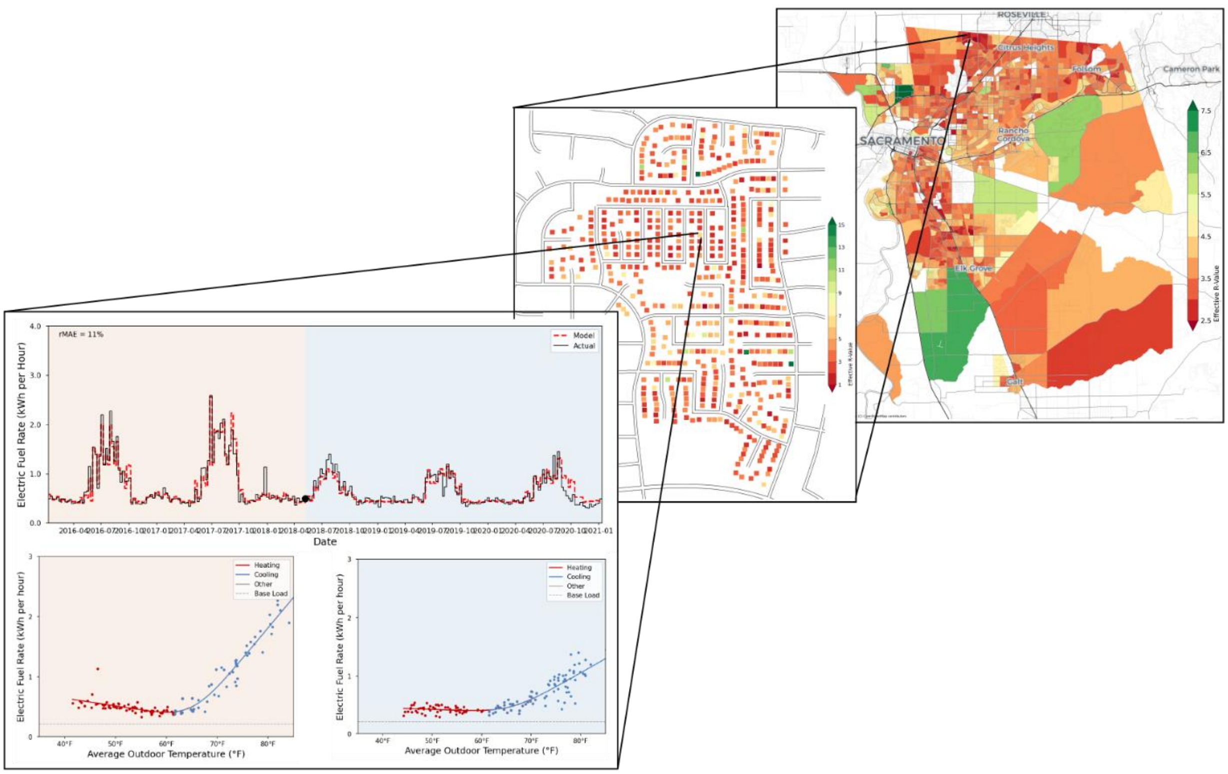

Figure 3 - Zooming in on Census Block Group and Individual Homes

As an example of the range of values, Figure 4 shows a map of Effective R-Values for the 259 homes in the Census Block Group with the highest median value. Even here, where the median is seven and the mean is eight, there are 43 homes with an Effective R-Values less than five.

Figure 4 - Census Block Group with Highest Median Effective R-Value

Similarly, Figure maps the Effective R-Values for the 540 homes in the Census Block Group with the lowest median value. But again, with a median Effective R-Value of three and a mean of four, there are 15 homes with an Effective R-Values greater than eight.

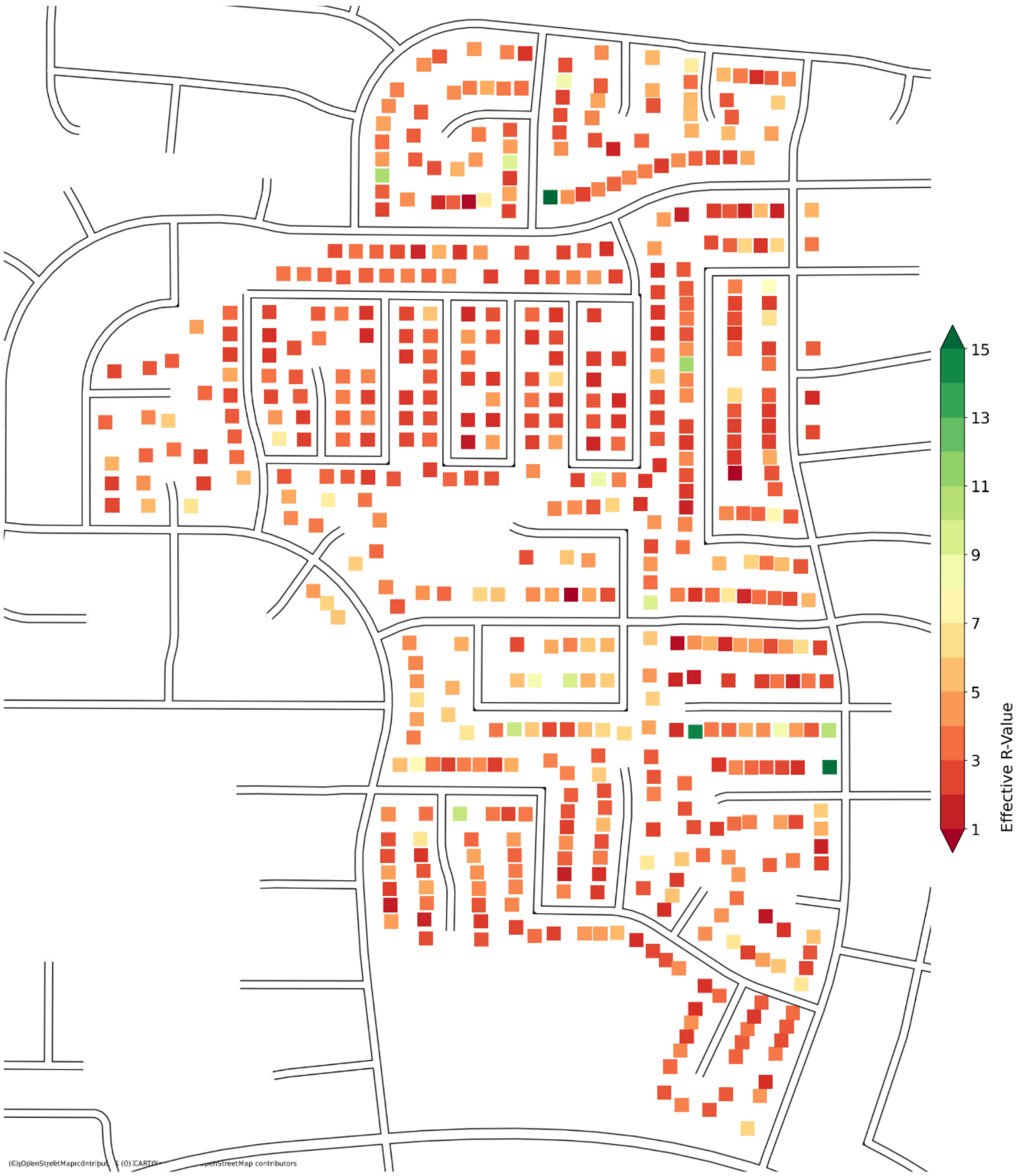

Figure 5 - Census Block Group with Lowest Median Effective R-Value

Virtual Energy Audit results can be aggregated at any level from small neighborhoods to Census Block Groups, Census Tracts, cities, utility territories, or larger areas. However, regardless of the level at which results are aggregated, they are based on an evaluation of individual buildings which often exhibit a wide range of energy consumption and efficiency characteristics – even within a small geographic area.

Conclusions

In this case study, Clean Power Research completed a Virtual Energy Audit for nearly 350,000 single-family residential buildings in SMUD territory. The audits resulted in an Effective R-Value - a consistent measure of building efficiency - for a large percentage of their customer base. Clean Power Research mapped median Effective R-Value by Census Block Group and determined that there is not a strong correlation between median Effective R-Value and median income at the Census Tract level.

The model used by the Virtual Energy Audit, and the model parameter values identified, resulted in modeled energy consumption that exhibited low error, compared to measured energy consumption. Using efficiency program data from SMUD, Clean Power Research was able to demonstrate the ability of the Virtual Energy Audit to accurately identify changes in heating and cooling equipment or the building shell efficiency improvements.

The ability to rapidly calculate building shell efficiency for large numbers of customers while identifying changes to equipment and the building shell, provides utilities' efficiency program managers with tools to validate improvements and quantify their effectiveness. Correlation with income and geography can help identify target groups for those programs. Though not demonstrated in this study, the Virtual Energy audit is also capable of calculating the impact of building electrification on load and on customers' utility bills.

Please refer to the full case study for more detailed information, charts and figures.

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