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Title 24 and HES Comparison

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EXECUTIVE SUMMARY

To express and rate the energy efficiency of newly constructed homes, California uses three Title 24 based metrics: compliance percentage, the Energy Design Rating, and the CAHP score. Builders, energy consultants, utilities, and researchers use these metrics variably for code compliance, utility incentive programs, and general marketing of a home's energy efficiency. These metrics each compare a proposed home to a reference home, all using Title 24's energy modeling engine and code interpretation rules. Home energy ratings outside of California rely on alternative metrics, including the Department of Energy's (DOE) Home Energy Score (HES). HES is becoming a more commonly used metric; it expresses a home's total annual energy use in comparison to existing building stock, and adjusts for climatic differences. HES uses a 1-10 scale, where 10 signifies very low home energy use.

The goal of this study is to analyze and compare the California-specific metrics with the national HES metric in terms of both process and results. The comparison datasets in this study consist of homes enrolled in 2013 code California Advanced Homes Program (CAHP) and homes developed for 2016 code CAHP research. CAHP homes must meet a certain performance level above code baseline, which is already very efficient in comparison to national home performance standards. Because of the high eligibility standards of CAHP, the initial expectation is that most CAHP homes will demonstrate a narrow range of HES results, i.e., from 7 to 10.

First, TRC developed a process that takes Title 24 energy models, parses their data, converts it to HES inputs, and then produces their HES. TRC ran the models from each data set through this process, analyzed the results, identified overall trends, and investigated individual building characteristics. The objectives of the study were to:

- Compare Title 24 and CAHP metrics with HES
- Compare and catalogue process differences including data collection, energy modeling, and meaningfulness of results
- Identify common trends in building characteristics that correlate with good or poor HES
- Identify outliers on the HES scale and the potential reasoning for these outliers

The conversion process effectively and efficiently produced reliable HES results from Title 24 energy models. Title 24 modeling requires a granular level of data collection to represent the energy efficiency components of a home. In some cases, converting from the detailed data required for Title 24 into a simplified data representation for HES proved difficult, but ultimately resolvable for most cases. The process differences between the two systems were not inconsequential, and also easily understood and documented in this report.

As anticipated, the majority of homes from both datasets received a HES of 7 or above although 22% of the 2013 code CAHP homes had a HES of less than 7, including some of with a HES of 4 and below. TRC identified that conditioned floor area is the single biggest predictor of HES since larger homes inherently use more energy, and therefore score lower. The number of bedrooms increases the number of assumed occupants and increases energy use for miscellaneous load and water heating. HES is not normalized by home size (CFA or bedrooms), so any increase in consumption lowers HES. While HES accounts for climate zone when calculating the final score, TRC was not able to thoroughly analyze the climate zone groupings to draw conclusions regarding climate zone and HES.

To investigate the impact of other building characteristics, TRC considered a subset of the homes with similar size, climate zone, and number of bedrooms. The observed trends were not consistent throughout the data and did not produce conclusive findings. It appears that attributes such as system efficiencies and envelope insulation R-values have a similar impact on HES. It does not appear that implementation of one single high performing measure can guarantee a higher HES. Rather, the combination of multiple high performance attributes together tends to improve HES.

1. Background and Introduction

TRC conducted a comprehensive comparison between California energy efficiency metrics and the Department of Energy's (DOE) Home Energy Score (HES). This comparison was based on a large existing dataset of homes built in PG&E territory as part of the California Advanced Homes Program (CAHP) during the 2013 version of the Title 24, Part 6 energy code (2013 code), and an existing data-set of energy models that TRC developed when designing CAHP's 2016 code offering. TRC compared the differences of the tools and scoring systems, and investigated the cause of any data outliers. This report includes an overview of the study, goals and objectives, research methodology, data analysis methodology, data sources, modeling selection criteria, analysis results, conclusions, and recommendations. Under the review of Resource Refocus, TRC developed the analysis methodology, performed the analysis and evaluated the results.

1.1 Overview of Study

The DOE developed the HES as an energy efficiency metric for new or existing homes. The score rates buildings on a scale from 1 to 10, where 1 is the least efficient and 10 is the most efficient. The score intends to provide a simplified miles-per-gallon style comparison tool for consumers to quickly judge the expected energy use intensity of a given home. Similar to other energy scores like RESNET HERS, California's Energy Design Rating (EDR) Score, or the California Advanced Homes Program's CAHP score, the HES is an asset rating based on energy modeling. In the case of the HES, the volume and detail of modeling data necessary to produce a score is far simpler than what RESNET or Title 24 energy modeling software platforms require. The benefit of this simplified approach is that it is relatively inexpensive to produce the HES. However, it is unclear whether this reduction in both data collection and modeling complexity results in a reduction in reliability, a lack of differentiation between buildings, or an increase in variability of HES.

1.2 Goals and Objectives

The HES is expected to gain traction nationally, and perhaps even within California, as a useful consumer-facing metric for comparing buildings. Therefore, it is important to understand how it relates to homes that take part in CAHP. Because of the high eligibility standards of CAHP, the initial expectation was that most CAHP homes will achieve narrow range of high HES results, likely from 7 to 10. The purpose of this study was to calculate the HES for CAHP homes to gain greater insight into HES generally, to understand where and why HES differs significantly from CAHP ratings, and to investigate the cause of any CAHP homes with a HES below 7.

1.3 Background Information

The industry uses a wide variety of metrics to express a home's level of energy efficiency and projected energy consumption. This study focused on four metrics, three of which are in use in California for various purposes: (1) the HES, (2) the CAHP score, (3) the Energy Design Rating (EDR), and (4) Title 24 compliance percentage. Of note, the HES system is intended for use with both existing homes and new construction nationally. The scale was constructed so that a HES of 5 indicates that the home's projected energy use falls within the 45th and 55th percentile of all homes within a similar region and climate.[1] This research only includes new construction homes in California. Due to the fact that new construction is more energy efficient than the existing building stock, and that California's rigorous and rapidly improving energy codes produce homes that are particularly energy

[1] The percentiles are based on an Energy Information Administration (EIA) nationwide survey in 2009 that collected residential energy consumption and built a database to reflect the existing building stock. More detailed information can be found from the U.S. EIA website: https://www.eia.gov/consumption/residential/data/2009/

efficient relative to both national standards and current California building stock, TRC anticipated that this research would yield narrow results at the upper end of the HES scale for all cases.

The basis of energy units between HES and Title 24 metrics is also different. HES uses total source energy, in MBtu. All three Title 24 metrics use Time Dependent Valuation[1] (TDV) energy, which is specific to California and measures the value of energy by commodity (electric vs. gas), climate zone, time of day, and other variations such as transmission constriction and source energy costs at peak production times.

Figure 1 summarizes the key features, similarities, and differences among the four metrics. More detailed introductions of each metric follow in sections 1.3.1 to 1.3.4.

	Title 24 Compliance	CAHP Score	EDR	**HES**
Scale Points	Percent energy reduction relative to a code baseline	0-100-250[2]	0-100-250	1-10
	The higher the compliance percentage, the better performance a building has	The lower a score is, the better performance a building has. A score of 100 is equal to the reference home		The higher a score is, the better performance a building has
Building Type	Single family homes, townhomes, duplexes, and low-rise multifamily homes			Single family homes, townhomes and duplexes
Reference Building's Code	Each specific Title 24 Code: e.g., 2008, 2013, 2016	2008 Title 24 Code	2006 IECC	An existing housing stock energy consumption database (2009 Residential Energy Consumption Survey (RECS) data)
Score System	Reduction of energy use between the proposed and the reference home	Energy use index of proposed relative to reference home. Kickers, e.g., additional score	Energy use index of proposed relative reference home.	Percentile rank of home's energy use intensity against

[1] Time-dependent valuation (TDV) factors, a statistical data for converting electric gas or propane to TDV energy, are used to evaluate a home's energy performance and the cost effectiveness of an energy measure. The factor was developed in 2005 by the CEC. The TDV factors have been updated in each code iteration (2008, 2013, 2016 and 2019). The purpose of developing the factors is to encourage a design team or a builder to design a building that performs better during the high-cost peak period.

[2] The CAHP score and EDR both claim 250 as their maximum possible value. This is not mathematically true. These maximum's are used to reflect the expectation that no rated home will ever demonstrate more than 2.5x energy use of the reference home. This is particularly true for residential new construction, where all homes are below 100 by definition due to code.

	Title 24 Compliance	CAHP Score	EDR	HES
	expressed as a percentage	reductions are available through the program for certain measures		a national database
Energy Unit Basis	TDV/sq.ft.	TDV/sq.ft.	TDV/sq.ft.	Total source energy MBtu
Regulated Loads (heating, cooling, ventilation and water heating)	Included	Included	Included	Included
Unregulated Loads (lighting, plug loads and appliances)	Not included	Included as defaults, except lighting which can be modeled	Included as defaults	Not included
PV Generation Credit	Included as a conditional offset, varying by code cycle and climate zone	Not included	Included	Included

Figure 1: Summary of Energy Efficiency Metrics

1.3.1 Title 24 Compliance Percentage

Compliance percentage is the primary metric used to demonstrate Title 24 compliance in California when following the performance compliance path. A proposed home that uses 10 percent less energy than a similar home built to prescriptive standards is said to show 10 percent compliance. Programs such as the CAHP, the New Solar Homes Partnership, and ENERGY STAR Home Certification have used compliance percentage as an eligibility metric during some code cycles, with eligibility requirements varying from 10 to 15 percent above code. The metric only considers the regulated energy end uses of heating, cooling, ventilation and domestic hot water (DHW). Additionally, compliance percentage is code-specific; the reference building changes with each code cycle. Therefore, a home with 15 percent compliance in the 2013 code will not achieve 15 percent compliance in the 2016 code. Energy use of both the proposed and prescriptive home is calculated using energy modeling software that the California Energy Commission (CEC) has approved for this purpose. Key aspects of compliance percentage calculations include:

- Relies on TDV energy use, normalized by home size
- Only includes regulated energy end uses of heating, cooling, ventilation and DHW.
- Includes photovoltaic (PV) generation on a conditional basis depending on the rules of each energy code
- Baseline reference changes with each code cycle
- Uses CEC-approved software
- Higher compliance percentages indicate more energy efficient homes
- Title 24 compliance requires that homes have a positive compliance percentage, which means the proposed energy budget cannot exceed the standard energy budget.

Homes from this research will by definition have a positive compliance percentage because that is necessary in order to comply with the CAHP eligibility requirements.

1.3.2 The CAHP Score

The CAHP score is a whole-house energy performance metric for a single family or a low-rise multifamily building that was used during the 2013 code offering. The CAHP score compares a proposed home to a California 2008 Title 24 code compliant home, and uses an indexed rating where a score of 100 is the exact equivalent to a home built to 2008 Code standards. As an example, a home that uses 20 percent less energy than a 2008 Code home would have a CAHP score of 80. The metric accounts for all energy end usages including heating, cooling, ventilation, domestic water heating, lighting, appliances and plug loads. The score does not factor in distributed generation (e.g. a photovoltaic system). Key attributes to the CAHP score include:

- Uses TDV energy, normalized by home size
- Includes all energy end uses, but not PV generation
- Uses the prescriptive 2008 Title 24 Code as the baseline reference
- Uses CEC-approved software for calculations
- A lower CAHP score indicates a more energy efficient home.

Because the CAHP score excludes the use of PV, it is impossible to reach a CAHP score below an inherent baseline of energy use specific to each building. This is typically in the range of 35 to 45 dependent on climate zone, home size, and other factors. The 2013 CAHP offering developed and adopted the CAHP score as its program metric. To be eligible for the program, participants must achieve a CAHP score of 84 (inclusive of kickers) or lower.

1.3.3 Energy Design Rating (EDR)

The Energy Design Rating (EDR) is another metric in California's 2016 residential compliance software that expresses home energy performance in accordance with CALGreen provisions (Title 24, Part 11). It is widely expected to become the primary energy efficiency metric for code compliance with the 2019 code, supplanting compliance percentage. Like the CAHP score, it uses an indexed rating where a lower EDR indicates a more energy efficient home. However, the EDR reference case is the 2006 International Energy Conservation Code (IECC). This reference case was chosen to better align with RESNET HERS, a nationally recognized energy efficiency index. The EDR accounts for all energy end uses, including PV generation, in TDV. A summary of the EDR is as follows:

- Uses TDV energy, normalized by home size
- Includes all energy end uses, plus PV generation
- Uses 2006 IECC as the baseline
- Relies on CEC-approved software for calculation
- Equates a lower EDR with a more energy efficient home, and assigns a score of zero or less to indicate a Zero Net Energy home, on a TDV basis

The 2016 CAHP offering will use the EDR.

1.3.4 Home Energy Score (HES)

The DOE HES is an asset-based scoring tool that quickly assesses a home's envelope and major energy systems, and provides recommendations for cost-effective retrofits. The HES rates a home on a 10-point scale, where a

10 corresponds to highest efficiency (lowest energy use) and a 1 corresponds to the least efficient (highest energy use). It is designed to reflect the rated home's energy use relative to the existing housing stock in accordance with the Energy Information Administration RECS 2009 data. Key attributes of the HES include:

- Uses total source energy, normalized by climate zone but not by home size
- Includes heating, cooling, ventilation and domestic hot water, plus PV generation
- Is based on a percentile ranking relative to the existing housing stock
- Relies on the DOE's HES scoring tool, which is a simplified energy modeling platform relative to Title 24 models, for calculations
- Assigns higher HES rating to more energy efficient homes

Unlike CAHP, EDR, or Title 24 Compliance, which are California specific, HES is a nationwide metric.

2. METHODOLOGY

This section outlines the overall method used to perform comparative analysis between Title 24 metrics and HES. First, the two systems were analyzed for their respective inputs and outputs to obtain the corresponding HES inputs for Title 24 models. TRC then developed a tool to convert the Title 24 model inputs to HES inputs and run the HES tool API. The results from this process were used to do the final analysis comparing the two types of metrics and investigating the similarity and differences between them.

2.1 Title 24 and HES System Comparison

TRC created a comprehensive comparison between energy efficiency metrics in use in California and the DOE HES. This comparison was based on a large existing dataset of homes built in PG&E territory as part of CAHP under the 2013 version of the Title 24, Part 6 energy code (2013 code), as well as an existing dataset of energy models developed by TRC when designing CAHP's 2016 code offering. This document compares the differences between the processes, modeling inputs, and data collection requirements for each of the systems.

2.1.1 Data Collection

Title 24 modelers use construction planning documents to gather the necessary input data for the simulation. Architectural plans, site maps, and equipment specification sheets are the primary sources. Those may be supplemented by direct knowledge of the builder's norms, or assumptions on typical efficiencies when plan sets and specific equipment are not yet complete or specified. The modeler performs plan take-offs to determine the building's geometry, orientation, and surface areas. This is true for window, wall, floor and attic areas. The modeler will also reference mechanical or electrical plans to determine equipment types and locations (such as water heating or space conditioning equipment). Finally, the modeler will determine nuanced modeling elements such as window overhangs from elevation pages in the plan set. When available, the modeler will use the window schedule and window specification sheets for window areas and NFRC-rated thermal properties. The modeler will use equipment specification sheets for equipment efficiencies such as AFUE, SEER, EER and Energy Factor.

The quality of data used will vary depending on the time of modeling relative to construction and the level of plan review rigor anticipated. Early modeling or models sent to non-rigorous building departments will often rely on less complete data, builder norms, and assumptions. Models finalized deep into the design process or those that need to hold up to detailed review will rely on more accurate and definitive data sources. Due to program rules, CAHP program models go through rigorous review for accuracy and are typically finalized quite late in the construction process. They are on the accurate end of the spectrum of Title 24 model quality.

The HES was conceived initially to serve the existing home market. Therefore, the modeling inputs are selected based on what is easy to learn through a simple and short field visit. An HES assessor collects information about the home during a home walk through. The DOE intention was that a typical walk through would take under one hour in the field. Some of the modeling inputs collected (and discussed in greater detail in the next section) are simplified so that the assessor can produce them within the field visit.

For new construction, the HES modeler uses a process and data set similar to what a Title 24 modeler uses. However, the simplification of HES modeling inputs discussed above results in a less detailed plan take-off process.

For the purpose of this research—which includes converting from Title 24 modeling inputs into HES inputs—TRC developed a set of mapping rules that convert detailed Title 24 modeling inputs into less detailed HES inputs. In some cases, the simplification of input data may result in approximated HES inputs that differ from results that would have occurred had the model been created for HES inputs initially. As an example, when a home has multiple heating systems of differing efficiency, the mapping ruleset will select the higher efficiency system for use in HES modeling rather than attempting a weighted average on load output. These approximations are not expected to have any significant impact on HES results, as the HES scoring system granularity is so low.

2.1.2 Modeling Inputs

This section individually evaluates and then compares both Title 24 and HES model requirements. The comparison provides the basis for conversion of Title 24 inputs to HES inputs.

Title 24 Modeling

As discussed in the previous section, Title 24 modeling requires detailed and precise modeling inputs. Both CBECC-Res and EnergyPro—the two primary Title 24 software programs—use a detailed building tree to construct the model. In the tree, whole-building data points such as address, climate zone, and square footage are applied at the highest level. Building components such water heaters, space conditioning equipment, walls, and attics are entered as subset branches to the whole-building zone. Some branches can expand further as needed to represent the building, such as in the case of multiple space conditioning zones or wall components. Further modeling details such as equipment efficiencies and window thermal properties are assigned to each component. Figure 2 shows an example building tree from CBECC Res. Most input fields are found by double clicking components of the tree and entering data into a pop-up window.

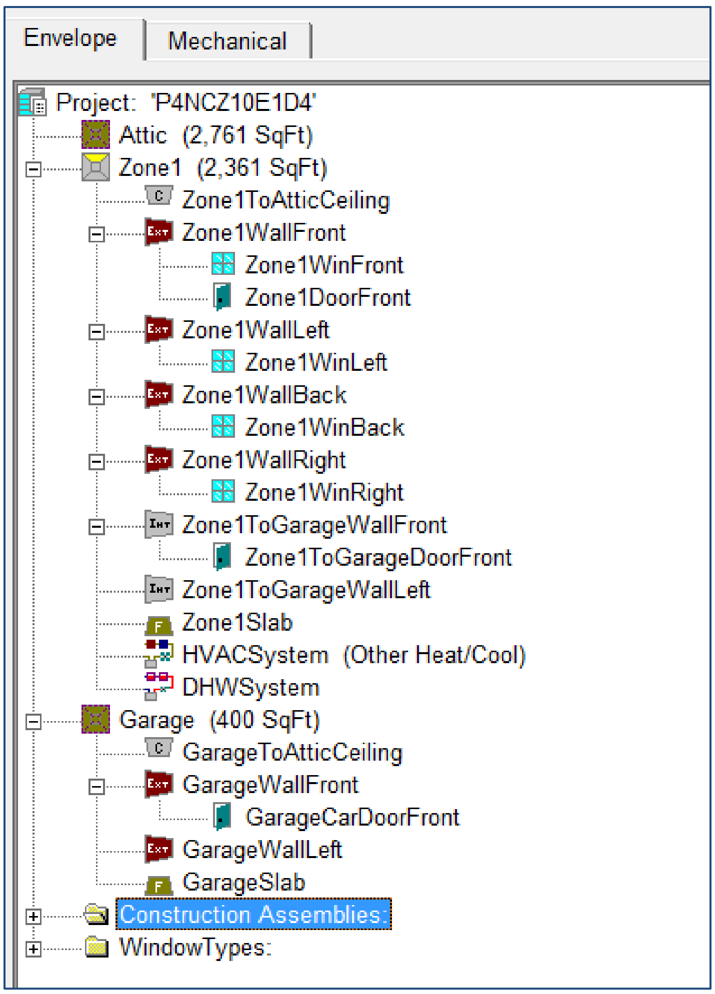

Figure 2: CBECC-Res Building Tree Example

An experienced modeler will need approximately four hours to develop a basic single family home model from scratch assuming access to plan sets and specification sheets for all components. Models for multi-zonal homes with a complicated geometry and a wide variety of surface areas could require as much as 20 hours to develop.

The modeler has control over the entire building tree, its structure, and specific values for each input within the model. For example and as illustrated in Figure 3 and Figure 4 below, a wall assembly contains the frame depth and spacing, the specific R-value and type of cavity insulation, the specific R-value and type of continuous insulation, the exterior surface, the wall orientation, and the precise surface area of each distinct wall section.

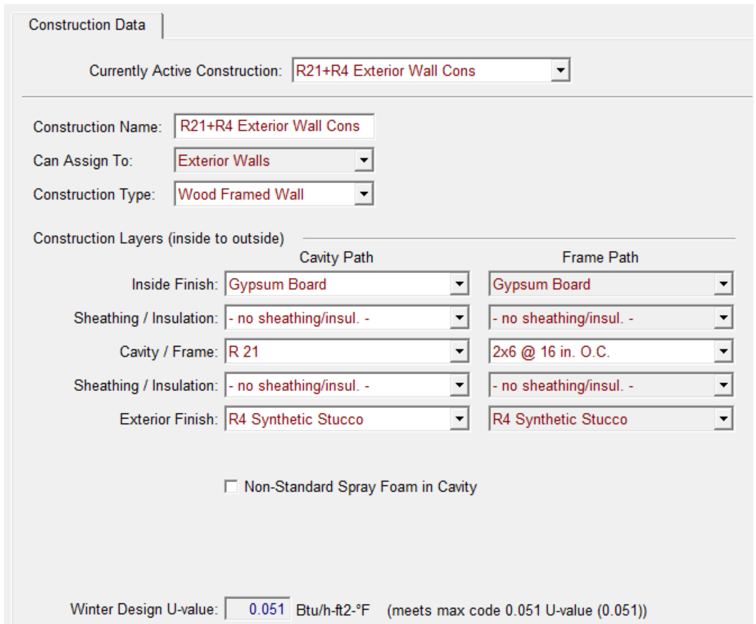

Figure 3: CBECC-Res Wall Assembly Example

Walls

Is this home a Townhouse or Duplex?: **Yes / No** Position of Unit: **Middle / Right / Left**

Wall Characteristics: **Front** or **All** (circle one)

Construction: **Wood Frame / Wood Frame with rigid foam sheathing / Wood Frame with Optimum Value Engineering (OVE) / Structural Brick / Concrete Block or Stone / Straw Bale**

Exterior Finish: **Wood Siding, Fiber Cement, Composite Shingle or Masonite Siding / Stucco / Vinyl Siding / Aluminum Siding / Brick Veneer**

Wall Insulation: **R-0 / R-3 / R-7 / R-11 / R-13 / R-15 / R-19 / R-21 / R-27 / R-33 / R-38**

Figure 4: HES Wall Component Assignment Example

HES Modeling

HES modeling occurs through an online portal that DOE manages. The user submits HES inputs into existing data fields on an approximately three-page online form. Alternatively, more sophisticated users can automate the process through an API with the DOE's system. In both cases, all available input fields are pre-assigned, and the modeler does not have the ability to add components, structure a building tree, or assign multiple systems or surfaces. Instead, a modeler must use area-weighted averages to bundle and approximate multiple surfaces and similar approximations to represent multiple space conditioning or water heating systems. In some cases the data required for HES are qualitative or descriptive rather than quantitative specifications (this is due to the requirement of a simplified data collection process detailed in the section above). Due to the simplicity of the modeling inputs, the DOE tool infers and assigns some building aspects from default assumptions and algorithms.

HES models take as little as 20 minutes to input into the HES portal or API once the data is collected. The modeler has no control over the input structure and often must choose from a short list of input options. For example and as shown in Figure 8 above, a wall is modeled from only four inputs with limited options for each: the orientation, the construction type, the exterior finish, and the cavity insulation value.

Figure 5 summarizes the number of inputs by building component category for a typical residential home. In addition to reducing the number of inputs from 70 to 50, HES also requires less precision or detail on the inputs it does use. Please refer to Appendix A for the detailed list of feature inputs.

Data Input Category	DOE HES	CEC CBECC-Res
House Characteristics	9	10
Envelope	27	39
Heating, Cooling and Hot water Heating	14	21
TOTAL	50	70

Figure 5: Number of inputs for a typical home

2.2 Title 24-to-HES Conversion Process Development

TRC developed a process by which any single-family residential Title 24 energy model can be used to generate a HES for that same home. The process applies to Title 24 models originating from either CBECC-Res or EnergyPro. The process is designed for the most recent versions of each software, but is also compatible with previous software versions in all tested incidences. Also, the process functions with models from either the 2013 or 2016 code. This conversion methodology yields Title 24 results, HES results, and a complete data set of modeling inputs used for each system. Of critical importance is that the conversion process is built to convert large volumes of Title 24 energy modeling quickly, and with minimal manual effort.

The conversions process has the following steps:

- Run Title 24 energy models for Title 24 results
- Generate the Title 24 XML data file
- Parse the input data from the Title 24 XML file
- Map the parsed Title 24 input data to HES input data
- Communicate with the DOE’s HES input API to generate the HES
- Correlate HES results to Title 24 results for the same building

The following sections detail each step in the process.

2.2.1 Run Title 24 Energy Models

TRC runs each Title 24 energy model through the code compliance simulation process. Each model is simulated via the software engine used to build it; EnergyPro for .BLD files or CBECC-Res for .RIBD files. However, each software platform references the same CEC-approved simulation engine and thus will yield identical results given identical inputs. EnergyPro files are run individually from within EnergyPro itself. In the case of CBECC-Res files, TRC uses a batching tool called CBECC.exe, developed by Ken Nittler. The batching tool runs a simple script which calls each .RIBD file, initiates the CBECC-Res simulation process, and returns Title 24 simulation results.

Running the Title 24 simulation generates all Title 24 resultant data. This includes, but is not limited to, compliance percentage, EDR, the CAHP score, and energy end use results in kWh, therms and kTDV. Once simulation is complete the software stores the Title 24 data within the .BLD or .RIBD file itself. This data is necessary for this research's comparisons. It is also necessary to populate the Title 24 XML file necessary for the next process steps.

2.2.2 Generate Title 24 XML files

When the Title 24 energy simulation is run, a user can select specific outputs for the software to generate. One of these output options is the Extensible Markup Language (XML), which takes the building data from the model and translates it to a plain text file format that can easily share the data on the internet and with other applications. This plain text file contains all of the building information in a readable format, which is then used in further steps for the analysis. CBECC-Res generates the required XML file while running the Title 24 simulation directly. EnergyPro generates a different XML file that CBECC-Res can read and convert into the XML preferred format.

2.2.3 Parse input data from Title 24 XML files

TRC developed a proprietary Title 24 XML parsing tool contained within an executable file. The executable takes the Title 24 XML output file and converts it into a Comma Separated Value (CSV) file, rearranging the data into a more usable format. The XML is a text-based file that contains the data within a logic-structure using a system of tags, elements, and attributes. For example, one line in the standard XML might read: <NumStories>2</NumStories>, which indicates a 2 story building. In contrast the CSV is a simple spreadsheet, with each column referring to a data point, and each row to an individual XML file. TRC defined the CSV structure and column headings. Following the prior example, number of stories is stored under the *NumStori*es header. The XML parsing tool reads the XML schema, identifies each data point, and stores it in the CSV structure. For homes run in all four orientations, the XML parsing tool represents each orientation as a separate row.

The parsing tool is structured to apply to multiple XML files sequentially. If a user saves multiple XML files within the Windows folder, the parsing tool will call each one and apply functions as specified by the user. For example, the parsing tool is able to open, parse, map the inputs, contact the HES API, run the HES simulation, and compile the results on multiple files in a single use. Other functions exist within the tool, but are not applicable to this research.

2.2.4 Map Title 24 Input Data to HES Input Data

TRC developed a mapping ruleset that takes the parsed Title 24 input data and produces equivalent input fields for use with the HES API (Refer Appendix A for detailed list of HES and Title 24 inputs). This ruleset is contained within a dynamic link library (DLL), which is called by the XML parsing executable file.

For some basic inputs, the DLL simply assigns the Title 24 version of the input to the HES version. For example, the tool works this way for number of stories and conditioned floor area. For other input data points, the mapping strategy is more complicated. The types of inputs, mapping strategies, and examples for such data points follow.

- **Condensing multiple entries using summations**: When there are multiple, summable, versions of a building component in Title 24 modeling, but HES can only accept a single entry—such as in the case of window surface area—the DLL sums the multiple parts. This applies to window, wall, attic, and floor-overhang areas.

- **Condensing multiple entries using area-weighted averages:** For some data points, particularly thermal properties related to surface areas, the mapping calculates an area-weighted average. The DLL applies this strategy, for example, to arrive at a single HES entry for the U-value and solar heat gain coefficient (SHGC) of all windows attached to each side of the house in the Title 24 model. This method also applies to skylights and wall, attic, and floor R-values.
- **Condensing multiple systems:** For space heating, space cooling, ducts, and water heating systems, HES limits the quantity of each system type to only two, while Title 24 does not limit the quantity. It is rare that a home has more systems than the HES allows. However, in the cases where this occurs, the DLL first determines if some of the multiple systems have identical efficiency specifications, and then ignores the redundant versions. If there are too many distinct efficiencies for this operation, the DLL selects the best-case efficiencies for each available system type. This presumes that the best-efficiency systems would be selected to serve the greater portion of the building's needs, and that low-efficiency system, if installed, would be relegated to back up service or specific task-needs.
- **Multi-input translations:** Some of the HES inputs call for a selection from a discreet list of options. The information required to determine the accurate option is often not directly evident from a single Title 24 data point. Instead, the DLL applies algorithms that reference multiple Title 24 inputs to arrive at the HES input. For example, in HES, external-rigid insulation on the walls is input as a component-feature of the wall construction assembly (along with the framing type). In Title 24, the rigid external layer is modeled distinctly and separately from the framing. The DLL reviews both relevant Title 24 data fields and selects the appropriate combined input in HES.
- **Conforming to HES rules**: HES includes a number of data validations behind the scenes to ensure the user isn't modeling a physical impossibility. Some of these validations have been shown to include design flaws and are triggered even when the underlying input is actually accurate.
  - **Window area cutoff**: HES assigns the wall areas using an arithmetic formula based on the conditioned floor area and average ceiling height. HES assumes that the home is a perfect rectangle with a 3:5 ratio between the side wall and the front/back walls. For example, a 2,363 square foot home with 9 foot ceilings is assigned a side wall area of 37.65 ft. x 9 ft. = 338 sq.ft. In reality, U-shaped and L-shaped floor layouts will have significantly higher surface areas than this arithmetic assumes. The application of this system results in an underrepresentation of wall surface area, and elevated HES results, for homes with complicated geometric footprints. The extent of this particular bias cannot easily be tested and so was not part of this research scope.

    In addition to divergence in modeling results between HES and Title 24, it is particularly problematic when the total window area modeled in Title 24 exceeds the wall area assumed by HES. In these cases, HES will reject the window area summation as a physical impossibility and result in an error. This is exceedingly rare, and only occurs in heavily glazed homes with intricate layouts. To avoid failed runs in these rare cases, the DLL assigns any excess window area from one surface to the one immediately clockwise to it so that all window area is accounted for in the HES simulation.
  - **Radiant barrier exception:** HES assumes that all roof-deck insulation is cavity insulation between rafters. It does not account for the real possibility that above-deck rigid insulation can also be installed. HES further assumes, accurately, that a radiant barrier is incompatible with below-deck insulation. In the case that above deck insulation and radiant barrier are both modeled in Title 24, the DLL cannot accurately represent the full roof deck assembly. Instead it will ignore the radiant barrier, as its energy reduction benefit is significantly lower than the benefit from the rigid insulation.

The DLL, when called by the parsing tool, takes data points from the Title 24 CSV and converts them to HES inputs. These inputs come in the form internal objects (SOAP) that are sent directly to the DOE's API tool (described in the following section). The input items are also stored in a HES CSV for reference.

2.2.5 Communicate with the DOE's HES Input API

Generating a DOE HES requires accessing the HES Sandbox environment located at https://sandbox.hesapi.labworks.org/st_api/serve. Access to the API methods needed is accomplished via SOAP Web service calls. It is a three part process.

Step 1 requires the creation of a new building assessment case. The assessment case uses a subset of the HES values determined from the mapping. If for any reason the building assessment case is not created, the parsing tool will skip the second and third steps and move on to the next XML file in the folder.

Step 2 is the submission of building inputs and can happen in multiple stages. However, the XML parser tool handles this in just one call, sending the remaining HES inputs from the mapping.

Step 3 will call the HES API method that calculates the base home energy use and will then generate the HES if there are no invalid inputs from Step 2. If there are invalid inputs from Step 2, the Web services call will return a detailed list of the inputs and reasons for failures.

2.2.6 Retrieve and Correlate HES Results

The XML parser tool appends the HES results to the output elements generated while processing an XML file. These are stored in the CSV file as additional data points to each line-item. Since this entire parsing system can be used on multiple XML files sequentially, and each XML file may represent four orientations, the CSV result will contain multiple rows each representing a distinct plan orientation.

2.3 Implementation

TRC ran the conversion process with files from two data sources; PG&E's 2013 code CAHP participant base and statewide research files developed for the 2016 code CAHP offering. TRC ran all files in each data set to eliminate any possibility of selection bias. TRC removed research selection bias by eliminating any selection process from the two data sets; however, some score bias remains. For example, by their nature, these two data sets only include highly efficient buildings, constructed above California code, and well above national codes. It was therefore expected that this research would demonstrate that above-code, newly constructed California homes will achieve Home Energy Scores in the 7 to 10 range, and that the continuum of home scores evaluated using Title 24 metrics will be mirrored in the HES. TRC assessed the root cause for outliers in the HES results, both in the case of being outside the expected range and/or being in the range but not in the same place in the continuum of scores. To ensure unbiased research, TRC subcontracted to Resource Refocus to review this analysis and provided comment or verification on the results.

2.3.1 Data Sources

- **PG&E's 2013 Code CAHP Projects:**

  As of March 15, 2017, PG&E's 2013 code CAHP offering received 341 projects, consisting of 15,124 building lots. TRC's database from this program cycle includes 7,026 plans. Those plans have an average compliance of 18 percent and an average CAHP score of 76. Over 99 percent of these plans are in cardinal orientation; four distinct plans represent one building design. However, as each orientation has its own unique energy dynamic, compliance percentage and CAHP score, TRC treated each plan-orientation as a unique case.

  Since these homes were from real program participants in PG&E territory, this research's analysis only covers 6 of California's 16 climate zones. These climate zones are CZ02, CZ03, CZ04, CZ11, CZ12, and CZ13. The 2013 code compliance percentage ranged from 1 to 57 percent, and the corresponding CAHP scores ranged from 86[1] to 51. TRC analyzed various home characteristics and system types including, but are not limited to, 1 to 3 floors, 6 to 28 percent glazing to floor ratio, R30 to R60 ceiling insulations, R11 to R23 wall insulations, gas furnaces, split AC systems, heat pumps, gas water heaters and heat pump water heaters.

Figure 6 demonstrates the distribution of each climate zone and

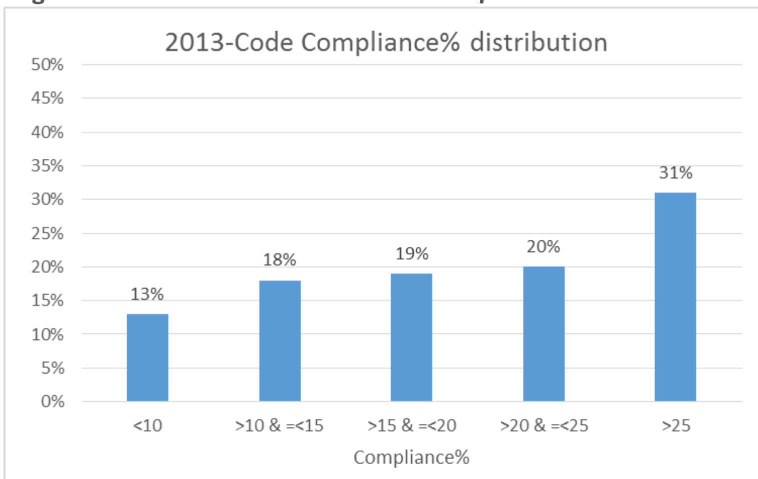

Figure 7 provides the percentage better than the code distribution.

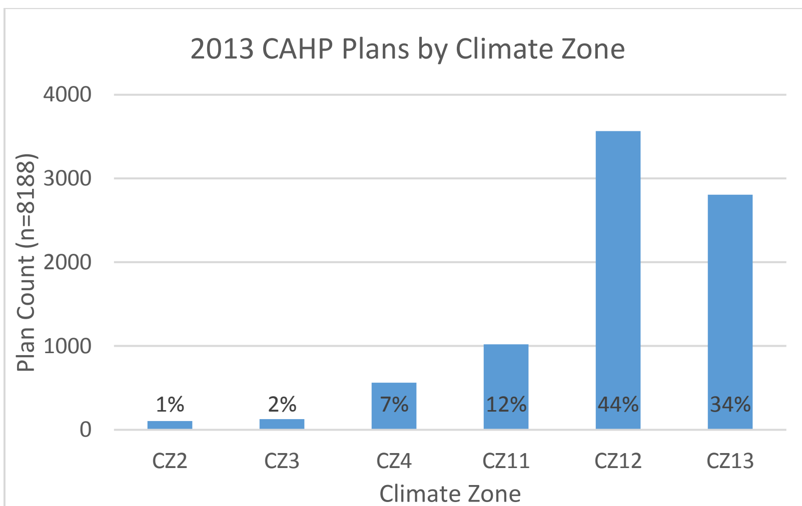

Figure 6: 2013 CAHP Plan Distribution by Climate Zone

[1] CAHP includes a 3 point program kicker for homes that achieved a high efficacy lighting credit. The HES construct does not include lighting energy. Therefore the CAHP scores used for this research are the modeled scores only, without any kickers. Hence some CAHP scores that appear to exceed the program eligibility requirement of 84 or lower.

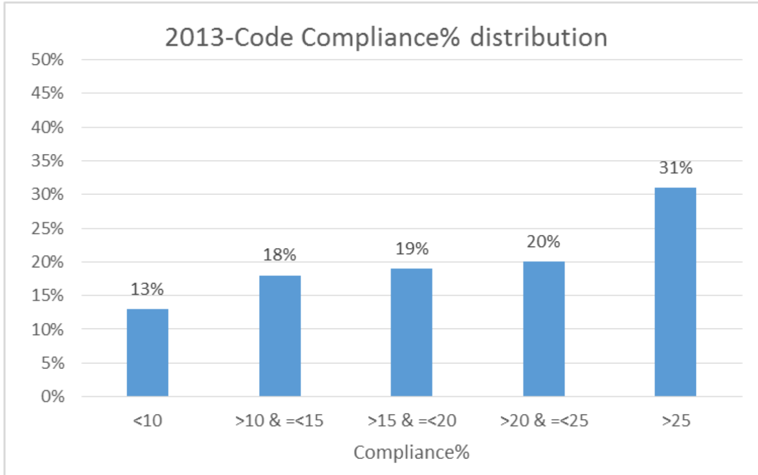

Figure 7: Compliance % distribution for 2013 Code CAHP projects

- **Statewide 2016 Code CAHP Research Homes**

  TRC received a contract from PG&E to develop the 2016 code CAHP offering. TRC developed research energy models based on four prototypes that TRC identified as collectively representative of the common home seen in prior CAHP participation. P1 is a CEC prototype used for all Title 24 codes and standards research. The other three prototypes are former CAHP participants. Figure 8 shows the basic details of each of the four prototypes.

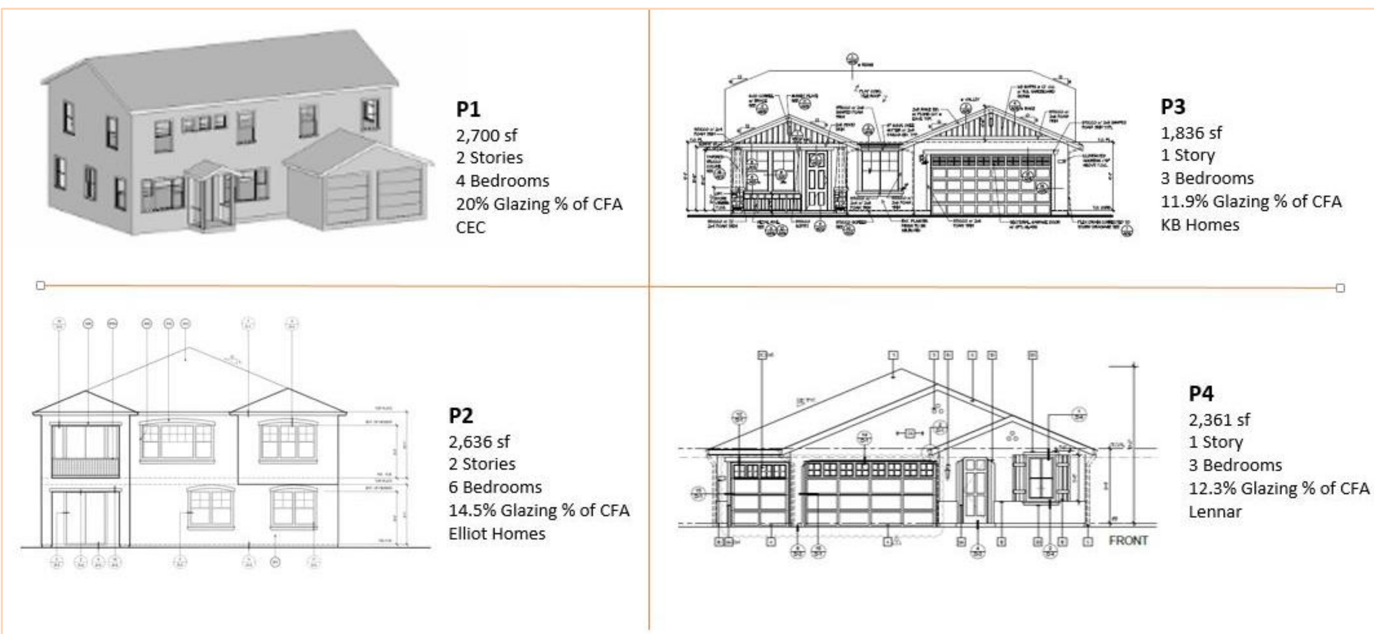

Figure 8: 2016 CAHP Research Prototypes

The 2016 code CAHP research consisted of analysis of over 50 different measure packages for all prototypes, across all 16 California climate zones. The energy measures included, but were not limited to, the 2016 code prescriptive requirements with high performance HVAC systems and/or high performance water heaters and the 2019 code prescriptive requirements. However, heat pump space heaters and heat pump water heaters were not covered in the statewide CAHP development research for 2016 code. With the combination of prototypes, energy measure-packages and climate zones, TRC developed 1,924 energy models in CBECC-Res 2016.2.1. All 1,924 models were included in the analysis.

2.3.2 Selection Criteria

TRC ran nearly all plans available from each data set to produce a HES for comparison against Title 24 metrics. There were few known or anticipated causes of a data selection process. In no cases were plans selected based on an intention to demonstrate favorable results; methods to avoid selection bias follow below. TRC was interested in exploring the nuances of the HES, and any differences within the results are cause for improved knowledge and understanding, not as a cause to doubt the quality or functionality of any of the metrics. Overall, TRC anticipated that over 95 percent of homes from this data set would be included. TRC documented the existence and cause of each exception. Some potential causes of data selection include:

- **Building aspects that cannot be appropriately mapped from Title 24 modeling inputs to Home Energy Score inputs**: TRC anticipated that there may be a small volume of homes that cannot be easily mapped from Title 24 inputs to HES inputs. In general, these files were managed on a case-by-case basis as to the cause of a secondary mapping process or the exclusion of that plan type from the research scope. For example, HES cannot manage homes with more than two attic types, more than two floor types, or more than two heating or cooling systems. If a file from the Title 24 dataset exceeds those limits, TRC first determined if an averaging of multiple components is reasonable and appropriate. If so, TRC documented the method of averaging for those files. If not, TRC excluded that plan from the research scope and documented the cause. Additionally, there may be some obscure heating, cooling or water heating system or distribution types that exist within the models of the Title 24 data set that cannot be appropriately represented in the HES inputs. No such examples were revealed. Had they been, TRC was prepared to determine an appropriate course of action and document those decisions with Resource Refocus's oversight and review, be it to exclude the data point, or to choose an approximation within the HES modeling options.
- **Duplicate files:** Some modeling files from the 2013 code CAHP offering dataset are duplicates. Some builders use the same plan sets on multiple projects. All plan sets were included as part of the final analysis as the other building characteristics can still differ.
- **High-efficacy lighting files:** CAHP offered a bonus measure, worth a reduction of three CAHP points, for homes that complied with a high efficiency lighting credit that they earned for meeting a more stringent lighting standard. Since the HES assumes default lighting energy use for all files, it is not capable of differentiating between a house that took the high efficiency lighting credit and the same home design that did not. TRC removed the high efficiency lighting credit from all homes that took it, essentially raising the CAHP score by three points for those cases. In some instances, where homes were enrolled both with and without the high efficiency lighting credit, this led to duplicate plan types. Those duplicates were excluded from the analysis. TRC conducted similar treatment for the DOE Zero Energy Ready, early code adoption, low energy use and ultra-low energy use bonuses.
- **Data errors in the data set:** A preliminary review of the existing 2013 code CAHP data set revealed a need for data integrity review and data clean up. For instance, some database records were blank in fields that should have had a value (such as the CAHP score). In other cases, data was outside the expected bounds, such as one plan's compliance percent listed at 71, not-coincidentally the same as the CAHP score for that same project. TRC reviewed the dataset and cleaned up any discrepancies or errors if possible, using Title 24 modeling files already on record that back up the true aspects of each energy model (even if that data was inaccurately entered into the database). In some rare circumstances where an accurate representation could not be established, TRC excluded the plan from the research scope entirely. Such selection choices were documented and submitted as part of the research results to comply with review on potential selection bias. Overall, fewer than 25 files required such treatment.
- **Broken versions of CBECC-Res and EnergyPro:** The modeling engine behind CBECC-Res 2, 2b and 2c as well as EnergyPro 6.2 contained calculation errors and reporting bugs that were corrected in subsequent releases of the compliance software (CBECC-Res 3/EnergyPro6.3 and later). The Energy

Commission decertified these early software versions on October 13, 2014. In some instances, CAHP accepted files from earlier versions before the decertification date. TRC ran all files from all versions; however, running simulations in these original decertified modeling platform software versions may cause inconsistent results.

- **Adding PV simulations:** As CAHP does not permit PV modeling, neither dataset contains any files with PV panels. However, Title 24 modeling does allow conditional compliance credit for PV in each code cycle, and the HES also includes PV modeling as a component. Due to time and budget constraint, TRC did not evaluate the relationship between PV modeling in Title 24 versus HES.
- **Additional files:** TRC intended to develop additional models as directed by PG&E to better test certain home aspects that are underrepresented in the existing models, but did not see the value of this exercise during the course of this research.

2.4 Analysis

TRC compiled the results from the HES API to assess the results and analyze trends regarding primary causes for variation between HES and CAHP scores including: climate zone, orientation, home size, number of bedrooms, number of stories, equipment types, and similar common factors that may be cause for differentiation. Throughout the analysis, TRC kept the two datasets, the 2013 code homes and the 2016 code CAHP research homes, separate. As previously stated, the 2016 code CAHP research homes are less diverse in home size and layout than the 2013 homes and may have inappropriately skewed the results if combined with the more diverse 2013 dataset. Resource Refocus reviewed and performed oversight on TRC's analysis.

First, TRC compared the predicted performance for the same homes calculated from the two tools, DOE's HES online tool and the Title 24 software platforms, to understand the similarity and the differences between the two tools' predictions. Next, TRC further investigated individual characteristic analysis results to understand the possible reasons and trends for the correlation between the scores, such as particular building characteristics or systems. Finally, TRC identified and analyzed outliers both in cases of low HES or if a home did not fit within the same place on a continuum of scores as predicted by the Title 24 metrics.

2.4.1 Comparison of HES and Title 24 Metrics

To broadly understand how Title 24 metrics (i.e., compliance percentage, CAHP score, and EDR) compare to HES, TRC conducted correlation analysis. The purpose of this exercise was to establish the statistical summary of the similarity and the differences between the two tools' predictions. Hence, TRC was able to determine how the 2013 code PG&E CAHP homes and statewide 2016 code CAHP research homes perform in the nationwide home rating system.

2.4.2 Analysis of Specific Inputs

TRC investigated specific building characteristics and analyzed HES outliers. The purpose of the more granular analysis is to identify which, if any, building characteristics have significant influence on the HES. TRC conducted a correlation analysis of the HES with each major building characteristic and system. This includes:

- Conditioned floor area (CFA)
- Climate zone
- Envelope insulation, including walls and attics
- Window performance (i.e., U-factor and SHGC values)
- HVAC system and efficiency
- DHW system and efficiency

TRC analyzed conditioned floor area and climate zone impacts with the full data sets. Then, in order to better assess individual characteristics and systems, TRC looked at subsets of 2013 code CAHP and 2016 code CAHP research homes that had similar or the same characteristics, thus eliminating the influence of characteristics other than the ones under investigation. The subset of 2013 code CAHP and 2016 code CAHP research homes are designated through the filters in Figure 9 and Figure 10 below.

Feature	Selected Value(s)	Rationale
Climate Zone	CZ 12	CZ 12 has the largest portion of plans (44%)
CFA Range	2,200 to 2,400	This range has the largest portion of plans in CZ 12, and spans the median home size in CA so is therefore representative of normal construction
No. of Bedrooms	4	4 bedrooms is most common in CZ 12 in the above CFA range

Figure 9: Selected Variables for Additional Analysis of 2013 Code

Feature	Selected Value(s)	Rationale
Climate Zone	CZ 12	Consistent with 2013 code CAHP homes Selection
CFA Range	1,838, 2,361, & 2,700	Only 2,636 CFA homes were excluded as they had 6 bedrooms; the median home size in CA is selected with 3 out of 4 type of home sizes
No. of Bedrooms	3 and 4	Both 3 and 4 selected to have a decent sized subset

Figure 10: Selected Variables for Additional Analysis of 2016 Code

Finally, TRC identified and analyzed outliers both in the case of a HES below 7, if discovered, or if a home's HES did not fit within the same place on a continuum of scores as predicted by Title 24 metrics. For example, TRC further investigated the potential reasoning as to why a home would achieve a high compliance percentage, a low EDR, but also low HES. Some possible reasons for outlier cases include:

- The impact of using different weather files or poor climate zone overlaps
- An unvented attic configuration, which can be modeled in the CBECC-Res software, yet is not an option for the HES tool
- Nontraditional equipment or distribution types
- Conditioned floor area, especially as Title 24 metrics normalize by square foot and HES does not
- Use of a decertified Title 24 modeling tool
- Differences between PV modeling allowances

3. Analysis Results

The results show that most plan types (78 percent of 2013 code CAHP plans and 94 percent of 2016 code CAHP Research Homes plans) received a score of 7 or above. However, there is a significant volume of plans (22 percent of 2013 code CAHP plans) scoring between 1 and 6, with most (21 percent) scoring between 4 and 6. The distribution of 2013 and 2016 CAHP plans on the HES scale is shown in Figure 11. This analysis anticipated HES results of 7 or above for almost all homes. The unexpectedly large number of homes with scores below 7 led to further investigation to identify potential causes for sub-7 scores.

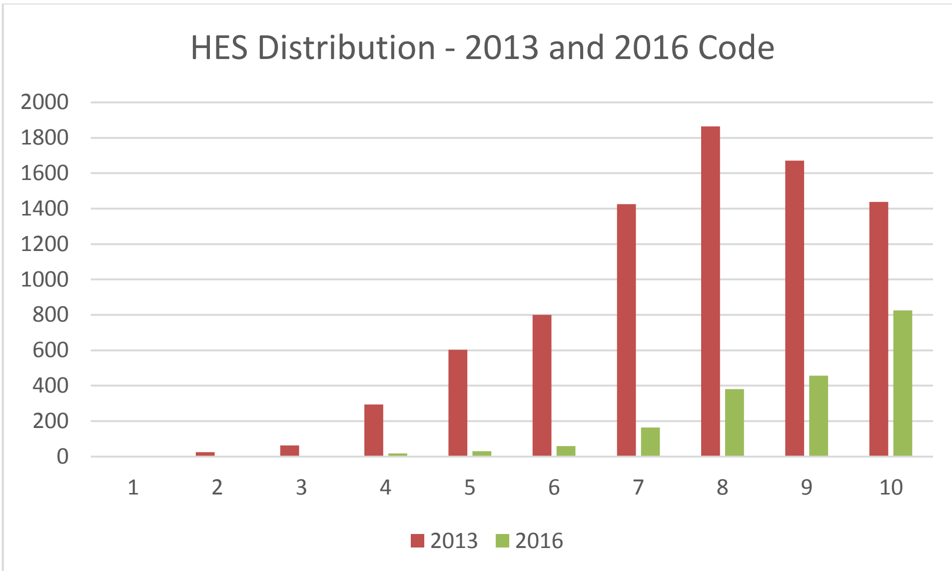

Figure 11. 2013 and 2016 CAHP Plan HES Distribution

3.1 Comparison of Metrics

HES ranks homes on a scale of 1 to 10, with 10 being the low energy use compared to existing building stock. CAHP and EDR each use a scale of 0 to 250, with lower scores signifying better energy performance in comparison to a reference home (defined to be a 100 on each scale. As part of the analysis, TRC analyzed whether a trend exists between HES and CAHP or EDR. The trend was expected to show an inverse correlation between HES versus CAHP or HES versus EDR; meaning, lower CAHP score or EDR would correlate with higher HES results.

3.1.1 2013 Code CAHP Homes

The following box plots demonstrate a range of statistical distribution of the data correlation between CAHP and HES results. As shown in **Error! Reference source not found.** the 2013 code CAHP data did not result in the expected trend. Instead, the average CAHP score (as identified by the black dotted line) remains fairly consistent among the HES bins. Additionally, the two mid quartiles (middle 50 percent of data points) and total range of CAHP scores for each HES bin are also fairly consistent across the scale, with the exception of HES 1-3, where the sample size is small compared to the rest of the bins. TRC investigated this further by isolating a single climate zone to see if the variation in CAHP and HES results among different climate zones was obstructing any other potential trends. The results for only climate zone 12 are shown in **Error! Reference source not found.**; no clear trend exists between CAHP score and HES.

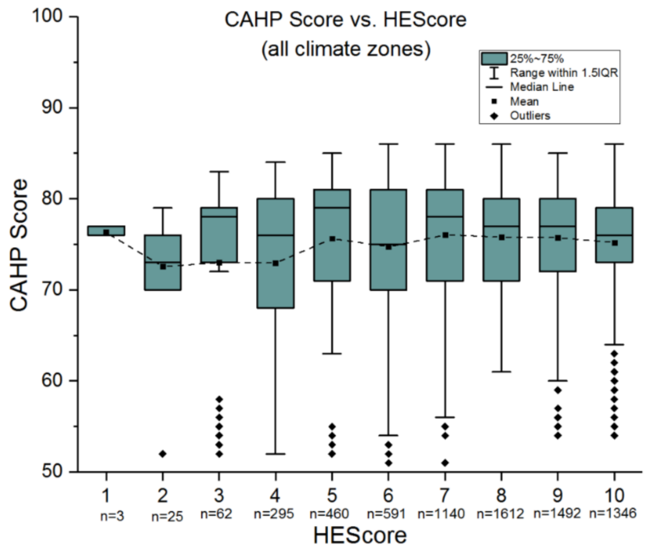

Figure 12: Statistical Distribution of 2013 CAHP Score by HES in all Climate Zones

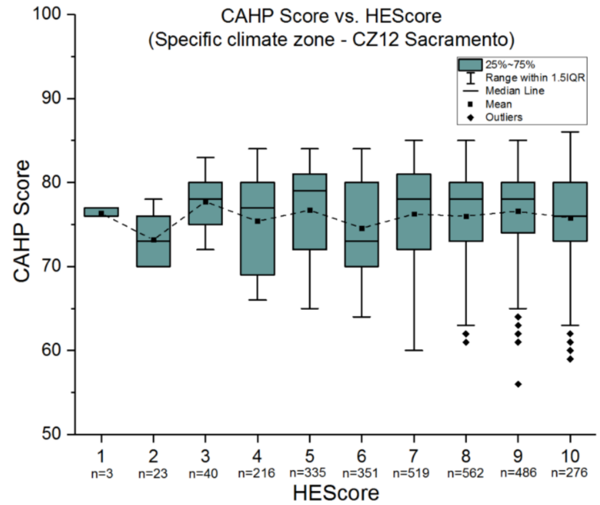

Figure 13: Statistical Distribution of 2013 CAHP Score by HES in Climate Zone 12

The absence of a correlation between the two metrics is caused by core differences in the constructs of HES and the CAHP score. The biggest differences are:

1. HES is a representation of total energy use, while the CAHP score is a representation of energy use intensity per square foot of conditioned floor area.
2. HES rates the house's energy use relative to the existing house stock from the RECS data, while the CAHP score rates the house relative to the reference building of Title 24 2008 Code.
3. HES only includes heating, cooling, and water heating loads, while the CAHP score also includes lighting and appliance loads.
4. HES is based on source energy use, while the CAHP score is based on TDV energy. The complexities of this comparison are nuanced and variable home to home. It may be playing a larger role in the overall results than immediately apparent.

Hence, a large home in an extreme climate zone can require substantially more energy than a small home in a mild climate zone. Both homes can receive a low CAHP score with an energy efficient design, but the larger home has an upper limit to its potential HES due to the baseline energy required to condition a large home in a particularly hot climate zone. HES does consider climatic variations when assigning a score to a home; however, this study did not fully analyze the climate zone mapping and comparison process to determine if HES appropriately accounts for California microclimates. More information is provided below.

Additionally, CAHP score calculation includes the contribution of lighting and unregulated loads (appliances and electronics), while HES tool only includes heating, cooling, and domestic hot water loads. This is more significant for projects in mild climate zones where heating and cooling loads are small portions of total energy use in comparison to lighting and appliances; therefore, these projects are favored on the HES scale which does not include these loads, as shown in Figure 14 below.

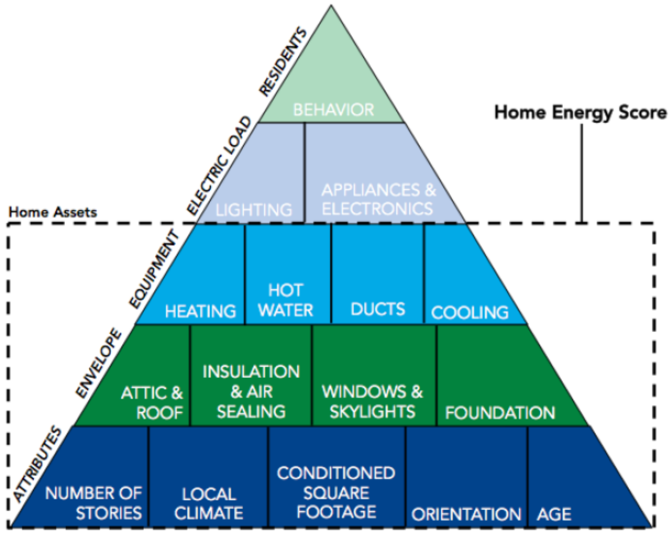

Figure 14: Home Energy Use Factors[1]

3.1.2 2016 Code CAHP Research Homes

For the 2016 code CAHP research homes, the box plot compares the EDR with HES as shown in Figure 15 below. The trend observed in HES distribution among 2016 research homes is very similar to the one observed above for 2013 code homes. There is less variance in EDR values for the specific HES bins as compared to above, but a similar horizontal trend in terms of correlation between the two scores. As shown previously in Figure 11, the overall volume of homes skews considerably more towards high HES results across the 2016 code dataset than the 2013 code dataset. It is possible that this is a reflection of the overall improvement in envelope and energy use inherent from the 2016 code update. But more likely this is due to the limited range of 2016 home types in this research.

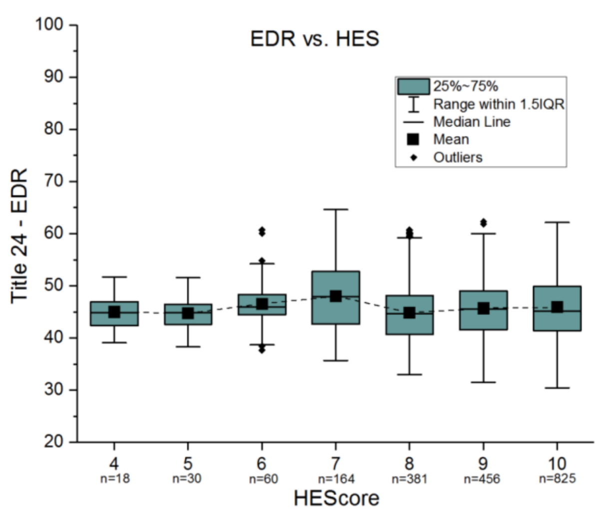

Figure 15: Statistical Distribution of EDR by HES

[1] U.S. DOE Better Buildings. 2017. Home Energy Score Scoring Methodology. Available online at: https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Home%20Energy%20Score%20Methodology%20Paper%20v2017.pdf

3.2 High Level Building Characteristics Overview

TRC investigated some high level building characteristics and analyzed HES outliers. The purpose of the more granular analysis was to identify which, if any, building characteristics tend to have significant influence on the HES and should be filtered for normalization of data. TRC conducted correlation analysis on specific characteristics on the entire 2013 and 2016 datasets, separately. The results suggest a strong correlation between CFA and HES, with larger CFA trending towards lower HES. Additionally, hotter, more extreme climate zones and increasing number of bedrooms tend to correlate with lower HES results.

3.2.1 Conditioned Floor Area

The HES description specifically says that a "home's score is based on estimated annual energy use, not energy per square foot; so, given all other things equal, a larger home will score lower than a smaller home."[1] The analysis results reflected this statement, regardless of how the Title 24 tools rate the home's efficiency.

2013 Code CAHP Homes

Figure 16 shows that the majority of homes less than 2,000 square feet received a HES of 7 or above in this analysis; the majority of homes with a size of 4,000 square feet[2] and above received a score of 7 or less. This correlation becomes more distinct as home size moves towards either end of the spectrum on the CFA scale. Homes with CFA in the mid-to-large-range, especially from 2,500 to 3,500 square feet, are spread across a wide range of HES values, suggesting that other characteristics begin to influence home energy use.

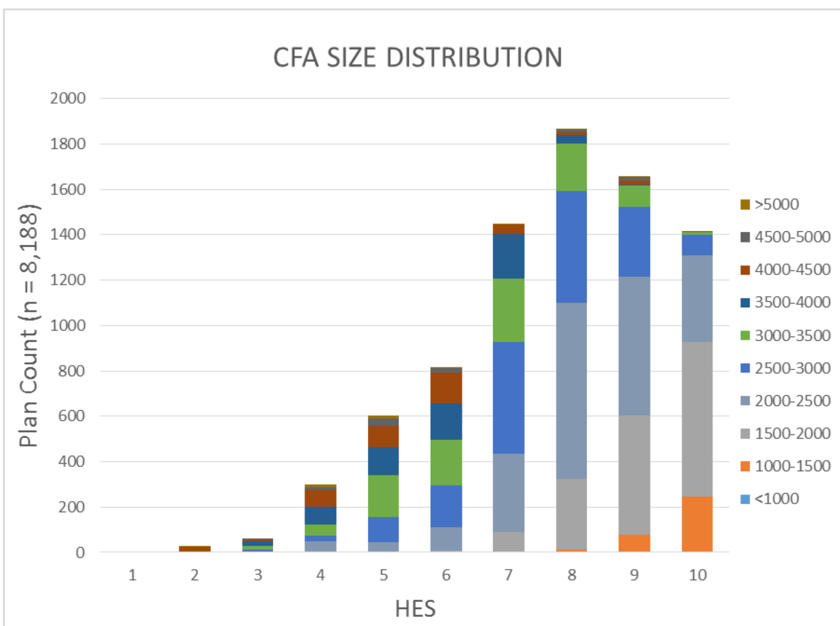

Figure 16: 2013 CAHP Plan CFA Distribution across HES Bins

[1] U.S. DOE Better Buildings. 2017. Home Energy Score Scoring Methodology. Available online at: https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Home%20Energy%20Score%20Methodology%20Paper%20v2017.pdf

Figure 17 shows a trend in decreasing CFA for higher HES results. The trend appears to be the strongest at either end of the scale, while average CFA of projects is fairly similar between HES 3 and 6. Additionally, the range in CFA values is widest between HES 4 and 6, while the range of CFA values is smaller for HES 7 and above.

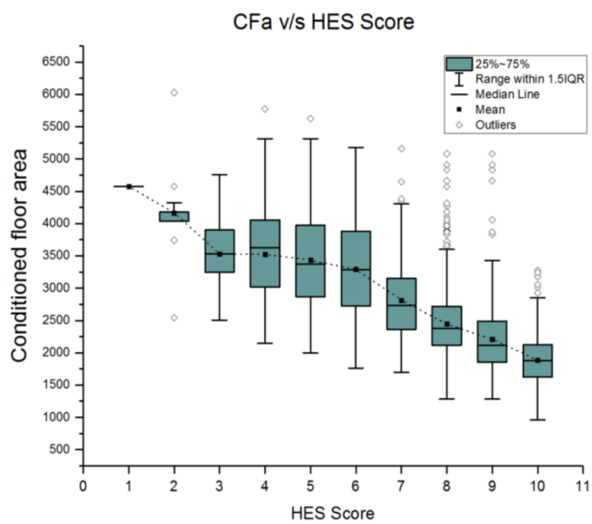

Figure 17. Statistical Distribution of Conditioned Floor Area (CFA) by HES Bins

3.2.2 Number of Bedrooms

2016 Code Research Homes

Figure 18 below shows the distribution of HES for all four prototypes considered in 2016 code CAHP research homes. Given the similar suite of energy measures applied to each prototype and the limited range of square footages, TRC expected to see a similar distribution of HES for each of the four size prototypes or a trend similar to that observed with 2013 code homes where results were correlated with conditioned floor area. The 2,636 square foot prototype deviates from the trend, as it has six bedrooms as opposed to three or four in other prototypes. The high number of bedrooms affects the water heating consumption and hence shifts the distribution of HES results to lower scores, centered on a HES of 8. TRC further tested this theory by adjusting number of bedrooms on other individual runs and observed the same trend.

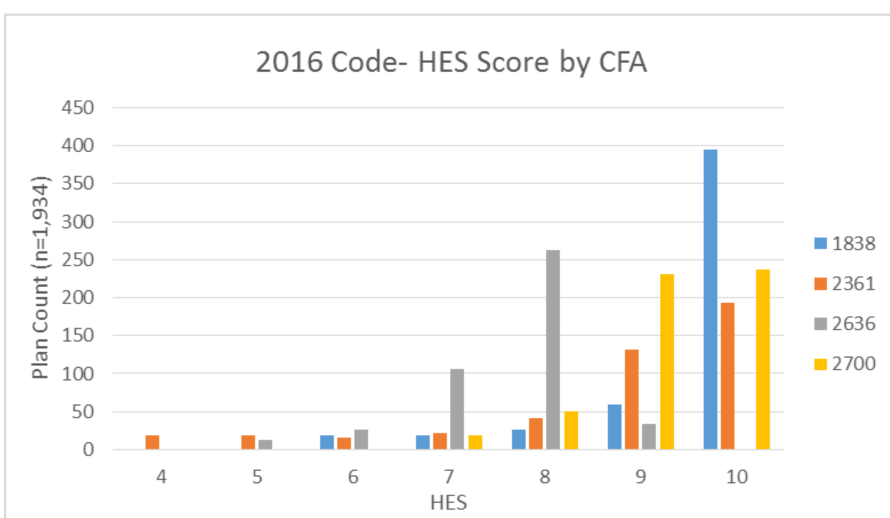

Figure 18. 2016 CAHP Plan CFA Distribution across HES Bins

3.2.3 Climate Zone

2013 Code CAHP Homes

The 2013 CAHP plans are distributed in six northern California climate zones within PG&E territory, as shown in Figure 19 below. While mild coastal climate zones 2, 3, and 4 have scores of 7 to 10 for the vast majority of projects (95, 100, and 95 percent, respectively), the hot inland climate zones 11, 12, and 13 are more widely spread among the HES range. The data is insufficient to definitively state a cause of this variation. However the following hypotheses are possible:

1. There are innate energy differences between mild coastal climate zones versus hot inland zones. Coastal climate zone homes likely score consistently well on the HES scale because the heating and cooling load requirements are low with limited variability; whereas, inland climate zone homes have a higher variability and magnitude of heating and cooling needs.
2. HES may not properly capture the highly variable microclimates of California, or the borders between them. HES compares homes with those in the same or similar climate, based on proximity to a weather station. Although HES uses approximately 70 weather files for California, compared to 16 in Title 24, it is not clearly stated how the comparison climate groups are selected, how large of an area the comparison climate groups span, and whether those groupings include climate regions outside of California. More details on the comparison climate groups are of particular interest and concern due to the microclimates in California that can cause climatic variations within a short distance, meaning that the closest weather station may not be the most accurate weather station in the coastal region of California. In comparison, Title 24 uses carefully carved out boundaries based on microclimates. The precise map of comparison regions is not available. However, it is possible that HES compares a home within a hot climate to homes in a mild climate and vice-versa.
3. High HES results in coastal climate zones could be the result of relatively more aggressive improvements in Title 24 code in those zones over the last 30 years. Since the CAHP score and EDR compare planned homes against a new and ever improving Title 24 code reference home, and HES compares homes against building stock, a climate zone with a relatively strong improvement in new construction standards will result in new homes that more consistently perform better than the average building stock.

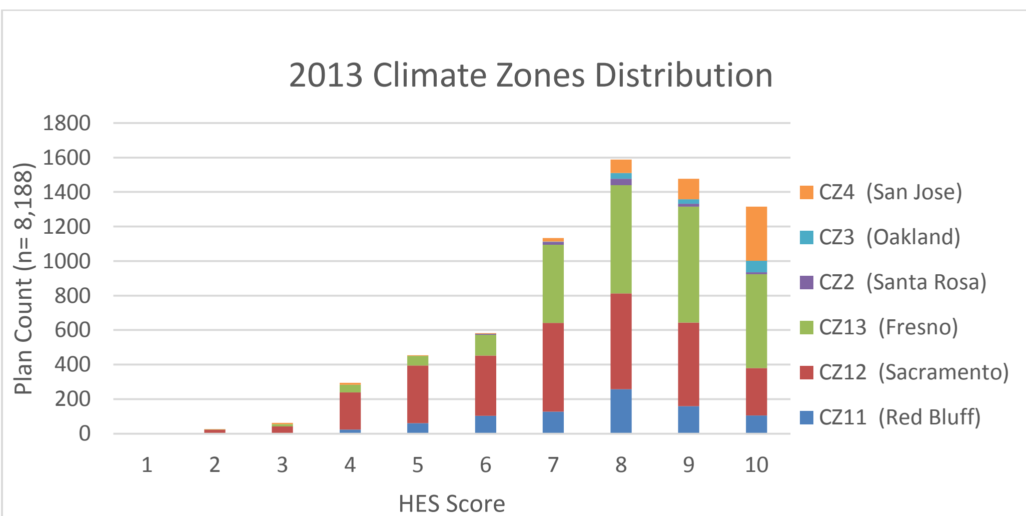

Figure 19. Climate Zone Distribution across HES results for 2013 Code

2016 Code CAHP Research Homes

The 2016 code CAHP research plans are from all 16 California climate zones, allowing for comparison of energy efficiency package performance across all of the climate zones; whereas, the 2013 code CAHP homes are focused only in climate zones within PG&E territory, with a self-selection bias towards inland climates. The HES results from the 2016 code dataset show a more even distribution by climate zone and climate zone type in Figure 20 below. Generally, the 2016 code homes score higher on the HES scale and with a smaller range of scores than the 2013 code homes; however, this could be due to the narrow band of energy efficiency measures and home geometry within the 2016 code CAHP home dataset. Therefore, any inherent trend is more difficult to detect.

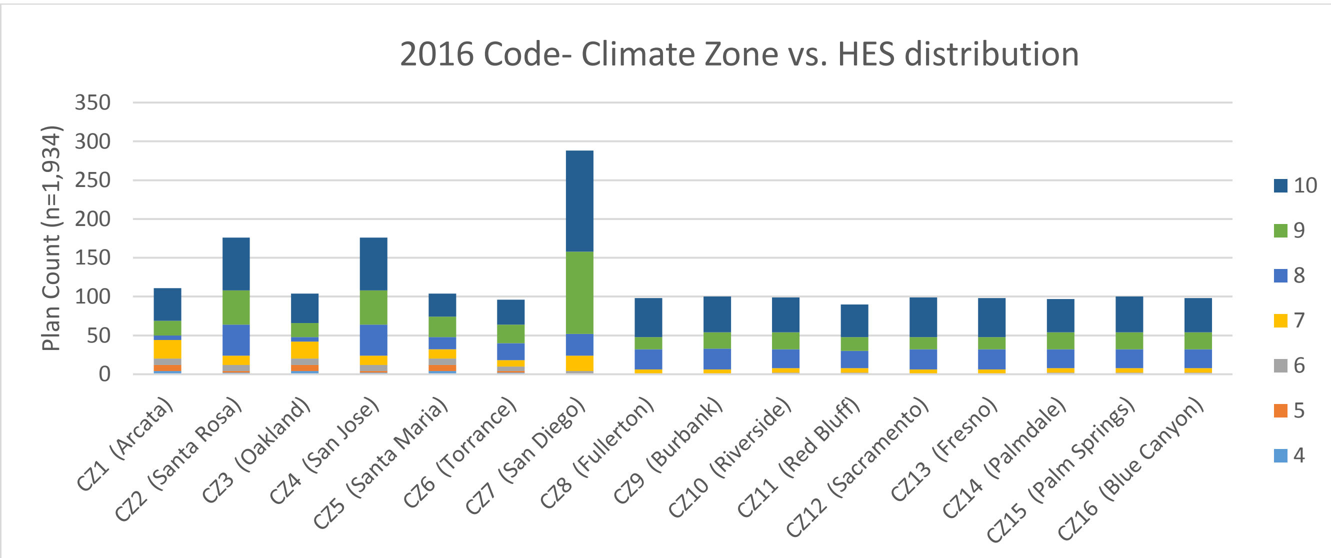

Figure 20: Climate Zone Distribution by HES for 2016 Code

3.3 Individual Building Characteristics Impacts

When looking at the entire 2013 code CAHP or 2016 code CAHP research home datasets, no one building characteristic or system type and efficiency appeared to have had a strong correlation with an HES trend. To better assess the potential influence of individual characteristics, such as insulation or system efficiency, TRC looked at a subset of homes from each dataset, as described in the methodology, to isolate individual measures and observe trends that are not clearly apparent when comparing the entire dataset. To do this, the subset selection eliminated the influence of the biggest factors—CFA, climate zone, and number of bedrooms—by holding them constant and then conducting correlation analysis on individual characteristics. The selection criteria of the subsets for both 2013 and 2016 code homes is outlined in the methodology section above. The remaining analysis below looks at this subset of plans in expectation that by removing the influence of high impact parameters, trends in other building characteristics may be better observed.

3.3.1 Envelope

The analysis suggests that specific individual envelope features, such as insulation, construction type, roofing material, and window performance, do not have much influence on a project's HES. While each envelope feature contributes to a project's HES, it appears that each may have an equal or similar influence on the HES energy load calculation. Therefore, no single feature, such as high performance walls or efficient windows, will have enough weight to solely influence a HES if other building and equipment features are poor performers.

When TRC assessed envelope efficiency qualitatively and holistically, it became apparent that homes with better overall envelope designs have higher HES results. However, the nuances between the envelope quality is not readily quantifiable for data analysis.

2013 Code CAHP Home Envelope Measures

Figure 21 and Figure 22 show various levels of cavity wall and attic insulation across the HES range for the identified subset. Besides the presence of R-21 exterior wall insulation and R-49 ceiling insulation exclusively in HES 7 and above, the data suggests there is no distinct trend in higher insulation and better HES results. Additionally, a majority of plans include continuous exterior wall insulation, so small variations in cavity insulation will have a minimal effect on energy performance.

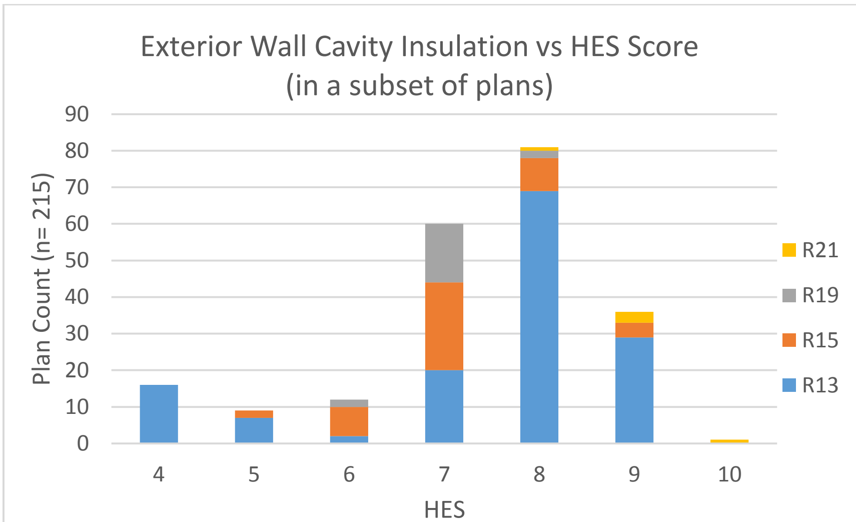

Figure 21: Exterior Wall Cavity Insulation Distribution in normalized Subset of 2013 CAHP Plans

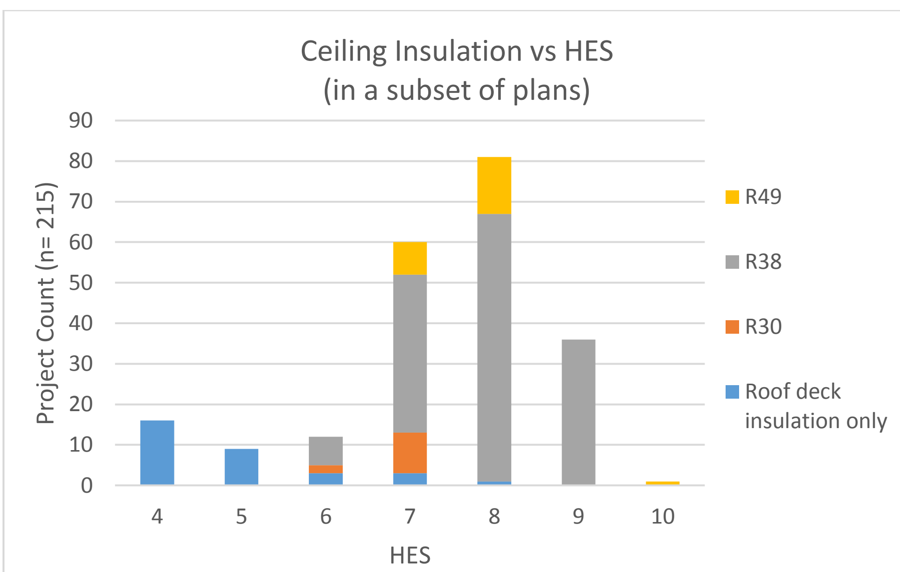

Figure 22: Ceiling Insulation Distribution in Normalized Subset of 2013 CAHP Plans

Similarly, window U-factors and SHGCs do not show a distinct trend with HES. There is no best window U-factor and SHGC that is ideal for every climate zone; coastal homes may actually benefit from higher SHGC in the winter to reduce heating load. When analyzing only CZ 12, which is a hot inland climate zone that would benefit from low U-factors and SHGC values, the data does not suggest that lower values are more often associated with better HES results.

2016 Code CAHP Research Homes: Envelope Measures

TRC analyzed 2016 code CAHP research plans for CZ12 and all prototypes combined, except 2,636 square footage with 6 bedrooms.

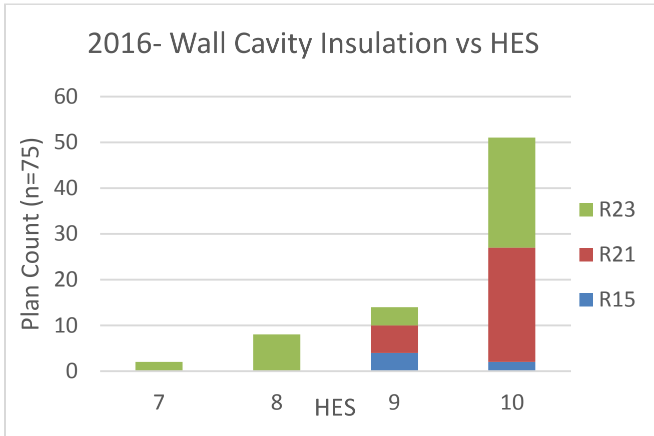

Figure 23: Exterior Wall Cavity Insulation Distribution in Normalized Subset of 2016 CAHP Plans

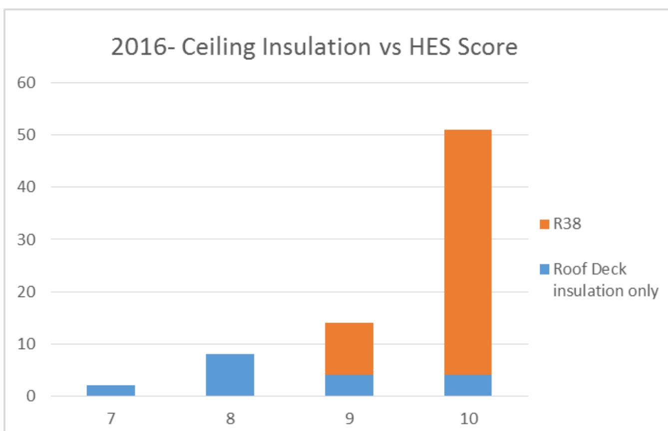

Figure 24: Ceiling Insulation Distribution in Normalized Subset of 2016 CAHP Plans

3.3.2 HVAC

When evaluating all projects, it does not appear that HVAC efficiency exhibits a clear correlation with HES results; there is a narrow range of AFUE and SEER/EER values generally, and there is no statistically valid trend relating HVAC system efficiencies to HES bins, even when controlling for climate zone and home size.

Heat Pump Space Heaters

There are about 200 plans designed with heat pump space heaters in the 2013 code dataset and the majority (80 percent) achieve HES of 10. TRC anticipated that heat pump homes might score poorly on the HES scale due to the higher source energy required by electric heat pump use relative to gas furnaces. One explanation for this finding is that heat pump projects are smaller on average and designed to a higher efficiency standard than gas home counterparts. The homes in this data set range from 1,000 to 2,500, which are on the smaller side of the complete datasets CFA range. Additionally, those designing to an all-electric specification often have high efficiency goals. This is coupled with the fact that due to Title 24's adverse treatment of heat pumps in the energy simulation engine, designers must demonstrate high levels of efficiency in other parts of the building design in order to achieve high Title 24 compliance and program-eligible CAHP scores. It is likely that the correlation between heat pump space heaters and high HES is due to these broader design truths rather than a clear case of causation from the equipment choice itself. There are too few heat pump projects in the data set for a statistically relevant correlation. However, a qualitative review of the limited volume of projects with heat pumps supports this hypothesis.

3.3.3 Domestic Hot Water (DHW)

Similar to HVAC equipment, DHW efficiency alone does not guarantee a project will receive a high HES. The degree of influence that DHW efficiency has on HES appears to be linked to climate zone. Water heating is a larger portion of total energy use in coastal climate zones than inland climate zones; therefore, having an efficient water heater has more impact on total energy use for coastal projects. This is apparent in the data for CZ 3, where all projects have DHW systems with 0.95 EF, and CZ 4 where all projects have DHW with 0.82 EF or above. CZ 3 and 4 plans all achieve HES of 7 or above, likely due mostly to the climate zone.

Although there is no distinct trend for higher EF and a higher HES, there is an odd trend with Heat Pump Water Heaters (HPWHs) achieving high HES results; 50 out of 53 HPWH plans achieve a HES of 9 or 10, with 40 achieving a HES of 10. TRC has not identified the exact reason for this, but two possible explanations are that either the HES algorithm predicts lower energy use from HPWHs than Title 24 does relative to traditional gas water heaters, or that these homes happen to be smaller and designed by progressive builders who are aiming for very efficient homes. The latter would indicate that the HPWH is not the cause of the high HES results, but rather correlates with other efficient features.

4. Conclusions and Recommendations

This research study met its objective to compare the Title 24 process and metrics with the Home Energy Score (HES). TRC successfully converted and analyzed data from both data sets (2013 code CAHP homes and 2016 code research homes). The results broadly aligned with expectations, showing high HES for nearly all California new construction. TRC identified primary driving factors for variations, including the conditioned floor area, the number of bedrooms, and the climate zone. TRC hypothesized secondary driving factors such as specific space and water heating system types and attic insulation arrangements, but was not able to definitively assess the relative correlation or impact of these factors. Because it is not normalized by conditioned floor area, HES is able to capture a different essence of energy efficiency and energy usage that would be valuable for a homeowner to be aware of, as it relates closest to actual energy bills. TRC suggests that if existing homes could also be given a HES that it could be a helpful additional metric for home buyers to use when comparison shopping.

4.1 The Conversion Process

Through this research initiative, TRC developed a functional, simple to use, and cost effective process to convert Title 24 energy model data into unofficial HES values. This conversion process is feasible and seemingly accurate for most standard homes. All the data needed for HES is included within the Title 24 models and is translatable into HES inputs. TRC noted and documented some exceptions from this norm for less common building design and efficiency features, particularly in the use of advanced attic, attic insulation, and duct system location designs.

The conversion process required simplification of modeling inputs. These simplifications were manageable, but in some cases may have caused end result bias. In rare cases these simplifications may have resulted in error; particularly in the case of non-rectangular geometric footprints, high variability of envelope features, uncommon attic-insulation arrangements, heat pump systems, or multiple zones and/or systems. The depth and triggers of these biases and errors were not fully explored.

4.2 Data Results

Title 24 metrics did not track with HES as expected. There was some correlation at the high end of the spectrums – most of the best CAHP score homes achieved HES scores of 9 and 10. However multiple outliers existed. Additionally, marginally above-code homes from CAHP and Title 24 landed in a wide range of HES results in ways that are not easy to discern. As expected, the homes from each data set had HES results of 7 and greater for most cases. However almost 22% of the 2013 code CAHP homes had HES of less than 7. TRC could not definitively identify the root causes of such discrepancies.

TRC identified that home size is the largest differentiator within HES. This is primarily due to the fact that HES takes whole house energy use into account, while Title 24 metrics are normalized to a per-square foot calculation. The number of bedrooms is another differentiator within HES, for similar reasons. The number of bedrooms (i.e., the number of occupants) greatly impacts total more than normalized energy use. Finally, different climate zone regions within the systems may be another factor that contributed to some of the observed variances. TRC did not fully explore the exact nature of this relationship due to limited budget and a lack of transparency into the HES system of climate regions.

4.3 Recommendations

HES could become an effective complementary data point to traditional Title 24 metrics. It conveys valuable information about a home's efficiency, albeit from a slightly different angle than Title 24. Utility programs and home sales agents could use HES's whole-home source energy in the form of Btus to compare and contrast, supplement, or replace Title 24 metrics (e.g., kWh, Therms and their conversion to TDV) that use per-square foot site energy. Neither method is universally more accurate or useful. But the simplicity of a 1 to 10 scale may be more easily understood by home-buyers at large.

However, the use of HES in California as a comparative metric just for new homes would not likely add value to market differentiation. The range of results is too slim. If coupled with comparisons to existing homes, the differentiation would become much more noticeable, and might help drive efficiency-minded home buyers to newer building stock, smaller homes, or highly-efficient existing buildings.

Additionally, it would be feasible to apply the conversion tool developed for this research into CAHP implementation to produce HES results for any participating homes. Implementation of this concept would require some extra work to clean up any remaining oddities in the conversion process and to coordinate with the U.S. DOE to create, log, and register official scores for real homes at a specific address, rather than unofficial scores, as were produced in this research.

5. Appendix A

This table lists all the inputs required by each of the tools categorized by sections such as house characteristics, envelope, fenestration and energy systems.

	Feature Input	DOE HES	CBECC-res
House Characteristics	*Assessment date*	X	
	Year built	X	
	Number of bedrooms	X	X
	Stories above ground	X	X
	Interior floor-to-ceiling height	X	X
	Interior floor-to-floor height		X
	Foundation or floor bottom height		X
	Window head height		X
	Conditioned floor area	X	X
	Direction faced by front of house	X	X
	Measured or estimated air leakage rate	X	X
	Whether Home was professional air-sealed	X	X
Envelope	*Garage foundation area*		X
	Garage wall		X
	Garage walls construction		X
	Attic area	X	X
	Roof construction	X	X
	Roof color	X	
	Roof solar reflectance		X
	Roof thermal emittance		X
	Attic or ceiling type	X	X
	Roof Rise		X
	Attic Conditioning (ventilated or unventilated)		X
	Foundation Area	X	X
	Foundation perimeter		X
	Insulation level of the attic floor	X	X
	Foundation type	X	X
	Foundation insulation level	X	X
	Insulation level of the floor above the basement or crawlspace	X	X
	Building type; townhouse or otherwise	X	
	Building position; required if type is townhouse	X	X
	Walls construction same on all sides (yes/no)	X	X
	Front; Back; Right; Left (if type is townhouse adjoining wall(s) set by system)	X	X
	Front; Back; Right; Left wall area		X
	Materials	X	X

	Insulation levels	X	X
	Knee Wall/ interior wall area		X
Window, Skylight and Door	*Knee Wall/ interior insulation level*		X
	Does house have skylights? (yes/no)	X	X
	Skylight size	X	X
	Skylight type	X	X
	Skylight Glazing, frames, fill	X	X
	Skylight U-Factor	X	X
	Skylight Solar heat gain coefficient	X	X
	Window areas	X	X
	Window types are same on all sides	X	X
	Front; Back; Right; Left	X	X
	Glazing, frames, fill	X	X
	Glazing U-Factor	X	X
	Glazing Solar heat gain coefficient	X	X
	Exterior shade (overhang and fin)		X
	Door Area		X
	Door U-factor		X
Heating, Cooling and Hot water Heater	*Percentage of conditioned floor area served by system*	X	X
	Type of heating system	X	X
	Heating system efficiency	X	X
	Year heating system installed	X	
	Furnace fan (W/CFM)		X
	Type of cooling system	X	X
	Cooling system efficiency	X	X
	Year cooling system installed	X	
	Cooling flow (CFM per Ton)		X
	HVAC zonally controlled		X
	Refrigerant charge verification		X
	Indoor air quality (IAQ) fan		X
	Whole house fan		X
	Duct location; up to three	X	X
	Percentage of total ducts in each location	X	X
	Duct insulation	X	X
	Duct sealing	X	X
	Water heater type	X	X
	Year water heater installed	X	
	Water heater input rating		X
	Water heater tank volume		X
	Water heater pilot energy		X
	Water heater Energy Factor	X	X

	Water heater Distribution Type		X
	Total Number of inputs	50	70