# An Exploratory Comparative Assessment of the California Advanced Homes Program (CAHP)

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By


**Policy Consultants, LLC DBA Residential Energy & Water Intelligence (Res-Intel)**

4110 SE Hawthorne Blvd #143

Portland, Oregon 97214

Hal.Nelson@Res-Intel.com



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## Executive Summary/Abstract

This report provides an analysis of the builders' efficiencies distributions in the California Advanced Homes Program (CAHP). The study computed the energy efficiency of single-family residences (SFR) as the home energy intensity score (HIS) by builder and compared their distributions using Tukey Honest Significant Differences to identify builders that were statistically different from their peers as more or less energy efficient.

Summary of the study findings are as follows:

Twenty-six builders in the CAHP were included in the analysis. The temporal coverage of the study is from May 2011 to December 2014 and the geographic coverage concentrated in the Los Angeles – San Bernardino metropolitan area. The distributions suggest two builders were significantly more efficient than their peers and two others less efficient. Builders seem to construct SFR that are similar in terms of energy efficiency. Further examining the few builders that different from their peers may lead to uncovering relevant factors of interest for improving the construction of energy efficient SFR. Some of the limitations of the study were data availability for key variables such as home occupancy rates. Lastly, the current research design is not fully robust to certain phenomena such as geographical clustering factors which may drive a portion of the results.

## Study Scope

The study explores of the efficiency distribution of single family residences (SFR) in the California Advanced Home Program (CAHP) from twenty-six participating builders. The participation criteria exclude appliance-only programs and considers only whole house efficiency projects. As a consequence of this criterion, the sample is composed exclusively by fully electricity-powered SFR, i.e., power is received from a combination of photovoltaic power generation or electricity from the grid. The time coverage extends from 2011-05-01 to 2014-12-31. The spatial distribution of the sample for analysis is heavily concentrated in the Los Angeles – San Bernardino metropolitan area.

## Research Questions

The California Advanced Home Program provides financial incentives for residential new construction projects that were at least 15% more efficient than Title 24 Energy Efficiency standards. The effectiveness of the program relies on the validity of its mechanism. Do builders respond to the offered financial incentives resulting in the desired behavioral change? Statewide, the CAHP program was found to substantively reduce gas and electricity use (KEMA, NMR Group, Summit Blue Consulting, and Itron 2010).

Builders that have been granted these financial incentives develop residences that meet at least the standard to qualify in the program. What is the relative energy efficiency distribution of these new residences? Are there significant differences in the energy efficiency of SFR in the CAHP that can be attributed to their builders? If so, which builders seem to build more or less energy efficient residences?

## Research Design

When analyzing the energy efficiency of a building the standard approach is to benchmark the energy usage of the building relative to similar buildings using source energy divided by floor area otherwise known as Energy Use Intensity (EUI). The EUI normalizes the energy consumption.

The sample contains only single-family residential houses (SFR) which rely completely on electric energy (grid or photovoltaic) for space cooling and baseload energy. Program rebate information was analyzed to find data on electricity used for space heating, as compared to the assumed default of gas forced air heating. If a builder installed heat pumps for space heating, this would increase the electricity consumed per FT2. The results below assume that natural gas is used for space heating in the homes in the sample.

A common issue with benchmarking is adjusting for occupancy. We do not have house occupancy data, but instead control for building FT2 which is a reliable proxy for the number of bedrooms that is typically used for occupancy. To account for zero occupancy in homes, a simple rule is imposed which excludes observations with less than 100 kWh (our definition of trivial energy usage due to vacancy) in a month.

## Sample Data

- Number of houses: 2,549
- Time Coverage: 2011-05-01 to 2014-12-31
- Number of Builders: 26
  - Excluded accounts for which builders had less than 7 valid observations (houses)
  - Excluded builders identified in the data as Southern California Gas (SoCal Gas). These homes received incentives through SoCalGas and were therefore deemed to be potentially a single rebate house (gas appliance) rather than participating in the whole home program portion of CAHP
- We applied the following filters:
  - Excluded usage data before the NPR Signature Date (the date incentives were authorized to be paid)
  - Excluded accounts with less than eleven *consecutive* months of usage data (sequence considered valid if kWh skipped no more than one month in thirteen)

## Data Pre-Processing

- We aggregated hourly usage data to monthly
- We merged Net Energy Meter (Solar PV) data files with SCE usage (grid) data files to estimate the total kWh usage at each house.
- We matched CAHP Program data files, and the Usage files based on service number
- We merged Weather data from the Global Daily Summary (Menne, Durre and Korzeniewski, et al. 2012) for calculated values of cooling degree days (*CDD)* (base temperature 65˚F) and heating degree days (*HDD)* (base temperature 72˚F) by Zip Code using Vincenty (ellipsoid) great circle distance formula and the NAD83 datum.

- Zip Codes were geocoded using the (US Census Bureau 2010) data and Weather Stations geocoded using information from (Menne, Durre and Vose, et al. 2012).
- To limit potential bias from outliers, we excluded housed with mean EUI Z-scores greater than +/-2.5

## Exploratory Data Analysis of the CAHP

After filtering the program data for only Single-Family Residences, the houses that were denoted as only "appliances" rather than "lot" were identified. Appliances were typically single rebate houses where "lots" were whole house efficiency projects. The following consist of the data summary for incentives paid out for appliances. The different types of appliances along with the frequency of each are identified below on Table 1.

*Table 1: Number of Appliances in the Program by Year*

| | Year of NPR Signature Date | | | | | |
|---|---|---|---|---|---|---|
| Measure Desc | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| Clothes Washer | 1 | 36 | 34 | 3 | | 1 |
| Compact Fluorescent Light .. | 1 | | | | | |
| Dishwasher | 5 | 741 | 599 | 165 | 98 | 38 |
| High Efficacy Lighting | | 1 | 1 | | | |
| Quality Insulation Install | | | 97 | | | |
| Refrigerator | | 25 | 15 | 4 | | 2 |
| Tight Ducts | | | 59 | | | |

Count of Measure Desc: 1 – 741

Count of Measure Desc broken down by NPR Signature Date Year vs. Measure Desc. Color shows count of Measure Desc. The marks are labeled by count of Measure Desc. The data is filtered on NPR Signature Date Year, which excludes Null. The view is filtered on Measure Desc, which excludes Null.

Figure 1 shows that most of the incentive paid for the sample are early adopters from the first wave (2010-11) of NPR Signatures including appliances.

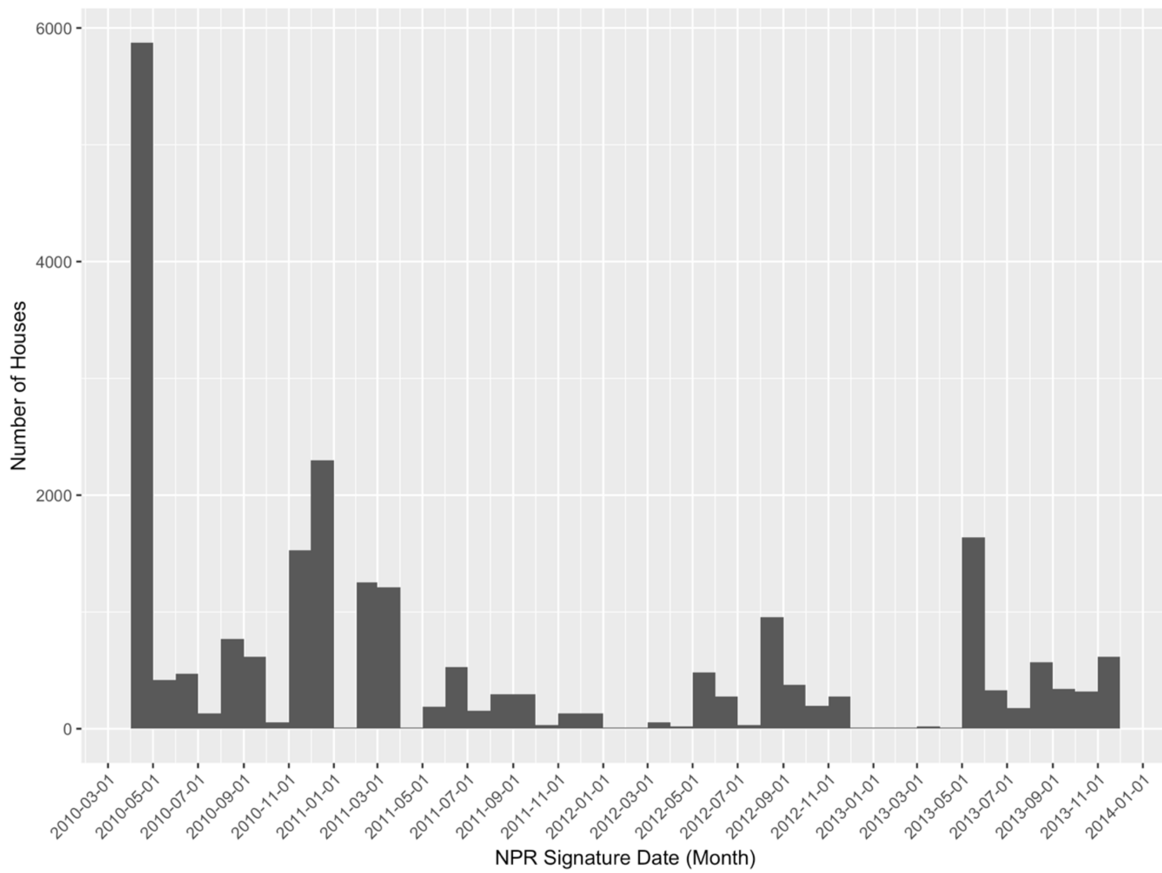


*Figure 1: Histogram of NPR Signature Dates by Month*

The spatial distribution of the zip codes of the houses sample is mostly in the Los Angeles – San Bernardino metropolitan area as it can be seen in Figure 2.

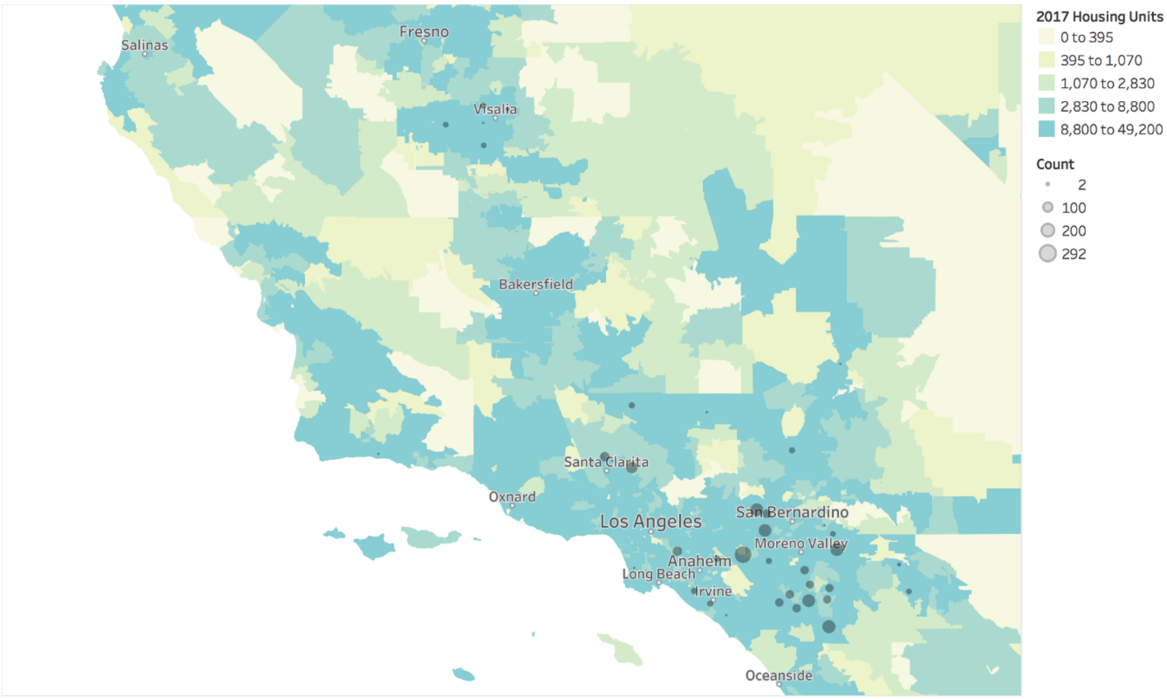


*Figure 2: Spatial Distribution of the Sample*

Next, we performed exploratory data analysis on the raw monthly usage and climate data. The monthly usage in the included houses ranged from 100 kWh to 5,635 with a mean of 622. The monthly Cooling Degree Days and the monthly Heating Degree Days represent the range of weather in the sample period. Monthly cooling degree days ranged from 0 to 725, with a mean of 260. Monthly heating degree days ranged from 0 to 587 with a mean of 98.

## Summary Statistics

To prepare the data for the regression analysis, we aggregated each houses' kWh usage, as well as the weather data, over the first 11-13 month period following the NPR signature date. Each included house had to exceed the minimum 100 kWh/month vacancy exclusion listed above in each given month. Once each house's usage and climate data was aggregated, it was divided by the number of months in the sample to create average monthly EUI and weather values.

Table 2 shows the summary statistics for the variables used in the regression. The outcome variable is the monthly Energy Use Intensity (EUI) which is in kWh/FT2 per month, which ranges from 0.04 to 0.56. The natural log of floor area in SQFT (*LnSQFT*) is the size of the house, and the home's claimed percentage above California's Title 24 energy code is represented by *T24.* Finally*,* whether the tariff type is domestic rate is a yes or no variable labeled *Domestic*. Nearly three fourths of the sample were domestic rate with Care, Time of Use, and Summer Discount Plan accounting for the majority of the other rate codes.

*Table 2: Summary Statistics of Regression Variables*

Number of observations: 2,549

| | Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max. |
|---|---|---|---|---|---|---|
| EUI | 0.04 | 0.19 | 0.25 | 0.26 | 0.32 | 0.56 |
| CDD | 82.23 | 226.42 | 264.54 | 261.45 | 285.00 | 371.54 |
| HDD | 4.00 | 78.67 | 97.85 | 97.41 | 124.00 | 262.65 |
| T24 | 15.00 | 15.00 | 15.00 | 20.21 | 25.00 | 42.30 |
| LnSQFT | 7.12 | 7.54 | 7.74 | 7.74 | 7.94 | 8.36 |
| | No | Yes | | | | |
| Domestic | 681 | 1868 | | | | |

## Multivariate Regression Analysis

The first step taken was to predict each home's EUI-based on its climate and building characteristics.

- We fit a regression with the following formula:

$$\boldsymbol{EUI \sim CDD + HDD + LnSQFT + T24 + Domestic + \varepsilon}$$

  Where

  - EUI is the mean monthly EUI in the 11-13 months period
  - CDD is mean monthly Cooling Degree Days (base temperature 72˚F),
  - HDD is mean monthly Heating Degree Days (base temperature 65˚F)
  - Ln(SQFT) is the log of home square footage,
  - Title24 is the percent more energy efficient that the home is modeled to be above California Title 24 energy code,
  - Domestic indicates the tariff rate
  - $\boldsymbol{\varepsilon}$ indicates a stochastic error term

We used ordinary least squares to estimate the model for each of the ~2,500 houses in the sample that had valid data.

Next, we compare the predicted EUI with the actual EUI by creating an indicator called the Home Energy Intensity Score (HIS) for each of the houses. The HIS indicator is calculated by ACTUAL EUI / PREDICTED EUI. The HIS indicator controls for building attributes, climate, and other relevant factors in determining electricity intensities for the CAHP homes. The average value of HIS is 1.0, where a house's actual usage is exactly what was predicted. Houses with high HIS values are more energy intensive, controlling for important building and climate attributes, while houses with HIS values below 1.0 are more energy efficient. This technique let us estimate any substantive and statistically significant differences between builders using a level playing field.

- We then grouped the HIS values by builder to test for differences using Tukey Honest Significant Differences of the energy efficiency distribution of houses.

In sum, these two methods allow us to reliably estimate what electricity consumption SHOULD be, then determine if any of the builders ACTUAL electricity consumption deviated from those expectations.

## Regression Results

Table 3 shows the regression results for the EUI outcome variable.

*Table 3: Regression Results for EUI*

Model: Ordinary Least Squares
Cross-sectional unit: Single-Family House
Response Variable: EUI (Site Energy - Floor Area adjusted)
Variance Covariance Estimator: Clustered by Builder
Number of Observations: 2,549

| | β | Std. Error | t | Pr > \|t\| | 2.50% | 97.50% | |
|---|---|---|---|---|---|---|---|
| (Intercept) | 0.9050 | 0.1059 | 8.55 | 0.000 | 0.6870 | 1.1231 | *** |
| CDD | 0.0003 | 0.0001 | 3.55 | 0.002 | 0.0001 | 0.0004 | *** |
| HDD | 0.0005 | 0.0001 | 4.74 | 0.000 | 0.0003 | 0.0007 | *** |
| LnSQFT | -0.0953 | 0.0121 | -7.86 | 0.000 | -0.1203 | -0.0704 | *** |
| T24 | -0.0008 | 0.0005 | -1.51 | 0.145 | -0.0019 | 0.0003 | |
| Tariff: Domestic | -0.0136 | 0.0048 | -2.84 | 0.009 | -0.0235 | -0.0037 | *** |
| | R-Squared | | | | 0.14 | | |
| | Wald Test | | | F (5, 25) | 34.36 | Pr > F | 0.000 |

The EUI regression results for each houses' 11-13 months average EUI and climate data are consistent with theoretical expectations. The model explains approximately 14% of the variation in average monthly electricity/FT2 usage. The intercept shows the estimated value of the monthly kWh/FT2 variable when all the covariates are zero. This is not a readily interpretable value, since none of the homes have zero FT2 (see below for more information). More *cooling degree days* are associated with higher EUIs. More *heating degree days* also predict more electricity usage, which could be electricity usage from furnace fans, but could also be increased usage from lighting as winter days are shorter than summer days. The *LN(SQFT)* variable indicates that larger houses use less electricity on a square footage basis, which is typical in the building energy regression literature.

The coefficient for the Percent above *Title 24* variable is negative but loses statistical significance at the 5% level when analyzed with a robust covariance matrix estimator clustered by builders.[1] Estimating a 15 percent increase in modeled efficiency predicts roughly a .012 kWh/ FT2 decrease in usage (15 * (-0.008)), all other factors being held constant. This 0.012 kWh/FT2 decrease represents nearly a 5% decrease in EUI compared to the mean monthly average EUI of 0.26 kWh/FT2. Recall that this analysis includes only electricity impacts, which is likely what explains the difference between the 15% modeled improvement and the 5% reduction in EUI in this analysis. Other possible explanations for the difference are explained below.

Finally, the *Domestic* tariff variable indicates that these houses used around 0.013 KWh/FT2 less per month on average than houses with CARE, Time of Use, and Summer Discount Program tariffs.

A robustness test of the regression without the LN(SQFT) variable is included in Appendix B.1. This model shows that without the LN(SQFT) variable, the variation in EUI is explained by the remaining explanatory variables whose coefficients increase in size (as expected). Appendix B.1 also shows that the baseload monthly energy use (no heating and cooling) for domestic customers is estimated at 0.10 kWh/FT2, with no Title 24 improvements. This is about 40% of the monthly mean electricity usage (0.10/0.25). Appendix B.1 also shows that without the LN(SQFT) variable, the coefficient for Title 24 increases by over 50% with no change in its standard error, making the variable statistically significant.

[1] The coefficient was significant at the 5% level when not clustered by builder.

## Builder EUI Differences

In order to potentially discover significant differences in means for the EUI of homes by builders, we next estimate the Home Energy Intensity Score for each house. Recall this is actual EUI divided by EUI predicted by the above regression model above. The HIS value allows us to compare EUI's controlling for important factors such as climate, tariff type, and FT2. This gives us an apples to apples comparison of builders' EUI (not accounting for behavioral variables).

Using the HIS values, we then conducted a Tukey Honest Significant Differences test. In essence, this tests pair-wise differences in means for each builder and adjusts the statistical significance appropriately. We examined builder differences which were significant at the 5% confidence level. The results show the builders that were repeatedly found to be more or less energy efficient than others.

Figure 3 shows the distribution of HIS grouped by builder. The vertical axis depicts the distribution of energy efficiency of homes (HIS values with a mean of 1.0) built by the various builders on the horizontal axis. The width of the boxes represents the number of houses in the sample for each builder. The boxes indicate the interquartile range (the bottom of the box is the first quartile, and the top is the 3rd quartile). Also visible with blue *x's* are the group means, while the dots outside the boxes represent outlier observations.

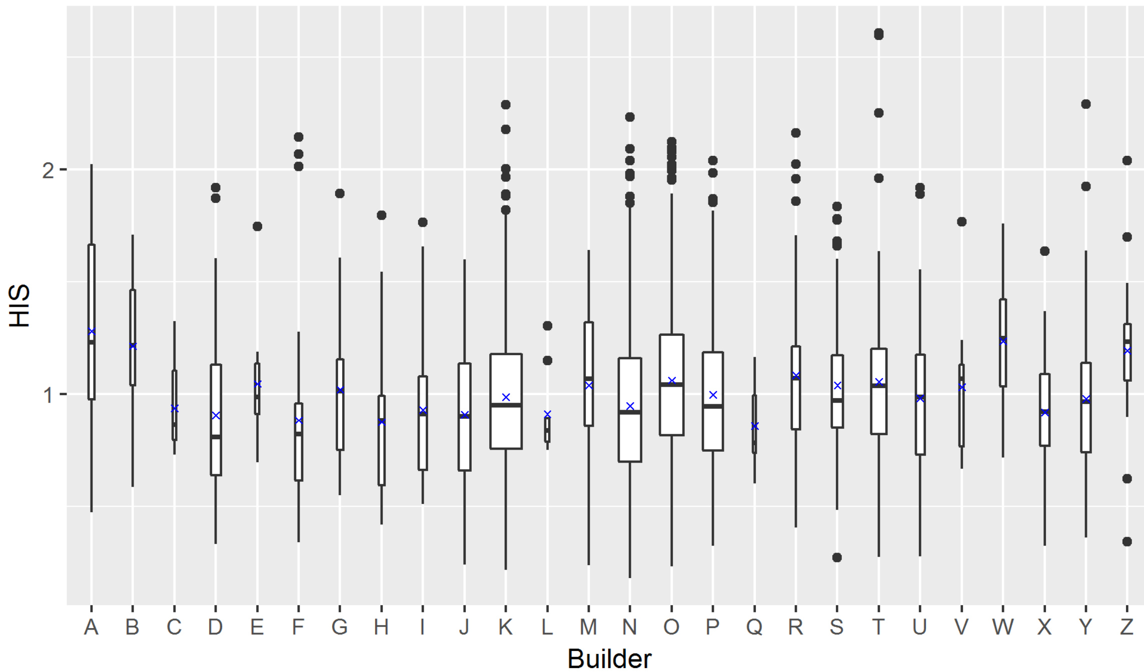


*Figure 3: Distribution of SFR Energy Efficiency (HIS) by Builder*

Our results are that builders A and W showed evidence of being less efficient than their peers while builders J and N showed evidence of being more efficient than their peers. In sum, of the 26 builders that met the exclusion criteria, only 4 showed statistically significant differences after controlling for key climate and building characteristics.

While not examined here, there are other plausible explanations for differences in HIS values between builders that are not related to building envelope, lighting, and appliance efficiencies, and other measure. Note that the EUI values calculated here include occupancy and behavioral factors. Houses built by builder W were largely located outside the core LA and San Bernardino counties in the Southern California region. This could indicate different socioeconomic, behavioral and lifestyle factors.

A supplemental regression in Appendix B.2 shows the same regression model with an additional explanatory variable of Solar Photovoltaic (PV). The Photovoltaic variable received a value of 1 if the house had any Net Energy Metering generation, and a 0 if otherwise. Homes with distributed generation were associated with an EUI of about 10% lower than the average EUI, all other variables held constant. This could reflect environmental values differences between homeowners as the purchasers of houses with green energy might be likely to have stronger energy conservation ethics; a “self-selection” of green homeowners into PV houses that have result in lower EUIs.

## Conclusions

The results showed that the energy efficiency of the CAHP builders to be relatively homogenous. The distribution of HIS by 22 of 26 builders were not statistically distinguishable from one another. However, the effects of the CAHP incentives on occupied house EUI’s are dependent on a complex set of factors. Many non-CAHP houses in California were constructed to be more energy efficient than Title 24 energy codes. KEMA (2010, p. vii) estimated that statewide, 58% of homes were above-code, 29% homes were code compliant, and 13% were below-code. Should construction practices by CAHP builders reflect this trend, the study’s research design would likely *understate* the gross electricity savings if the CAHP program houses energy modeling included energy savings measures that were not explicit in the 15% above Title 24 efficiency requirement.

Furthermore, rather than physics-based building energy modeling, the results presented here also include human behavior as well. EUI is an “operational” measure. As discussed relative to PV generation, the types of homeowners who purchase a builder’s house can affect the EUI. Similarly, there are likely geographical clustering factors that are not measured in the current design. Some builders’ communities might attract families with more children or a greater share of retirees, both of which can increase operational EUIs.

Finally, there are other sources of unmeasured variation in this exploratory study. The Title 24 measure savings assumes a constant quality of installation of the efficiency measures. Installation quality has been shown to explain up to 30 percent of space condition energy differences (NIST 2014). Future research efforts should include builder participation in CAHP trainings and other contractor quality install programs.

## Extensions of this Methodology

Should other sources of program data, such as builder training participation, be made available, they could easily be included in the current research design. The methodology developed in this study of benchmarking energy efficiency for houses and then comparing the distributions is generalizable to other program evaluation questions. For example, the same methodology could be used to analyze the distribution of building energy efficiency based on particular measures such as high efficiency AC's. Certain other aspects of the methodology could be adapted such as extending the sample to new multi-family homes.

However, extending the methodology to estimate pay-for-performance incentives would be difficult. Typically, pay-for-performance is calculated on a pre-post basis where weather normalized energy savings are measured following an intervention such as an appliance installation or deep retrofit. For the CAHP and similar new construction programs, there is no "pre" period. A relevant comparison would then be other new homes built in the same region in the same period but that were only Title 24 energy code compliant. The development of an appropriate control group could prove difficult because the control group would need to reflect whether the CAHP homes were custom homes or tract homes. The utility would need to secure county or municipal building permit data in order to identify the street addresses of the comparison group and then match those addresses into its own service address database. In sum, developing performance-based incentives for new construction would likely need significant investment in labor and data in order to be successful. Program stakeholders might be hesitant to accept the results from such a methodology regardless of the quality of the data and results.

## Recommendations

This study identified the builders that differ significantly from their peers in the energy efficiency of their residential projects. The next step would be to analyze in more detail the particular characteristics of these builders and practices to identify what is driving the disparity. In addition, further robustness checks could be explored to discern builder effects from other factors such as geographic or demographic considerations. Learning what makes these builders construct more energy efficient residential units could lead to developing best practices or adapt program policies to incorporate these evidence-based effective building techniques.

## Works Cited

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Menne, Matthew J., Imke Durre, Bryant Korzeniewski, Shelley McNeill, Kristy Thomas, Xungang Yin, Steven Anthony, et al. 2012. "Global Historical Climatology Network - Daily (GHCNDaily) Version 3." NOAA National Climatic Data Center.

Menne, Matthew J., Imke Durre, Russell S. Vose, Byron E. Gleason, and Tamara G. Houston. 2012. "An Overview of the Global Historical Climatology Network-Daily Database." *Journal of Atmospheric and Oceanic Technology* 29 (7).

NIST. 2014. "Underperforming? Energy Efficiency of HVAC Equipment Suffers Due to Poor Installation." *National Institute of Standards and Technology*, November 07.

US Census Bureau. 2010. "ZIP Code Tabulation Area." *United States Census Bureau.* https://www.census.gov/geo/mapsdata/data/gazetteer.html.

# Appendices

## Appendix A: Data Sources

- adhoq728 (directory)

◦ Confidential_adhoq728_1.csv

  - CAHP-SingleFamily qryActivityReport_DataFileFieldOrder12.9.15.csv
  - Confidential_adhoq728_8_monthly_usage_tier.csv
  - Confidential_adhoq728_6_monthly_genkwh_netkwh.csv
  - Confidential_adhoq728_intrvl_2011.csv
  - Confidential_adhoq728_intrvl_2012.csv
  - Confidential_adhoq728_intrvl_2013.csv
  - Confidential_adhoq728_intrvl_2014.csv

## Appendix B: Additional Regression Results

### *B.1: Regression Results without the Natural Log of Floor Area*

A robustness check is included excluding the natural log of floor area and the results are presented on Table 4.

*Table 4: Regression Results without Floor Area*

Model: Ordinary Least Squares
Cross-sectional unit: Single-Family House
Response Variable: EUI (Site Energy - Floor Area adjusted)
Variance Covariance Estimator: Clustered by Builder
Number of Observations: 2,549

| | β | Std. Error | t | Pr > \|t\| | 2.50% | 97.50% | |
|---|---|---|---|---|---|---|---|
| (Intercept) | 0.1022 | 0.0268 | 3.81 | 0.001 | 0.0469 | 0.1575 | *** |
| CDD | 0.0005 | 0.0001 | 7.32 | 0.000 | 0.0004 | 0.0006 | *** |
| HDD | 0.0007 | 0.0001 | 6.86 | 0.000 | 0.0005 | 0.0009 | *** |
| T24 | -0.0013 | 0.0005 | -2.50 | 0.019 | -0.0024 | -0.0002 | ** |
| Tariff: Domestic | -0.0141 | 0.0047 | -2.97 | 0.006 | -0.0238 | -0.0043 | *** |
| | | | | | | | |
| | R-Squared | | | | 0.0748 | | |
| | Wald Test | | | F (4, 25) | 24.45 | Pr > F | 0.000 |

### *B.2: Regression Results with Indicator for Photovoltaic Use*

A robustness check is included excluding the natural log of floor area and the results are presented on Table 5.

*Table 5: Regression Results with Indicator for Photovoltaic Usage*

Model: Ordinary Least Squares
Cross-sectional unit: Single-Family House
Response Variable: EUI (Site Energy - Floor Area adjusted)
Variance Covariance Estimator: Clustered by Builder
Number of Observations: 2,549

| | β | Std. Error | t | Pr > \|t\| | 2.50% | 97.50% | |
|---|---|---|---|---|---|---|---|
| (Intercept) | 0.8751 | 0.0916 | 9.55 | 0.000 | 0.6864 | 1.0638 | *** |
| CDD | 0.0003 | 0.0001 | 4.06 | 0.000 | 0.0001 | 0.0004 | *** |
| HDD | 0.0005 | 0.0001 | 4.92 | 0.000 | 0.0003 | 0.0007 | *** |
| LnSQFT | -0.0925 | 0.0103 | -8.95 | 0.000 | -0.1138 | -0.0712 | *** |
| T24 | -0.0002 | 0.0005 | -0.43 | 0.673 | -0.0011 | 0.0007 | |
| Tariff: Domestic | -0.0132 | 0.0045 | -2.91 | 0.008 | -0.0226 | -0.0038 | ** |
| Uses Photovoltaic | -0.0231 | 0.0079 | -2.93 | 0.007 | -0.0393 | -0.0068 | ** |
| | | | | | | | |
| | R-Squared | | | | 0.1477 | | |
| | Wald Test | | | F (6, 25) | 42.68 | Pr > F | 0.000 |

Several tests were run on the regression models to assure readers of their validity.  The regression showed no evidence of serious multicollinearity through the variance inflation factor test. We used robust standard errors clustered by builders to limit the effects of heteroscedasticity.

## CONFIDENTIAL Appendix C: Codebook for Symbol and Builder in Report

REDACTED