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CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

Arup US, Inc.

CONSULTANT REPORT

Key Performance Indicators to Track Energy Code Compliance Rates

Final Report

Prepared for: California Energy Commission

Prepared by: Arup US, Inc.

ARUP

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ABSTRACT

This report, prepared by Arup for the California Energy Commission (CEC), investigates key performance indicators (KPIs) and data streams needed to assess Energy Code compliance in California. As part of the state's ongoing efforts to enhance energy efficiency and reduce greenhouse gas emissions, compliance with California's Energy Code (Title 24, Part 6) is a critical metric. However, high rates of unpermitted and non-compliant work—especially in the residential sector—impede these goals. The CEC commissioned this study to address these challenges by providing actionable insights and proposing methods for tracking and verifying compliance rates.

Through a systematic review of existing literature and an analysis of available datasets, this report identifies and evaluates data sources for measuring unpermitted work, non-compliant work, and building savings potential. Findings indicate that unpermitted work is particularly prevalent in residential HVAC installations, where permit compliance rates range from 3% to 29%. Additionally, many permitted projects remain partially compliant with Energy Codes, revealing significant enforcement gaps across jurisdictions. The study highlights critical data deficiencies - including a lack of centralized datasets and limited consistency in compliance tracking - which complicate efforts to quantify non-compliance accurately.

To address these issues, the report recommends strengthening local building department resources, developing a centralized compliance tracking system, and implementing streamlined checks (such as automated verification tools). It also underscores the value of regular compliance audits and standardized procedures to bolster adherence to the Energy Code. By supporting a more uniform and enforceable compliance process - and by introducing KPIs tailored to California's data landscape - these recommendations provide the CEC with a practical framework to enhance energy efficiency in the building sector, ensuring steady progress toward the state's goals.

Keywords: Energy Code, Non-Compliance, Unpermitted Work

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EXECUTIVE SUMMARY

This report, commissioned by the California Energy Commission (CEC), consolidates and synthesizes existing studies on Energy Code compliance in California. It highlights key areas of unpermitted and non-compliant building work and proposes Key Performance Indicators (KPIs) to help quantify and reduce these gaps. By presenting an overview of the current literature base in a single document, the report provides decision-makers with a comprehensive reference for understanding where Energy Code compliance breaks down—and how to improve it.

This Executive Summary offers detail on the literature review, which covered 20 studies spanning multiple building types, geographical areas, and research methods. These studies collectively inform our proposed KPIs for Energy Code compliance. They also identify significant data gaps and underscore the need for enhanced enforcement and more streamlined compliance tools.

Methodology

To generate a list of recommended KPIs, Arup first performed a literature and data review to understand the types of data currently collected and used to approximate unpermitted work and non-compliant work.

Literature Review

A total of 20 studies were examined, drawing on both CEC-provided documents and additional sources. The review explored unpermitted and non-compliant work in various building typologies—both residential and commercial—and documented the energy savings that might be lost when projects do not adhere to California's Energy Code. While much of the research focuses on residential HVAC work, some studies also address nonresidential projects or additional systems (e.g., lighting, building envelopes, windows).

Data Review

The second element of our methodology involved identifying datasets that can help the CEC estimate compliance rates, unpermitted work prevalence, and overall building energy savings. Key data sources range from U.S. Census housing statistics to HVAC product shipment databases, real estate APIs (e.g., Zillow), and California-specific resources (e.g., California Department of Finance and CPUC's DEER database). Due to fragmented permitting processes across hundreds of local jurisdictions (Authorities Having Jurisdiction, or "AHJs"), the data landscape is highly decentralized and often paywalled or incomplete.

Key Findings

This report identifies several key issues that hinder Energy Code compliance in California, particularly regarding unpermitted and non-compliant work.

Unpermitted Work in the Residential Sector

Numerous studies indicate widespread unpermitted work in residential HVAC replacements, with permit rates reported anywhere between 3% and 29%. Insufficient local resources and inconsistent enforcement at the AHJ level exacerbate the issue. Notably, the extent to which unpermitted projects may conform to Energy Code requirements (i.e., meet the technical requirements without a formal permit) is still unknown, underscoring the need for further research. While anecdotal or limited data suggest there may be fewer unpermitted alterations in the commercial sector, solid evidence to confirm or quantify this trend does not currently exist.

Non-Conformant Work Among Permitted Projects

Even when projects do obtain permits, many studies report low rates of full conformance to Energy Code requirements. Compliance rates can vary significantly (e.g., from 16% up to near 100% for specific measures), indicating that obtaining a permit ("compliance") is not synonymous with "conformance" (fully meeting all code requirements in practice). Key systems prone to non-compliance include HVAC, lighting, envelope sealing, and windows.

Defining "Compliance" vs. "Conformance"

- Compliance typically means meeting official requirements under an approved permit application—i.e., adhering to procedural rules.
- Conformance refers to actually meeting the technical requirements of the Energy Code in the as-built condition.

Some unpermitted projects may, in fact, be code-conforming but skip the permitting process. Conversely, permitted projects sometimes fail to conform to the code despite formal approval.

Unrealized Energy Savings

Studies show that non-compliant and unpermitted work translates into substantial unrealized energy savings, directly impacting California's broader savings targets. High-impact measures—like HVAC system replacements and lighting controls—are critical to reducing building energy use and cutting greenhouse gas (GHG) emissions. Yet inconsistent compliance practices limit the full potential of these measures.

Inconsistent Permitting and Enforcement Procedures

Although enforcement procedures are nominally standardized (e.g., refusing certificates of occupancy for non-compliant work), their implementation varies widely across AHJs. Many smaller jurisdictions lack dedicated staffing and training to prioritize energy efficiency enforcement. Meanwhile, the CEC provides compliance manuals and tools (such as simplified forms and online resources) to reduce administrative burdens, but local uptake is uneven. This reactive rather than proactive stance often hinders robust enforcement.

Data Gaps and Reliance on Sampling

Because permit data is scattered across hundreds of independent AHJs, most existing studies rely on sampling-based methods: site visits, interviews, or self-reported information from industry professionals. While sampling can yield statistically significant insights, it is time-, labor-, and cost-intensive, limiting both scope and frequency.

Recommendations

From the research conducted, Arup recommends several KPIs as well as potential steps the CEC can take to address unpermitted work and non-compliant work.

Proposed KPIs

To fill knowledge gaps and enhance compliance monitoring, this report introduces four KPIs, primarily leveraging existing datasets and/or low-burden data sources:

1. **Product-to-Permit Compliance Ratio**: Uses equipment product and HVAC sales to represent the number of permits that should have been issued.
2. **End-of-Life Equipment Permitting Gap**: Uses typical useful life of common equipment like heat pumps to inform the total number of permits for replacement equipment that should have been issued.
3. **Permit Correlation to Real Estate Estimates**: Tracks changes in property value and features through the Zillow API to estimate the volume of work that should have been permitted.
4. **Energy Code Driven Savings Impact of Non-Compliant Work**: Multiplies non-compliant work rates derived from literature by energy consumption statistics in an existing database (DEER) to quantify unrealized energy savings.

Future Compliance Audits and Studies

The literature strongly supports recurring (e.g., 3–5-year) compliance audits. By sampling permitted buildings - comparing approved plans and inspection notes to actual, on-site conditions - researchers can quantify non-compliance more accurately. These audits should particularly focus on high-impact measures (HVAC, lighting, envelope sealing) and help track compliance trends over multiple code cycles.

Targeted Enforcement Strategies

The following steps can be taken to improve Energy Code enforcement:

- Proactive Enforcement: Instead of waiting to catch errors, AHJs can conduct early plan checks and frequent inspections of work-in-progress.
- Enhanced Tools and Training: Provide building officials and contractors with user-friendly compliance software, checklists, and accessible training. The CEC's ongoing simplification of forms and manuals can be leveraged to make enforcement more consistent and effective.

Collaboration with Third-Party Data Providers

Arup recommends expanding partnerships to tap external datasets such as aerial imagery, property tax records, or shipping logs - for identifying large-scale, unpermitted projects. These sources could uncover unpermitted solar installations, exterior envelope modifications, or mechanical equipment replacements that otherwise go untracked.

Commercial Sector Investigations

While data indicates unpermitted and non-compliant work is widespread in residential alterations, there is a dearth of focused research on nonresidential alterations, like tenant improvements. Additional studies should investigate commercial sector permitting to confirm or refute assumptions that less unpermitted work exists.

Conclusion

This report consolidates findings from 20 separate studies of building Energy Code compliance in California, synthesizing the landscape of unpermitted and non-compliant work, along with the data sources that might quantify the magnitude of these issues. By applying the recommended KPIs, the CEC can systematically monitor compliance rates, pinpoint priority areas for enforcement, and catalyze progress toward the state's energy efficiency objectives.

The extent to which unpermitted projects may still conform to the code—particularly in commercial contexts—remains an open question worthy of further research. This knowledge gap underscores the need for more standardized permitting data, proactive compliance audits, and collaborative partnerships to capture better real-world performance data. Strengthened by consistent enforcement procedures and targeted compliance tools, California can more fully realize the energy and climate benefits embodied in its building code.

CHAPTER 1: Introduction

This report, prepared for the California Energy Commission (CEC), details the findings and recommendations developed under the technical support contract aimed at improving California's Building Energy Efficiency Standards (Energy Code) compliance. This work is aligned with California's broader goals of reducing GHG emissions. Its findings contribute to ensuring that new construction, building alterations, and additions comply with the state's stringent Energy Code, and Associated Administrative Regulations in Part 1 of the California Building Code. Work was performed from August 2024 – December 2024 by a consultant team led by Arup US, Inc. with subconsultants KMEA. When the first-person plural ("we") is used in unquoted narrative, it refers to the consultant team.

Purpose of the Project

The CEC has commissioned this project to improve Energy Code compliance at the local jurisdictional level and to identify challenges related to unpermitted work and non-compliant work. The project aims to help the CEC achieve greater energy efficiency and GHG reduction targets by leveraging specialized expertise to tackle these issues.

Scope of Work

The scope of work includes a review of research, analysis of datasets, and development of KPIs or methods to be used for informing the metrics. This report outlines the literature review conducted, analyzes available data streams, and provides recommendations for how compliance rates can be monitored, tracked, and improved. The findings of this work will help the CEC achieve California's goals and streamline compliance processes across the state's building sectors.

CHAPTER 2: Methodology

This chapter outlines the methodology used by the consultant team to identify KPIs related to Energy Code compliance in California, and the data sources required to inform them.

Our approach was designed to inform a set of research targets. It was then divided into two key components: a literature review and a data review. Together, these efforts helped identify existing information, potential data sources, and methods for addressing these research targets. This information was then synthesized into the recommendation of four key performance indicators (KPIs) to characterize unpermitted work and building savings. Below is a summary of our approach.

Definitions

The methodology for this study relies on the definition of the following terms, which are used consistently throughout the report. These terms are essential to understanding the metrics and KPIs established in this paper, as they describe projects' relationships to the Energy Code compliance process. They include the following:

- Passing: Advancing to the next stage of the Energy Code compliance process, e.g., from plan review to inspections. Passing does not necessarily mean the project complies with the Energy Code.
- Conformance: Meeting the letter of the Energy Code regardless of whether the project has attained a permit.
- Compliance: Meeting the letter of the Energy Code with an error-free, approved permit application.
- Non-Compliant Work: Work that does not fully conform with Energy Code standards even if it has received an approved permit.
- Unpermitted Work: Construction activities performed without obtaining necessary permits.

Research Targets

The aim of the paper, as defined in the agreed scope for this subtask, was to characterize unpermitted work, non-compliant work, and building savings in relation to Energy Code compliance in California. These goals have been defined as quantifiable metrics to provide numerical feedback to the CEC.

Given that these metrics are comprehensive and broad in scope, Arup sought out several KPIs – more narrowly defined indicators – in support of estimating the metrics.

Metrics

At the outset of the study, the following three metrics were defined to explore and guide research:

- **Rates of unpermitted work** by location, building type (residential vs. commercial), project type (new construction vs alteration), system type (HVAC, lighting, envelope, etc. when prescriptive pathways are used).
  - This type of work involves construction activities performed without obtaining the necessary permits, making it challenging to track and ensure conformance with the Energy Code.
- Equation: $\frac{Number\ of\ Unpermitted\ Projects}{Total\ Number\ of\ Projects\ that\ Should\ be\ Permitted}$

- **Rates of non-compliant work** by location, building type, project type, system type.
  - This work refers to instances where the permit application passed through the stages of the code compliance process and received approval but had unrealized issues relating to Energy Code compliance. Note that within the context of this report, other aspects of California code compliance are not considered. Projects that partially conform to the local Energy Code but do not meet all requirements are considered non-compliant in this paper.
  - Equation: $\frac{Number\ of\ Non\text{-}Compliant\ Projects}{Total\ Number\ of\ Permitted\ Projects}$
- **Rates of Energy Code driven building savings.**
  - This metric refers to an estimation of the continued energy savings of buildings in California due to the Energy Code. The intention of the California Energy Code is to reduce building energy consumption and carbon emissions over time by increasing the stringency of the code with each update. The rate of savings is likely impacted by both unpermitted work and non-compliant work.
  - Equations:
    - $\text{Unrealized Savings from Unpermitted Work} = (EUI\ of\ Typical\ Unpermitted\ Project - EUI\ of\ Typical\ Code\ Compliant\ Project) \cdot Area\ of\ Unpermitted\ Work$
    - $\text{Unrealized Savings from Non-Compliant Work} = (EUI\ of\ Typical\ Non\text{-}Compliant\ Project - EUI\ of\ Typical\ Code\ Compliant\ Project) \cdot Area\ of\ Non\text{-}Compliant\ Work$

KPIs

As a result of the literature and data reviews, we recommended a set of KPIs, which support each of these three metrics. KPIs differ from the metrics in that they can be directly calculated or measured, unlike the metrics themselves, which currently can only be approximated.

Literature Review

The literature review focused on examining existing research related to Energy Code compliance rates, unpermitted work, and code driven energy savings efforts. Our process included:

- Selection of Studies: A total of 20 studies were reviewed, 16 of which were provided by the CEC. The studies encompassed diverse building types and locations, both within California and other states, allowing us to examine a wide range of Energy Code compliance scenarios.
- Analysis of Non-Compliant Work, Unpermitted Work, and Building Energy Savings KPIs: The selected studies were reviewed to identify existing KPIs and data used to estimate non-compliant work or unpermitted work and their effect on building energy savings. As part of this step, Arup grouped findings from these studies into key themes and outlined researched KPIs that could be used to better understand the Energy Code compliance landscape.
- Identification of Data Gaps and Future Analysis Methods: In addition to investigating existing methods, Arup reviewed the studies for new, potential methods to track, evaluate, or estimate Energy Code compliance in the future. This process involved identifying gaps in the research including both untapped and unaggregated data sources to approximate rates of unpermitted work and non-compliant work.

Data Review

In conjunction with the literature review, Arup conducted a data review to identify datasets that could help analyze KPIs related to Energy Code non-compliant work and unpermitted work. Data review was limited to only datasets with free access. The process involved:

- Identification of Datasets: Based on our review of the literature and discussions with CEC staff, we identified various datasets that could be valuable for understanding Energy Code compliance rates and trends. Datasets included those sourced from public records, proprietary databases, and academic research. Per the CEC's guidance, Arup focused on datasets with which the CEC was less familiar. The CEC already has investigated several datasets including some purchased ones like Construction Industry Research Board (CIRB).
- Dataset Evaluation: Key datasets, such as Zillow's Public Records API, were evaluated for their usefulness in assessing KPIs including rates of unpermitted work, non-compliant work, and building savings. Each dataset was reviewed through direct access or analysis of its documentation to determine its applicability to the study's objectives.

This methodology enabled us to compile a comprehensive understanding of both non-compliant work rates and unpermitted work, while also identifying gaps in the current data landscape that could be addressed in future research and exploration.

KPI Recommendations

From the literature and data review, Arup synthesized findings to recommend several KPIs in support of quantifying unpermitted work, non-compliant work, and building savings per the established metrics. In accordance with the CEC's guidance, Arup recommended KPIs meeting the following criteria.

- Robustness: KPIs must be well documented and researched in the literature. Moreover, they must not rely on too many assumptions.
- Accessible Data: The KPIs should make use of data already existing and available to the CEC to avoid having to collect or generate new data. KPIs relying on data sampling were not recommended.

Given the strict criteria, KPIs could only be recommended for the unpermitted work and building savings metrics. Rejected KPIs have been included in Appendix C: Rejected Key Performance .

CHAPTER 3: Literature Review

A comprehensive literature review was conducted to examine research on Energy Code non-compliant work and unpermitted work. The review aimed to identify and analyze existing statistical data, information sources, and methodologies that could help estimate or inform non-compliant work rates and building savings efforts. Additionally, it aimed to propose methods for tracking, monitoring, and investigating Energy Code compliance.

A total of 20 studies were reviewed, 16 of which were provided by CEC staff. These studies encompassed a variety of building types and locations, both within California and beyond, and explored non-compliant work, unpermitted work, and improvements to the compliance process. They are listed in **Table 1** below.

This chapter presents a summary of the reviewed studies and highlights key findings around emerging themes, including rates of unpermitted work, non-compliant work, unrealized energy savings, KPIs, and recommendations for future action.

Table 1. Studies Reviewed

Reference	Publication Title
(Pacific Northwest National Laboratory 2023)	Data Analysis of Energy Code Compliance in Commercial Buildings
(Ecotope; Slipstream; Center for Energy and Environment 2020)	Residential Building Energy Efficiency Field Studies: Low-Rise Multifamily
(Pacific Northwest National Laboratory 2018)	Residential Building Energy Code Field Study - Data Collection & Analysis Methodology
(Pacific Northwest National Laboratory 2022)	Residential Energy Code Field Studies: Assessing Implementation in Seven States
(U.S. Department of Energy 2013)	DOE 90 percent compliance pilot studies final report
(DNV GL 2017)	DNV GL Report 2017 HVAC Permit and Code Assessment

Reference	Publication Title
(KEMA n.d.)	Volume III Codes & Standards (C&S) Programs Impact Evaluation California Investor-Owned Utilities' Codes and Standards Program Evaluation for Program Years 2006-2008
(Cadmus; DNV GL; CPUC 2014)	• Statewide Codes and Standards Program Appendices to Impact Evaluation Report: For Program Years 2010-2012 • Statewide Codes and Standards Program Impact Evaluation Report: For Program Years 2010-2012
(Cadmus, Energy Services Division; DNV GL 2017)	• California Statewide Codes and Standards Program Phase Two, Volume Two: Appendices E – P Impact Evaluation Report • California Statewide Codes and Standards Program Impact Evaluation Phase Two, Volume Two: 2013 Title 24
(Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023)	2016-2018 Codes & Standards Advocacy Program Impact Evaluation Volume II – Draft Report
(Itron, Inc 2004)	Residential New Construction: Baseline Study of Building Characteristics - Homes Built After 2001 Codes
(Mohasci 2006)	Enforcement of T-24 Compliance Pertaining to Residential Alterations
(Quantec 2007)	Statewide Codes and Standards: Market Adoption and Noncompliance Rates
(Institute for Market Transformation; Natural Resources Defense Council 2017)	Evaluating Energy Code: Compliance in Cities
(Benningfield Group, Inc.; BKI; Association of Bay Area Governments 2015)	BayREN Codes & Standards: Permit Resource Opportunity Program -PROP Final Report and Energy Code Resource Guide
(California Energy Commission 2008)	CEC 2008 Strategic Plan to Reduce Energy Impact of ACs
(U.S. Department of Energy 2024)	Webinar from Corrie Anderson on "Best Practices for Understanding and Improving Compliance

Reference	Publication Title
(Pacific Northwest National Lab 2023)	A Review of the Evaluation of Building Energy Code Compliance in the United States
(Pacific Northwest National Lab 2018)	Assessing overall building energy performance of a large population of residential single-family homes using limited field data
(Pacific Northwest National Lab 2022)	Falling Short: Does Energy Code Compliance and Enforcement Vary by Income?

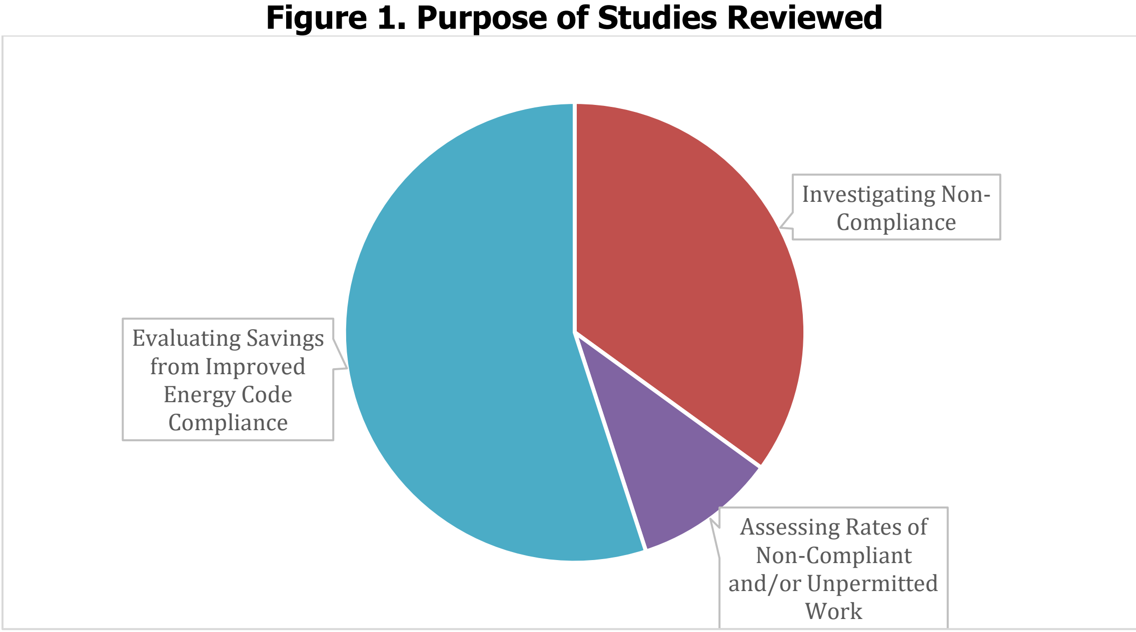
Study Characterization

The reviewed studies primarily focused on three areas:

- Investigating Non-Compliant Work (7 out of 20 studies): These studies focused on the accuracy of Energy Code compliance documentation, investigating errors in the permit application. They also attempted to calculate rates of non-compliant work with respect to the Energy Code.
- Assessing Rates of Both Non-Compliant and/or Unpermitted Work (2 out of 20 studies): These studies established mechanisms to estimate the extent of non-compliant work and unpermitted work relative to the applicable Energy Codes.
- Evaluating Savings from Improved Energy Code Compliance (11 out of 20 studies): These studies went one step further from simply investigating rates of non-compliant work and attempted to estimate the unrealized energy cost savings in non-compliant projects.

Figure 1 below provides a summary of the types of work reviewed, with more detailed discussion in the following sections. An in-depth summary of each paper is in Appendix A**.**

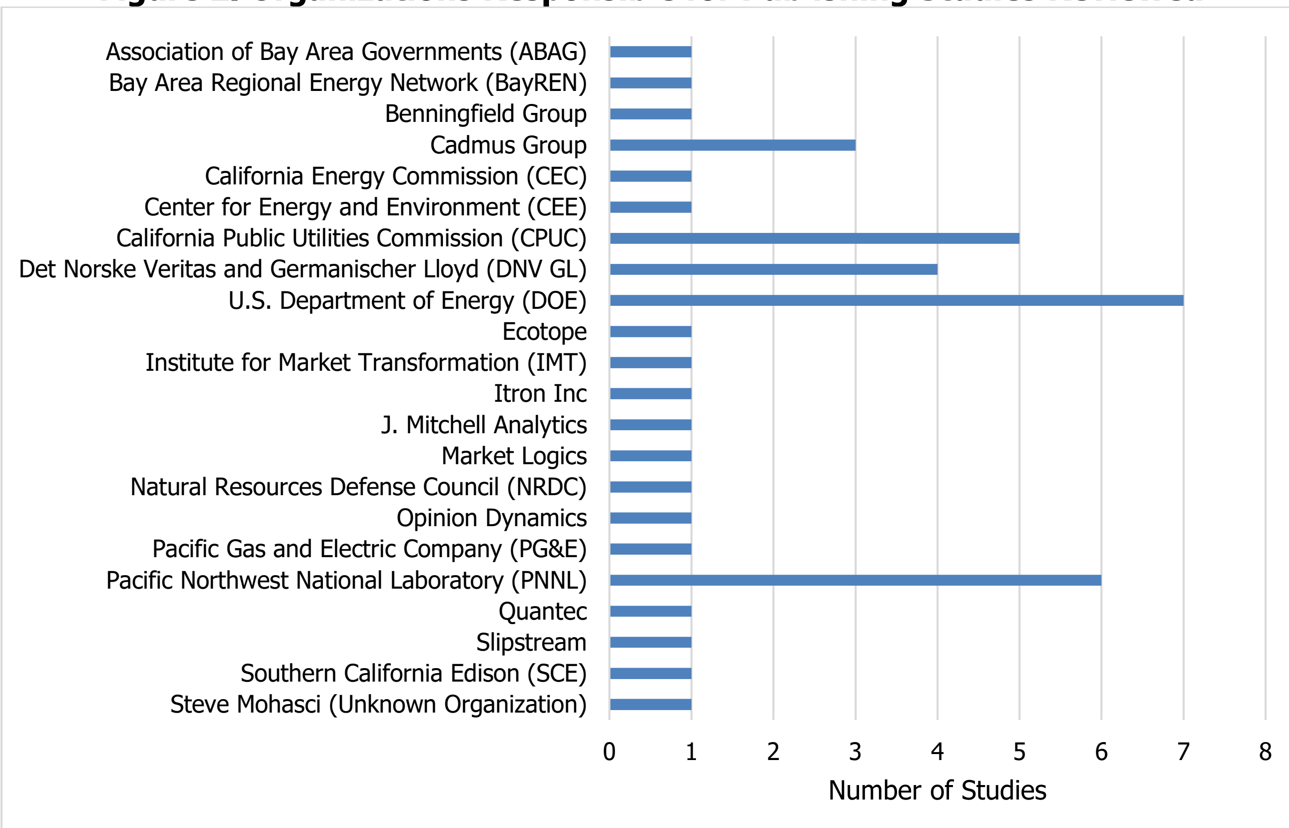
Figure 1. Purpose of Studies Reviewed



Authors and Publishing Dates

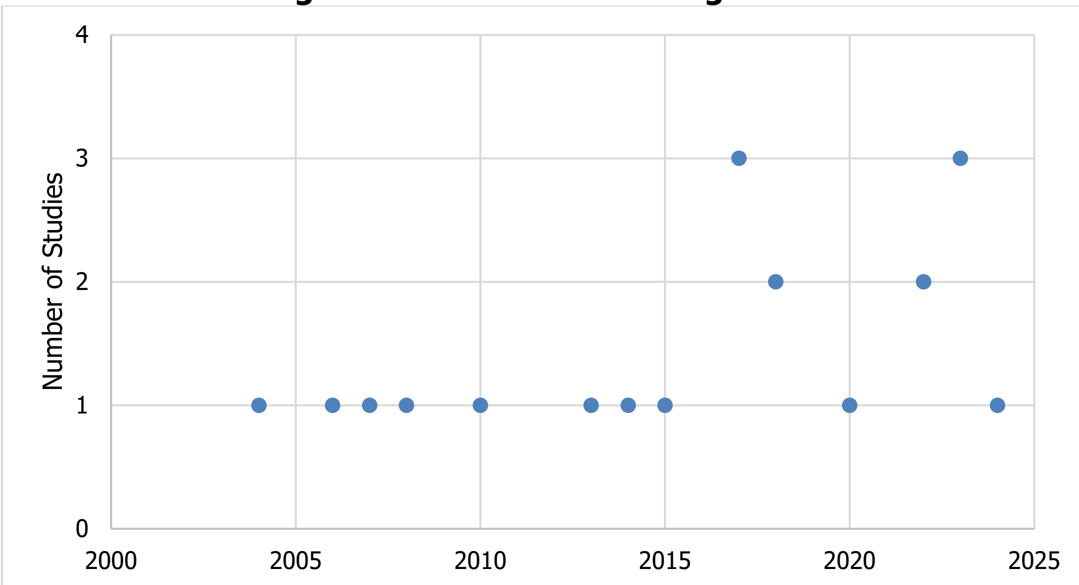
The studies reviewed were published by a diverse range of organizations, with the Department of Energy (DOE) and the Pacific Northwest National Laboratory (PNNL) being the most prominent contributors. The DOE and PNNL jointly authored many of these papers, most of which focus on areas outside of California. A summary of organizations responsible for publishing the studies can be found in **Figure 2** below.

Figure 2. Organizations Responsible for Publishing Studies Reviewed



Most of the studies were published within the last decade: 2014-2024. However, eight of the 20 studies were published over 10 years ago, between 2004 and 2015, and may be considered less relevant to present-day circumstances. The studies' publication dates can be found in **Figure 3** below.

Figure 3: Studies' Publishing Dates



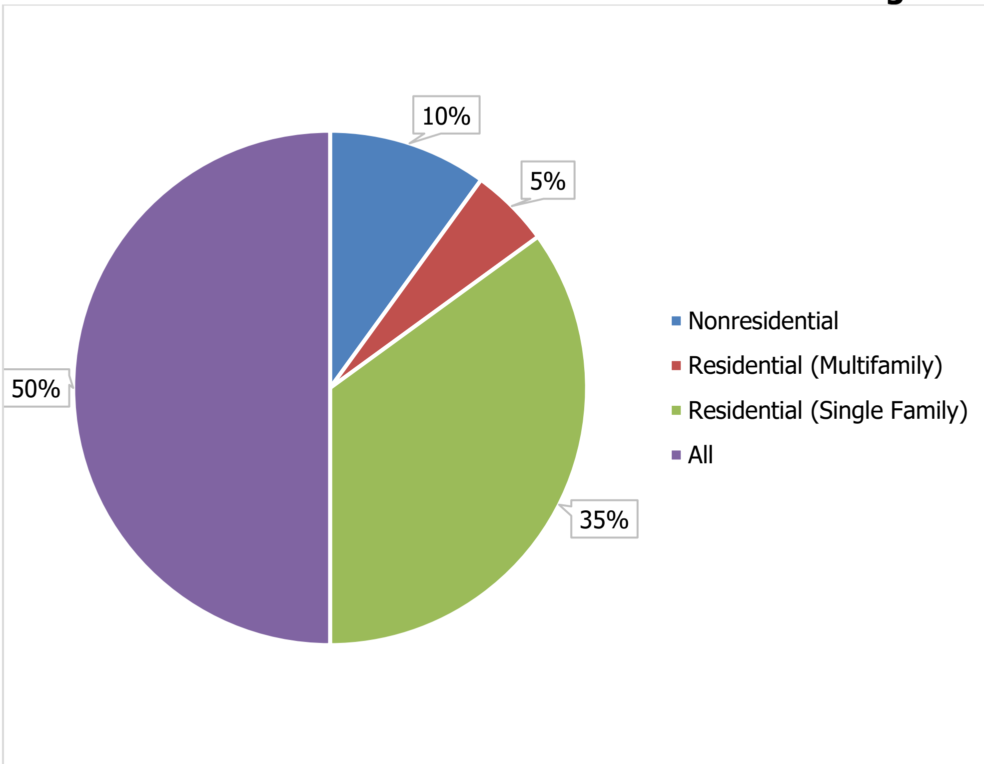
Types of Buildings

The code compliance studies reviewed covered nonresidential, single-family, and multifamily buildings, or a combination of all three building types. A breakdown of building types represented in the studies can be found in **Figure 4** below. For the purposes of this study, the building types have been categorized as they are defined in the 2022 Energy Code, which separates out multifamily buildings from residential (single-family) and nonresidential buildings.

As shown, most studies covered all three building types (11 out of 20). Only two studies focused solely on nonresidential applications and one other focused only on low-rise multifamily.

Notably, the second highest number of studies (7 of the 20) addressed single-family residential code compliance, which anecdotally is often the most challenging to regulate due to a higher presumed incidence of unpermitted work.

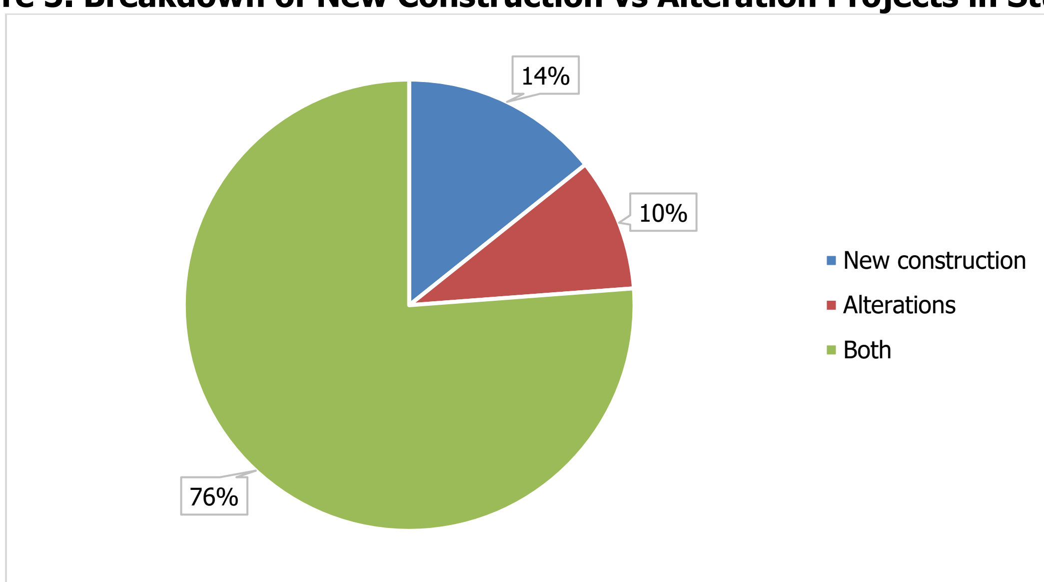
Figure 4. Breakdown of Residential vs Nonresidential Buildings in Studies



Most of the code compliance studies (16 out of 20) addressed both new construction and alteration projects. A smaller number focused exclusively on new construction (3 out of 20) or solely on alterations (2 out of 20). A breakdown of new construction versus alteration permits can be found in

Figure 5 below.

Figure 5. Breakdown of New Construction vs Alteration Projects in Studies



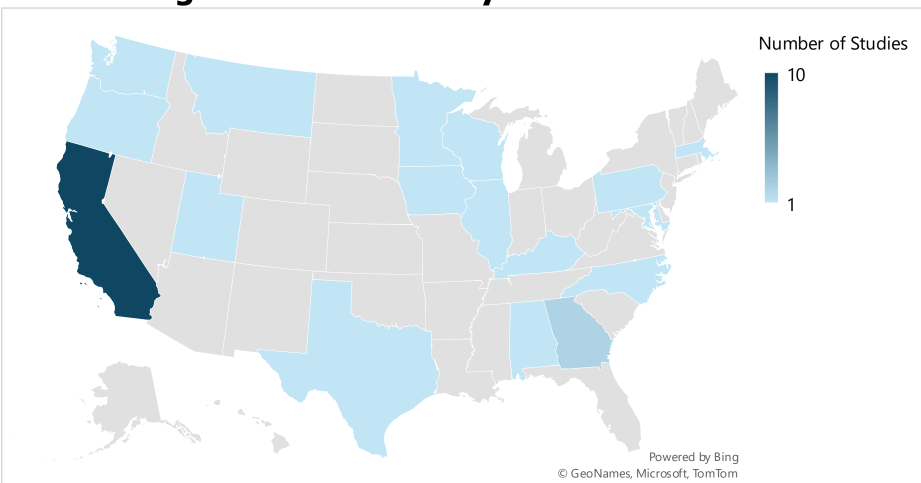
Applicable Locations

A significant portion of the code compliance studies focused on buildings in California (10 out of 20) and on a national scale (7 out of 20). However, (4 of 20) studies also included data from other states. It is important to note that studies categorized as "national" either utilized national datasets or incorporated data from 15 or more states into a single study.

Moreover, four of the studies (KEMA n.d.) (Cadmus; DNV GL; CPUC 2014) (Cadmus, Energy Services Division; DNV GL 2017) (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023) involving California were performed for the CPUC to verify energy savings attributed to the Investor-Owned Utilities (IOU) Codes and Standards (C&S) programs. Instead of evaluating code compliance as a whole, these studies assessed the compliance for the measures that the C&S program supports.

A breakdown of locations represented in the studies can be found in **Figure 6** below. Note that **Figure 6** does not account for studies whose locations were categorized as National or N/A.

Figure 6. States Analyzed in the Studies



Methodologies

The 20 studies employed various methods to assess non-compliant work and rates of unpermitted work, including site visits, energy modeling software, and the use of large existing datasets such as census or building financial data. Of the methods used, data sampling was the most common, featured in 18 out of 20 studies. The analysis of existing datasets — such as financial or census data — was utilized in 6 out of 20 studies, and energy modeling appeared in 12 out of 20 studies. Fifteen studies combined two or more of these approaches, with the most common pairings utilizing both data sampling and energy modelling. Two of the papers did not conduct specific studies, instead establishing frameworks or roadmap discussions on Energy Code compliance.

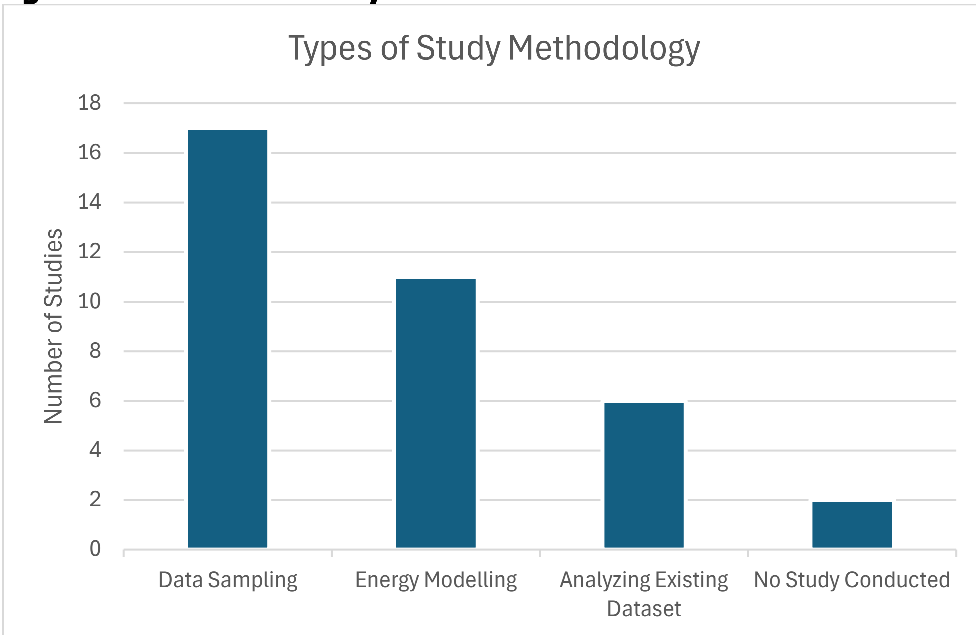
The following are summaries of the key methodologies observed in this literature review. They are plotted in

Figure 7. More detailed methodology descriptions can be found in Appendix A.

- Data sampling: This methodology involves collecting data from a representative sample to approximate a larger dataset. In every study involving data sampling, researchers performed site visits to collect field data on buildings' energy performance relative to the applicable Energy Code. In four of these studies, site visit data was supplemented with building permit data pulled for specific buildings. In seven studies, researchers also conducted surveys and/or interviews. The data points were processed through use of calculations, statistical modeling, and energy modeling to estimate rates of non-compliance and/or energy savings.
- Energy modeling: This analysis was used primarily as postprocessing of data points collected from site visits. The DOE and PNNL studies, for example, entered site-collected building data into a EnergyPlus prototype energy model, which was then compared against the performance of code compliant baseline. This method allowed researchers to estimate the unrealized energy savings from not complying with the Energy Code. A similar method was also performed in California for studies aiming to verify the energy savings associated with IOUs C&S programs. Sampled building data was entered into EnergyPro prototype models to estimate savings (KEMA n.d.) (Cadmus; DNV GL; CPUC 2014) (Cadmus, Energy Services Division; DNV GL 2017) (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023). One study in California used MICROPAS software to determine whether sampled buildings met code compliance. The approach of using energy modeling allowed the researchers to cover all compliance types including prescriptive, trade-off, and performance compliance. Buildings showing worse energy performance than their Energy Code Baseline counterpart in MICROPAS were assumed to not comply with code (Itron, Inc 2004).
- Analyzing existing datasets: Instead of collecting data from a representative sample, this method involves drawing from and manipulating large, existing datasets. It was primarily used in two studies to estimate the rate of unpermitted work in residential HVAC alterations. In these two studies, researchers used proxy data: HVAC sales to represent total number of HVAC alterations and HERS testing certificates to approximate number of permitted HVAC changeouts (Mohasci 2006) (DNV GL 2017). Mohasci used HVAC sales data from the Institute of Heating and Air Conditioning Industries (IHACI) while DNV GL used Air Conditioning Heating Refrigeration Institute (AHRI) data. Dividing HERS certificates (permitted projects) by HVAC sales (total projects) was then used to estimate the rate of permitted work. Note that IHACI does not collect installation data.

  The studies conducted to verify energy savings for the California IOUs C&S programs, mentioned above for energy modeling, also partially relied on existing datasets. While they primarily used data sampling and energy modeling, the studies also used census information to determine the number of new building units that fall under the purview of the IOU's C&S program (KEMA n.d.) (Cadmus; DNV GL; CPUC 2014) (Cadmus, Energy Services Division; DNV GL 2017) (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023).

Figure 7: Count of Study Methods Utilized in Studies Reviewed



Top-Down vs Bottom-Up

The detailed methodologies described above can be categorized into two approaches (DNV GL 2017) as defined below:

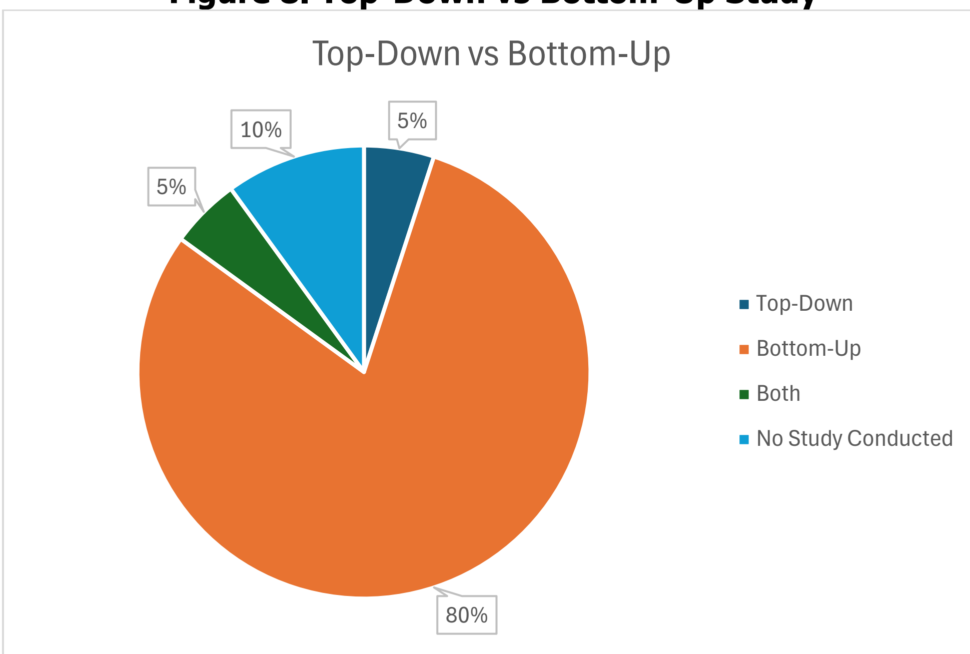
- Top-Down: This method analyzes large, existing datasets that approximate Energy Code non-compliant and unpermitted work rates. Databases referenced in the studies were aggregated from a variety of sources, including state and local permit registries, housing statistics, HERS Providers, electric and gas savings reported by Investor-Owned Utilities (IOUs), and equipment and material market data from wholesalers and distributors. Most data were obtained from public sources.
- Bottom-Up: This approach uses site visits to analyze a representative sample of data, providing detailed, project-specific insights. Datasets developed across studies represent a diversity of building sizes, locations, and measures for both residential and nonresidential properties. Residential studies focused primarily on single-family homes, apart from one focused on multifamily residential properties. Nonresidential building data represented a variety of building types, including office, retail, restaurant, and education buildings. Surveys and interviews involved various industry experts, including building department representatives, HERS raters, design professionals, code officials, and HVAC contractors. Following data collection, results were processed, analyzed, and often compared against a baseline scenario.

An example of a Top-Down approach methodology is the comparison of data from the IHACI and the California Building Industry Association (CBIA) against HERS data to determine rates of permitted work in residential alterations (Mohasci 2006). An example of a Bottom-Up approach methodology is the collection of data from site visits to 230 commercial buildings to determine rates of code compliance in commercial buildings (Pacific Northwest National Laboratory 2023). To process data in the Bottom-Up approach, researchers employed regression analysis to account for variability due to building type, building size, and/or American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE) climate zone by modeling these metrics as independent variables in a linear regression in the statistical software RStudio to determine the present value of lost savings by measure (Pacific Northwest National Laboratory 2023). An overview of methodologies represented in the studies can be found in **Figure 8** below.

The Top-Down approach offers the advantage of lower response bias, an implicit bias from question phrasing or survey method that may influence responses and skew the results. This approach is also more time and cost-efficient compared to Bottom-Up methods. However, it only provides broad estimates, relies heavily on assumptions, and often requires interpolation and extrapolation to address missing data.

The Bottom-Up approach, on the other hand, captures precise information. However, it is more prone to response bias and is more expensive and time-consuming, leading to a smaller dataset compared to the Top-Down approach.

Figure 8. Top-Down vs Bottom-Up Study



Although the four studies performed to verify savings for the IOUs' C&S programs involved Top-Down calculation (to determine the number of buildings in the regions studied), they relied much more heavily on the Bottom-Up approach to estimate energy. As such, they have been represented in **Figure 8** as Bottom-Up rather than Both.

Key Performance Indicators

The reviewed literature makes use of several KPIs to shed light on the quantity of unpermitted and/or non-compliant work. The main KPIs are summarized in

Table 2, which includes their definitions, units, calculation methodologies, data sources, as well as the articles in which they appear. For the full list of articles, please refer to Chapter 2.

Table 2. KPIs from the Reviewed Literature

KPI or Calculation	Definition	Units	Approach	Data Sources	References
Unrealized Energy Savings	Potential energy savings across a state from improved compliance with the Energy Code Generated using an energy model of prototype buildings	Present value of energy cost savings or energy use savings	Bottom-Up	• Building features recorded from site visits	(Pacific Northwest National Laboratory 2023), (Ecotope; Slipstream; Center for Energy and Environment 2020), (Pacific Northwest National Laboratory 2018), (Pacific Northwest National Laboratory 2022), (Pacific Northwest National Lab 2018), (Pacific Northwest National Lab 2022)
Compliance Score	Percentage of compliant building features (envelope, HVAC, etc.) relative to the total number of building features	Percentage or Score of 0-100	Bottom-Up	• Building features recorded from site visits	(U.S. Department of Energy 2013)[1], (Quantec 2007)[2], (Pacific Northwest National Lab 2022)
Compliance Margin (in Article 9 called Compliance Adjustment Factor)	Compliance margin between prototype energy model with building features modeled per site visit data and a baseline code compliance model	Percentage	Bottom-Up	• Building features recorded from site visits	(Itron, Inc 2004), (Benningfield Group, Inc.; BKI; Association of Bay Area Governments 2015)

KPI or Calculation	Definition	Units	Approach	Data Sources	References
Percentage of Error-Free Projects	Number of projects without permit errors relative to total number of projects sampled	Percentage	Bottom-Up	• Building features recorded from site visits • Permit reviews	(Benningfield Group, Inc.; BKI; Association of Bay Area Governments 2015)
Percentage of Projects Performing Worse than Predicted	Number of projects showing performance worse than the code requirement relative to total number of projects sampled	Percentage	Bottom-Up	• Building features recorded from site visits • Permit reviews	(Benningfield Group, Inc.; BKI; Association of Bay Area Governments 2015)
Number of Discrepancies	Number of observed differences between the code requirement and the actual building (field verified) or permit application	Numerical quantity	Bottom-Up	• Building features recorded from site visits • Permit reviews	(Benningfield Group, Inc.; BKI; Association of Bay Area Governments 2015)
Improvement from Code	The following calculation performed across a sample for building features and the building as a whole: (The Observed Value – Code Value) / Code Value	Percent difference	Bottom-Up	• Building features recorded from site visits	(Pacific Northwest National Lab 2022)
Potential Energy Savings	The theoretical maximum energy savings achieved in the first year of a new Energy Code compliance cycle, i.e., the difference in energy use between all building projects complying with the new code versus complying with the previous code. This KPI assumes all project work is code compliant. Generated using an energy model of prototype buildings	Annual energy savings	Top-Down	• Database for Energy Efficiency Resources (DEER) • Construction Industry Research Board (CIRB) Data • CPUC evaluation activities • Code Change Savings Reports (CSSR) • Code and Standard Enhancement (CASE) studies	(KEMA n.d.), (Cadmus; DNV GL; CPUC 2010), (Cadmus; DNV GL; CPUC 2014), (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023)

KPI or Calculation	Definition	Units	Approach	Data Sources	References
Gross Energy Savings	Amount of actual energy savings achieved in the first year of the new Energy Code cycle. This KPI accounts for the fact that not all work is code conformant.	Annual energy savings	Bottom-Up	• Potential Energy Savings multiplied by Compliance Adjustment Factor	(KEMA n.d.), (Cadmus; DNV GL; CPUC 2010), (Cadmus; DNV GL; CPUC 2014), (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023)
Natural Occurring Market Adoption (NOMAD)	The rate of energy efficiency adoption irrespective of code and standard updates, i.e., market share of energy efficiency measures over time	Percentage	Bottom-Up	• Delphi[3] or Delphi-inspired industry expert survey results	(KEMA n.d.), (Cadmus; DNV GL; CPUC 2010), (Cadmus; DNV GL; CPUC 2014), (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023), (Quantec 2007)
Attribution Rate	The percentage of savings that can be attributed to Investor-Owned Utility (IOU) Codes and Standards (C&S) programs relative to the total energy savings	Percentage	Bottom-Up	• Self-published evidence from IOU in Code Change Savings Report (CCSR) • Results from disinterested 3rd party review • Analysis of rulemaking documents and stakeholder interviews • Survey results	(KEMA n.d.), (Cadmus; DNV GL; CPUC 2010), (Cadmus; DNV GL; CPUC 2014), (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023)

KPI or Calculation	Definition	Units	Approach	Data Sources	References
Net Energy Savings	The amount of energy savings that can be attributed to Investor-Owned Utility (IOU) Codes and Standards (C&S) programs relative to the total energy savings	Annual energy savings	Bottom-Up	• Calculation involving Gross Energy Savings, NOMAD, and Attribution Rate	(KEMA n.d.), (Cadmus; DNV GL; CPUC 2010), (Cadmus; DNV GL; CPUC 2014), (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023)
Permitted HVAC Changeouts to Total HVAC Changeouts Ratio	Number of permitted HVAC changeouts relative to total number of permitted changeouts for a sample of buildings	Percentage	Bottom-Up	• Homeowner survey results • Permitting data	(DNV GL 2017)
HVAC Sales to HERS Verification Certificates Ratio	Number of HERS verification certificates relative to total estimated number of HVAC sales Meant to approximate the permitting rate of HVAC changeouts • HERS certificates are intended to represent number of permitted HVAC changeout projects (residential only). • Number of HVAC sales are intended to represent total number of HVAC changeouts (adjusted with census data to be residential only).	Percentage	Top-Down	• HVAC Sales (from IHACI, who currently do not collect HVAC sales data, or Air-Conditioning Heating Refrigeration Institute) • HERS Certificates provided by the California Building Performance Contractors Association (CBPCA) and the California Home Energy Efficiency Rating Service (CHEERS) • Census Data • CBIA Data	(DNV GL 2017), (Mohasci 2006)[4]

Notes:

1. (U.S. Department of Energy 2013) weighs building features differently depending on the impact they have on energy performance.
2. (Quantec 2007) uses the KPI non-compliance score rather than compliance score. This KPI is calculated in almost the same way but instead has non-compliant building features in the numerator. It can be calculated from the compliance score by subtracting the compliance score/percentage from 100%.

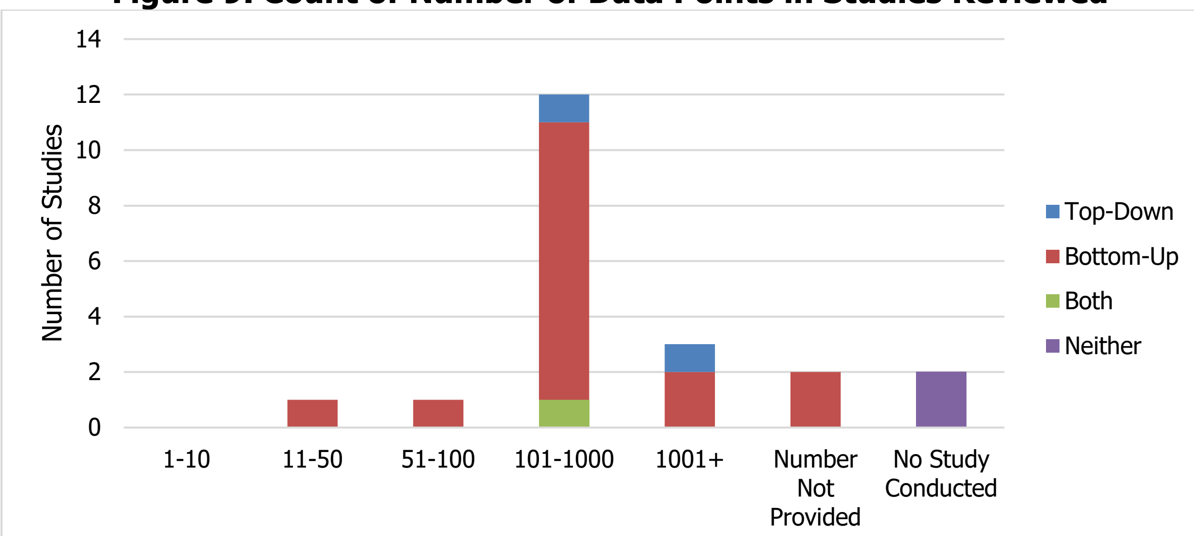
3. The Delphi process is an iterative survey process given typically to a group of topic experts to reach a consensus about a specific issue. The process has experts adjust their responses to a questionnaire in response to real-time results collected from the surveyed individuals.
4. In addition to HERS Certificate data, (Mohasci 2006) made use of CIRB data to fill in gaps in the permit data.

Quantity of Datapoints

Most studies (19 out of 20) utilized robust datasets with over 100 samples, while 2 out of 20 used datasets with 100 or fewer samples. Two studies did not specify the sample size.

Studies with smaller sample sizes were primarily Bottom-Up approaches, typically involving in-person site visits, where the number of samples was limited by time and budget constraints. In contrast, studies with the largest sample sizes were primarily Top-Down approaches, relying on existing datasets and census data, which could be more easily accessed online. A summary of the number of data points used in each study can be found in **Figure 9** below.

Figure 9. Count of Number of Data Points in Studies Reviewed



Key Themes

The following sub-section discusses key findings emerging from the literature review and analyzes how they can be used to shape future work for the CEC. Reflecting a range of building types, locations, and methodologies, the findings are divided into three analysis metrics: rates of unpermitted work, rates of non-compliant work, and associated unrealized carbon impacts due to reduced energy performance.

This section then concludes with an analysis of the KPIs, highlighting the strengths, weaknesses, successes, and opportunities of the methods used to calculate the tracked metrics.

Rates of Unpermitted Work

Unpermitted work is a key attribute in understanding building Energy Code compliance in the U.S. However, determining exact rates of unpermitted work is inherently difficult given the missing permit documentation. Of the 20 studies evaluated throughout the review, only two directly investigated unpermitted work as a compliance metric (Mohasci 2006) and (DNV GL 2017). These two studies focused specifically on residential HVAC alteration work.

The examination of literature reveals the most prominent barriers to permitting as:

- Resource availability among regulatory agencies to effectively enforce permit compliance.
- Low levels of permit and inspection enforcement, especially in residential work and alterations
- Limited communication between state and local agencies as code updates are published.

Permitting requirements are enforced at varying rates by state and local jurisdictions, which have vast differences in resources available for permit review and inspection. Energy code enforcement may be deprioritized by local building departments with limited resources compared to other building code requirements such as structural, fire, egress, and architectural requirements.

The common conclusion from these studies is that rates of unpermitted work are likely higher than estimated. Limited findings enumerated in the studies evaluated include:

- For residential HVAC alterations in 2006, one study estimated the permit rate at 3.2% (Mohasci 2006).
- The permit rate for residential HVAC installations in 2017 in California was estimated to fall between 8% and 29%, far below the CPUC's goal of 50% permit compliance (DNV GL 2017).

In a 2017 DNV GL study for the CPUC, most alterations requiring permits were found to be missing proper permitting documentation (DNV GL 2017), with less than 30% of all residential HVAC upgrades in the Sacramento area having a permit on file. When asked about this issue through a survey, HERS raters (who perform field verification and diagnostic testing) corroborated this finding, agreeing that "most" HVAC upgrades are installed without a permit. This study suggests that compliance gaps may be due to low levels of regulatory enforcement (DNV GL 2017).

A 2007 analysis of the California Energy Code non-compliant work rates by SCE noted that nonresidential buildings appeared to have fewer permits in comparison to the number of estimated buildings (Quantec 2007). This finding suggests that commercial buildings, at the time of the study, may be responsible for significant unpermitted work as well (Quantec 2007).

A summary of the rates of unpermitted work can be seen in **Table 3** below.

Table 3. Rates of Unpermitted Work

Type of Permit	Permit Rate	References
Residential HVAC alterations	3.2%	(Mohasci 2006)
Residential HVAC installations in California	8-29%	(DNV GL 2017)
Residential HVAC upgrades in Sacramento	30%	(DNV GL 2017)

NOMAD and the Conformance Rates of Unpermitted Work

While unpermitted work precludes the achievement of Energy Code compliance, it does not necessarily prevent conformance with the Energy Code. The literature review indicated projects under the California Energy Code purview may meet the letter of the code without filing for a permit.

As part of the 2017 DNV GL study of permitting rates for HVAC replacements, for example, a survey of 196 HVAC installations demonstrated that, while permitting rates are low, 100% of installations complied with mandatory requirements for minimum efficiency and duct insulation requirements (DNV GL 2017).

A Delphi panel used by Opinion Dynamics for their study on IOU C&S advocacy programs also suggested that conformance may not be tied directly to Energy Code enforcement, especially for residential alteration work. The panel was used to calculate the Naturally Occurring Market Adoption (NOMAD) of the California Energy Code requirements, i.e., compliance with the code regardless of whether the Energy Code exists. Note that NOMAD Delphi models are based on expert opinion, rather than empirical evidence.

The panel indicated residential single-family HVAC alteration work – including lighting fixtures, lighting controls, attic and wall insulation, duct insulation, water heaters, and heat pump – to have NOMAD rates of 78% for 2017 and 79% for 2018 (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023). In other words, experts feel as though much residential alteration work likely would conform with the Energy Code regardless of whether the code existed. All other building sectors evaluated, including nonresidential new construction, nonresidential lighting alterations, and residential new construction showed lower NOMAD rates: 30%, 20%, and 5% respectively for 2018 (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023).

The conformance of unpermitted work with the Energy Code can be attributed to a few causes. One, Title 20 appliance standards regulate the minimum efficiency of certain equipment and products that can be sold in the state, including several HVAC and domestic hot water heating systems used in residential buildings. Regardless of if a project pulled a permit, it would be unlikely that certain, limited types of equipment not complying with code could even be procured. Note however that the scope of Title 20 is very limited, especially in comparison to the Energy Code, and so this impact will be minimal. Secondly, as the NOMAD Delphi models indicates, the market drives adoption. Energy efficient equipment that has the same functionality and first costs as less efficient products tend to be preferred by consumers given their amount of energy cost savings. Architecturally, code conformant construction also may be preferred. For example, an installer may achieve the required insulation in a wall for acoustic reasons apart from compliance with the Energy Code.

Rates of Non-Compliant Work

Throughout the literature review, 7 of the 20 studies aimed to measure rates of non-compliant work with the Energy Code, i.e., a percentage of projects whose permit applications contained errors. The examination of literature reveals the most prominent reasons for non-compliant work as follows:

- Regulatory agencies' ability and resources.
- Updates to documentation and procedures alongside code changes.

Additionally, the examination of literature demonstrates evidence of differing non-compliant work rates by building typology and type of work. Across the reviewed studies, the following common themes emerged:

- Non-compliant work rates are relatively high.
- Non-compliant work rates vary drastically by Energy Code measure. Windows, lighting, HVAC, and envelope sealing requirements are among the most common found to not be in compliance with the local Energy Code.
- Non-compliant work rates differ when examining drawings vs verifying in the field.
- Rates of non-compliant work tend to be higher in lower income communities.

Based on a 2015 BayREN report, full Energy Code compliance in the San Francisco Bay area is rare. The study estimated that only 16% of projects were compliant with current Energy Code requirements, and over 50% of buildings revealed discrepancies between documented compliance and actual performance (Benningfield Group, Inc.; BKI; Association of Bay Area Governments 2015).

Estimated rates of California Energy Code non-compliant work across 418 residential and nonresidential building records for SCE demonstrate a significant variance in compliance by measure, ranging from 28% non-compliant work for hardwired lighting to 100% for duct testing and sealing in nonresidential buildings (Quantec 2007).

Based on a 2013 Energy Code enforcement survey of six states' building departments administered by the DOE, the primary areas of residential non-compliant work were envelope sealing and duct sealing; the main areas of commercial non-compliant work were envelope sealing, duct sealing, and lighting controls. When asked what discrepancies are typically identified that prevent determination of residential building Energy Code compliance, 57 responses referred to missing information on the building plans, and 5 noted a lack of accuracy on information that was supplied (U.S. Department of Energy 2013).

The 2007 SCE report revealed that non-compliant work rates estimated from drawings can differ significantly when informed from the site. The study found a 91% rate difference for commercial cool roofs between that shown in the paper documentation and that observed during field inspections (Quantec 2007).

One report by PNNL published in 2022 explored differences in non-compliant work rates between lower and higher income counties, finding that high income counties on average showed non-compliant work rates 6% points lower than non-compliance rates found in lower income counties. This same report also found that both the lower and higher income counties studied achieved slightly lower rates of non-compliant work (6 and 7% points lower, respectively) if the county had adopted an older Energy Code compliance standard: IECC 2009 instead of IECC 2018. PNNL's findings suggest that rates of non-compliant work may increase as documentation requirements change or become more burdensome alongside code updates (Pacific Northwest National Lab 2022).

A summary of the compliance rates is provided below in **Table 4**.

Table 4. Rates related to Non-Compliant Work

Compliance Rate	Value	References
Compliance Score (0% = non-compliant, 100% = compliance) across different measures	Residential averages: 62% - 94%. Commercial averages: 80% - 100%	
Single-family residential new construction compliance rate	• Non-compliant: 27% • Compliant: 34% • High efficiency: 13%	(Itron, Inc 2004)
Energy Code non-compliance by code requirement	Residential • Most compliant: hardwired lighting – 21% non-compliance • Least compliant: ducts – 73% non-compliance Nonresidential • Most compliant: lighting controls under skylights – 44% non-compliance • Least compliant: ducts – 100% non-compliance	(Quantec 2007)
BayRen jurisdiction compliance	16% compliance	(Benningfield Group, Inc.; BKI; Association of Bay Area Governments 2015)
Residential compliance rate across 19 states	• Higher Income: 73% compliance • Lower Income: 67% compliance	(Pacific Northwest National Lab 2022)

Estimates for Code Compliance Energy Savings

To quantify the influence of Energy Codes on building energy savings, 7 of the studies estimated energy savings that can be attributed to them. These articles used various metrics including annual energy cost savings, energy use intensities, as well as the unrealized energy savings over the life of a building to demonstrate the energy performance of a code compliant building relative to that of a non-compliant or average building.

In a 2020 evaluation of residential multifamily Energy Code compliance by the DOE, researchers found only six buildings that did not currently meet or exceed opaque exterior envelope prescriptive code requirements, pointing to limited opportunity for energy savings through envelope enhancements involving exterior ceiling, roof, and wall components. The study sampled 100 residential multifamily buildings across four states — Illinois, Minnesota, Oregon, and Washington. The sample buildings generally exceeded energy cost savings potential realized from minimum code compliance. Selected to represent a range of climate types, from mild temperature to very cold, buildings sampled under this study indicated the highest opportunity for additional savings is in improving window thermal performance and reducing lighting power densities (LPDs) in corridors, stairwells, and other common areas. Optimizing these measures offers a modest potential for additional energy savings at an average of 10% building energy cost (Ecotope; Slipstream; Center for Energy and Environment 2020).

A companion study conducted by DOE demonstrates slightly different results in single-family residential homes. Most residences investigated across seven states met or exceeded window thermal performance code requirements including both assembly U-factor and solar heat gain coefficient (SHGC). Individually, single-family homes showed a higher potential for energy cost savings through improvements in lighting and wall and roof insulation. Single-family residences appear to offer more savings potential within the building landscape: the study estimated $10.6 million savings (in 2022 USD) from increased code compliance (Pacific Northwest National Laboratory 2022).

In an analysis of Energy Code compliance across 50 measures in 230 commercial buildings, also administered by the DOE, potential energy cost savings were estimated at an average of $189 per thousand square feet (in 2023 USD) per year. The study used a regression analysis of 6 million square feet of commercial building space to estimate loss in energy savings due to non-compliant work. This methodology found commercial unrealized energy savings to average 15% in climate zones 2A and 5A, which represent both hot and cold climates as determined by ASHRAE's thermal climate zone designation. DOE's analysis found lighting controls and HVAC controls to be responsible for the highest unrealized energy cost savings in commercial buildings (Pacific Northwest National Laboratory 2023).

A summary of the energy savings related to code compliance is provided below in Table 5.

Table 5. Energy Savings Related to Code Compliance

Rate / KPI	Value	Article No.
Unrealized energy cost savings from non-compliance in commercial Buildings	15%	(Pacific Northwest National Laboratory 2023)
Unrealized energy use intensity Savings from non-compliance in low rise multifamily	10%	(Ecotope; Slipstream; Center for Energy and Environment 2020)
Unrealized Energy Savings from non-compliance in new single-family housing across 7 states	$18.6 million	(Pacific Northwest National Laboratory 2022)
Energy Savings Attributed to IOU C&S programs 2006-2008	• Electricity savings: 373.2 GWh • Electricity demand savings: 73.2 MW • Gas savings: 5.1 million therms	(KEMA n.d.)
Energy Savings Attributed to IOU C&S programs 2010-2012	• Electricity savings: 2,203 GWh • Electricity demand savings: 374 MW • Gas savings: 20.4 million therms	(Cadmus; DNV GL; CPUC 2014)
Energy Savings Attributed to IOU C&S programs 2013-2015	• Electricity savings: 217.5 GWh • Electricity demand savings: 97.2 MW • Gas savings: 5.1 million therms	(Cadmus, Energy Services Division; DNV GL 2017)
Energy Savings Attributed to IOU C&S programs 2016-2018	• Electricity savings: 653.1 GWh • Electricity demand savings: 114.9 MW • Gas savings: 3.83 million therms	(Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023)

Key Performance Indicator Calculations

The literature reveals two primary methodologies to estimate either rates of unpermitted work and/or rates of non-compliant work: the Top-Down Approach and the Bottom-Up Approach. The methodology, statistical significance, and limitations of each approach is described below.

Top-Down Approach

Only two of the 20 studies exclusively employed the Top-Down approach, with three studies employing a combination of Top-Down and Bottom-Up approaches.

Both studies that employed the Top-Down approach aimed to calculate the rate of unpermitted work in residential HVAC alterations. Although limited to two research exercises, this observation suggests that the Top-Down approach may be preferred or more effective to estimate rates of unpermitted work. Using a Bottom-Up approach for unpermitted work would involve having to seek out properties that should have pulled a permit. This process would be time consuming; moreover, it would likely prove difficult to engage such properties for participation in a study, since unpermitted work is against the law.

The achievement of statistical significance in studies employing Top-Down methodology is varied based on availability and accuracy of datasets employed; neither study characterized statistical significance of the Top-Down approach. The advantage of the Top-Down approach is that it avoids having to collect data, relying on that which is already available. However, it relies on many assumptions.

Both Top-Down studies, for example, employed the assumption that one HVAC sale, as recorded in the IHACI database, should correspond to one residential alteration (Mohasci 2006). In reality, one permit could involve the installation of many HVAC appliances. As such, this method may have overestimated the rate of unpermitted work. DNV GL's report demonstrates this point: when performing the same study using both the Bottom-Up approach and the Top-Down approach, the Bottom-Up approach produced a permitting rate of 29% while the Top-Down approach generated a permitting rate of 8% for residential alteration work. The report further acknowledges the uncertainty in this estimate given the embedded assumptions in the calculations, but it does not quantify the level of certainty (DNV GL 2017).

Bottom-Up Approach

Sixteen of the 20 studies exclusively employed the Bottom-Up approach, with one study employing a combination of Top-Down and Bottom-Up approaches. The studies using the Bottom-Up approach primarily collected data from the field by identifying, recruiting, and conducting site visits for a sample of buildings. A few of the Bottom-Up studies collated survey or interview data from a sample of industry experts. In some instances, studies extracted relevant data from entities indirectly involved in the permit or code compliance processes, including building department records and plans.

All the studies exploring rates of non-compliant work used the Bottom-Up approach. Building departments typically record Energy Code non-compliant work using a binary metric: compliant or not compliant. In many instances, projects marked as compliant contain errors, which would only be discovered when taking the Bottom-Up approach.

The advantage of the Bottom-Up approach is that it allows a site-specific profile. However, collecting this data requires significant time and budget investment. Moreover, four of the studies using Bottom-Up approaches failed to meet their target statistical significance. These studies attempted to observe many surveys, interviews, measures, and/or building samples but fell short given the typical challenges of recruiting buildings, verifying given measures in a single site visit, and acquiring information. Therefore, these studies provide directional recommendations for improving permit and Energy Code compliance rather than definitive quantitative guidance. A couple studies did not attempt statistical significance from the outset. Results and key recommendations remain valuable for continued development of new datasets.

Existing sources may be incomplete and/or contain conflicting datapoints, such as plans containing inaccurate energy documentation or missing field documentation related to the installed equipment's rated performance. Data availability was often limited for less-common code measures, such as cool roofs, which are only required for commercial re-roofing projects of a certain slope (Quantec 2007).

Recommendations Proposed by the Literature

The literature reviewed presented several recommendations to help inform future studies as well as improve Energy Code non-compliant work rates. The following are the key suggestions pulled from the conclusion sections of the studies.

- Prioritize Energy Savings Potential: Focus compliance verification efforts on measures with the greatest potential for energy savings, considering the diverse scenarios of non-compliant work (Pacific Northwest National Lab 2023).
- Simplify Code Complexity and Enhance Training: Provide enhanced and more accessible training for builders and inspectors to address common non-compliance issues related to complex code requirements. Update Energy Codes to be less complex, easier to follow, and reflective of best practices applicable in the field (Pacific Northwest National Lab 2022).
- Conduct Recurring Studies: Perform regular Energy Code compliance studies, ideally every three to five years, to identify savings opportunities, inform energy forecasts, and develop targeted training programs to support broader energy efficiency initiatives (Pacific Northwest National Lab 2022).
- Leverage Energy Efficiency Programs: Partner with IOUs, Community Choice Aggregators (CCAs), and Regional Energy Networks (RENs) to administer energy efficiency programs, enhancing compliance and enforcement efforts through direct collaboration with regional building departments. Simplify statewide codes for mandatory HVAC requirements and streamline permitting forms to reduce paperwork and inefficiencies (DNV GL 2017).
- Enhance the Permitting Process: Strengthen permitting compliance by developing customized field inspection checklists during the plan review, providing specialized Energy Code training, establishing consistent review and inspection procedures, utilizing permit checklists, and integrating Energy Code information into electronic permitting systems. Synchronize building department permit databases with the state's Home Energy Rating System (HERS) registry (Benningfield Group, Inc.; BKI; Association of Bay Area Governments 2015).
- Supplement Binary Metrics with Energy-Based Metrics: Use energy-based metrics like energy use or cost alongside simple binary compliance rates to more comprehensively capture the energy impact of non-compliant work (Pacific Northwest National Lab 2023).
- Address Differences Based on Income: Target education and training efforts in disadvantaged communities to improve compliance and maximize energy efficiency impacts (Pacific Northwest National Lab 2022).

Strengths and Weaknesses of the Studies

The reviewed studies produced both directional and statistically significant findings of great use to the research targets of this paper. Arup found the studies particularly strong in their methodological practices. However, a few contained shortcomings, limiting the significance of their findings.

The key strengths and weaknesses of the studies are outlined below.

Strengths

- Consistent and robust methodology: The studies employed consistent approaches to reduce the number of assumptions involved and allow for greater comparison across studies. The studies performed by Cadmus and Opinion Dynamics for the IOU C&S programs, for example, repeated the same methodology in all four studies completed from 2010 to 2023, with only minor adjustments made. Similarly, the DOE and PNNL employed their data sampling and prototype modeling methodology, established and corroborated through significant research, to estimate unrealized energy savings across four studies (PNNL 2022).
- Confidence Interval: Thirteen out of the 17 studies employing the Bottom-Up approach characterized confidence levels statistically. Twelve of these studies targeted a 90% confidence interval while one targeted 80% by designing samples of sufficient size. Given that the Bottom-Up approach involves data sampling to represent a larger dataset, this step proves critical to producing statistically significant results. Not all studies, as mentioned above, were able to meet their confidence interval targets, due to limitations in sample size.
- Sensitivity Analyses: To characterize uncertainty in the results, nine of the studies implemented sensitivity analyses and/or statistical procedures like Bayesian analysis, Monte Carlo simulations, and bootstrapping. These analyses help to characterize the effect of certain assumptions and inputs on the outcomes of the report. Reports that performed these studies and/or included a discussion of certain inputs and their effect on the results added strength to their findings.
- Multiple methods within One Study: Five studies approached their research objectives through more than one method, which helped to add certainty to the reports' outcomes. As mentioned, the DNV GL Study from 2017, for example, used two different approaches to estimate the permitted rate for residential HVAC alterations: a Bottom-Up approach using survey data from homeowners and a Top-Down approach using secondary HVAC market data and HERS certificates. By conducting these two different analyses, DNV GL was able to state the range of the unpermitted rate with greater confidence, underscoring the influence of methodology. Similarly, DOE in their 90 Percent Compliance Pilot Studies Final Report complemented their analysis of non-compliance rates by conducting jurisdictional surveys to understand building departments' practices and procedures around reviewing Energy Code compliance. These surveys helped to uncover and illuminate the reasons for the non-compliance rate (DOE 2013).

Weaknesses

- Reliance on sampling: As mentioned, eighteen studies implemented data sampling. This approach tends to be fairly time and labor intensive, making it challenging for the study to be scalable or replicable without significant resources. Quantec indicated in their study, for example, that it was difficult to recruit participants for their survey (Quantec 2007). Mentioned previously, four studies targeted samples that would provide statistically significant results but fell short, resulting in findings that were not or only partially significant.
- Lack of Diversity in Methodology Across Studies: With only two studies implementing a Top-Down approach in comparison to 18 studies using the Bottom-Up approach, the

literature review showed a limited diversity in methods taken to evaluate non-compliance, unpermitted work, and building savings.

- Site Visit Observations: All the data sampling studies used site visits to collect data on buildings features and characteristics. While allowing for many data points to be collected, site visits rely on observable data. At times, many targeted pieces of information were not observable and thus could not be recorded. Studies like the Residential Energy Code Field Studies performed by the DOE and PNNL implemented restrictions that precluded researchers from visiting sites more than once. This requirement made it difficult to capture all observations including those necessary to evaluate code compliance tradeoffs (PNNL 2022). To acknowledge these limitations, the DOE 90% Compliance Study counted non-observable features (DOE 2013). The DOE, PNNL, and Opinion Dynamics implemented methodologies to work around such limitations. In their other study of single-family residential code compliance, DOE and PNNL attempted to conduct site visits of buildings in construction, which would allow for certain measures typically hidden like ceiling insulation to be observable (PNNL 2022). Opinion Dynamics used thermal imaging to make observations about window u-value but noted limitations in this approach (Opinion Dynamics 2023).
- Reliance on prototype models: Ten of the studies use prototype energy models to simulate energy performance. This reliance on prototype models limits findings to the strength of the prototypes and how well they represent an average building. While the DOE and PNNL prototypes, for example, have been created and vetted through extensive research, they still have limitations. They only cover 16 types of nonresidential buildings, which the DOE claims account for 75% of nonresidential floor area in the US. Notable omissions in these prototypes include laboratories, data centers, manufacturing facilities, governmental buildings, and places of worship. For residential, they only have two prototypes: one for single-family and one for low rise multifamily (PNNL 2022).
- Proxy Data: To calculate the amount of unpermitted work, the two studies employing the Top-Down approach relied on proxy data, not direct measurements. Using proxy data increases the number of assumptions involved in the study by virtue of using one dataset to reflect another. This finding highlights the lack of data centralized and collected on permitted work and Energy Code compliance.
- Unpermitted work: Only two studies focused specifically on rates of unpermitted work with the rest studying non-compliance rates and building savings.

Summary and Recommendations

Chapter 3 presents a literature review on Energy Code non-compliance and unpermitted work, showing that both residential and commercial buildings often face high rates of non-compliant work, especially regarding HVAC, lighting, and sealing requirements. Residential alterations, particularly in HVAC, are notably affected by unpermitted work, with low permitting rates documented in multiple studies. Across studies, code enforcement inconsistencies, documentation challenges, and resource constraints emerge as barriers to compliance, underscoring the need for effective tracking, uniform permitting processes, and targeted energy savings strategies to mitigate compliance gaps.

After reviewing the literature, Arup has outlined key recommendations for CEC to further investigate unpermitted work and non-compliant work and improve rates of building energy savings:

- Periodically Inspect Non-Compliance: The most prevalent way to determine rates of non-compliant work involves auditing a representative sample size of buildings. In line with the recommendations from the literature, Arup recommends that the CEC perform periodic inspections of buildings holding Energy Code compliance permits. Plan review documents as well as field inspection data should be compared against the applicable revision of the Energy Code at the time of construction like in the BayREN study to identify instances of non-compliance and where they occur along the code compliance process. These studies should be standardized and focused primarily on measures that have the largest effect on building energy use.
- Capture Unpermitted Work Pertaining to Envelope and Lighting Alterations: The two studies estimating unpermitted work focused on HVAC alterations in residential buildings. The research reviewed indicates a gap in the unpermitted rate by not capturing other energy saving measures, primarily envelope and lighting retrofits, which can largely contribute to a building's energy performance. The IOU C&S reports (KEMA n.d.) (Cadmus; DNV GL; CPUC 2014) (Cadmus, Energy Services Division; DNV GL 2017) (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023) reviewed envelope and lighting alterations, but in terms of non-compliance rather than unpermitted work. Future studies should explore envelope and lighting in addition to HVAC in both residential and nonresidential applications to broaden the scope of unpermitted work estimated, with the understanding that some envelope modifications and many lighting changes (such as lamp replacement) do not warrant a permit application.
- Replace Binary Metrics with Energy-Based Metrics: Rather than measuring compliance and permitting rates as binary indicators (e.g., whether windows meet code or not), a more nuanced approach could be adopted. Site visits can assess targeted efficiency factors, such as how far a component deviates from code. For example, instead of a simple yes/no for compliance, evaluate whether a window's U-factor is 10%, 20%, or 50% below the standard via NFRC label review (or thermal imaging if the label is missing). This more detailed level of tracking can then be used to assess which building components are furthest from meeting code compliance, and an associated energy savings can be approximated. This approach will then shed insight into which areas of code compliance are most imperative to target to increase energy savings.

CHAPTER 4: Data Review

Overview

Arup conducted a comprehensive review of datasets based on the literature and scope of work provided by the CEC. The objective was to identify sources that could be utilized to analyze the following metrics:

- Quantity of non-compliant work
- Quantity of unpermitted work
- Rates of Energy Code driven savings

A total of 29 datasets were identified through Arup's expertise, research studies, discussions with the CEC, and the literature review detailed in Chapter 3.

This chapter presents a summary of the reviewed datasets and highlights opportunities to use them in the development of KPIs.

The datasets reviewed as part of this study are listed in **Table 6** below.

Table 6. Datasets Reviewed

References	Publication Title
(U.S. Census Bureau 2023)	Annual Estimates of Housing Units in California
(U.S. Census Bureau 2024)	Building Permits Survey
(State of California Department of Finance 2024)	E-4 Population and Housing Estimates for Cities, Counties, and the State
(U.S. Census Bureau 2024)	Historical Time Series of Housing Units Authorized, Started, Under Construction, and Completed
(U.S. Census Bureau; State of California Department of Finance 2022)	American Community Survey 1-Year and 5-Year Estimates Data Profiles
(State of California Department of Finance 2023)	E-8 Historical Population and Housing Estimates
(Air-Conditioning, Heating, and Refrigeration Institute n.d.)	Historic HVAC Shipments by Type
(State of California Department of Finance n.d.)	Construction Permits Annual Data
(ATTOM n.d.)	Nationwide Building Permit Data
(BuildZoom n.d.)	BuildZoom Building Permit Data

References	Publication Title
(National Association for Industrial and Office Parks 2022)	Development Approvals Index
(U.S. Energy Information Administration n.d.)	Residential Energy Consumption Survey
(U.S. Energy Information Administration 2018)	Commercial Building Energy Consumption Survey
(Redfin 2022)	Property Tax Information
(Zillow n.d.)	Public Records API
(California Energy Commission 2021)	Residential Appliance Saturation Study
(U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy 2024)	Energy Conservation Program: Energy Conservation Standards for Consumer Furnaces
(California Public Utilities Commission 2022)	Database for Energy Efficient Resources
(American Council for an Energy-Efficient Economy 2023)	Energy Efficiency in a High Renewable Energy Future
(American Council for an Energy-Efficient Economy 2022)	2022 State Energy Efficiency Scorecard
(U.S. Energy Star n.d.)	Energy Star Unit Shipment and Market Penetration Report
(TECH Clean California n.d.)	Heat Pump Data - Contractor Data
(HARDI n.d.)	HARDI Annual Benchmarking Survey
(IBISWorld 2024)	Remodeling in California - Market Research Report
(Construction Industry Research Board n.d.)	CIRB Database
(Internal Revenue Service n.d.)	IRS Form 5695
(California Environmental Protection Agency, Department of Toxic Substances Control n.d.)	Orphan Appliance Report

Dataset Targets

Based on the literature review and research targets, Arup sought out datasets that would provide either exact measurements or proxy data for KPIs to support estimating the target metrics: unpermitted work, non-compliant work, and building energy savings. We narrowed our search on the equation variables established in Chapter 2 for the target metrics. The equations, for reference, are provided below:

- Unpermitted work: $\frac{Number\ of\ Unpermitted\ Projects}{Total\ Number\ of\ Projects\ that\ Should\ be\ Permitted}$
- Non-compliant work: $\frac{Number\ of\ Non\text{-}Compliant\ Projects}{Total\ Number\ of\ Permitted\ Projects}$
- Unrealized Savings from Unpermitted Work: $(EUI\ of\ Typical\ Unpermitted\ Project - EUI\ of\ Typical\ Code\ Compliant\ Project) \cdot Area\ of\ Unpermitted\ Work$
- Unrealized Savings from Non-Compliant Work: $(EUI\ of\ Typical\ Non\text{-}Compliant\ Project - EUI\ of\ Typical\ Code\ Compliant\ Project) \cdot Area\ of\ Non\text{-}Compliant\ Work$

In addition to these variables, Arup investigated contextual datasets that would provide background information datapoints like total number of existing buildings, new buildings, existing building features under the California Energy Code's purview, as well as new features. Datasets for such fields can be critical to calculating unpermitted work, non-compliant work, and building energy savings. For example, knowing the number of existing buildings can help inform total number of building alterations that may warrant Energy Code compliance, since alterations will make up a portion of the total existing buildings.

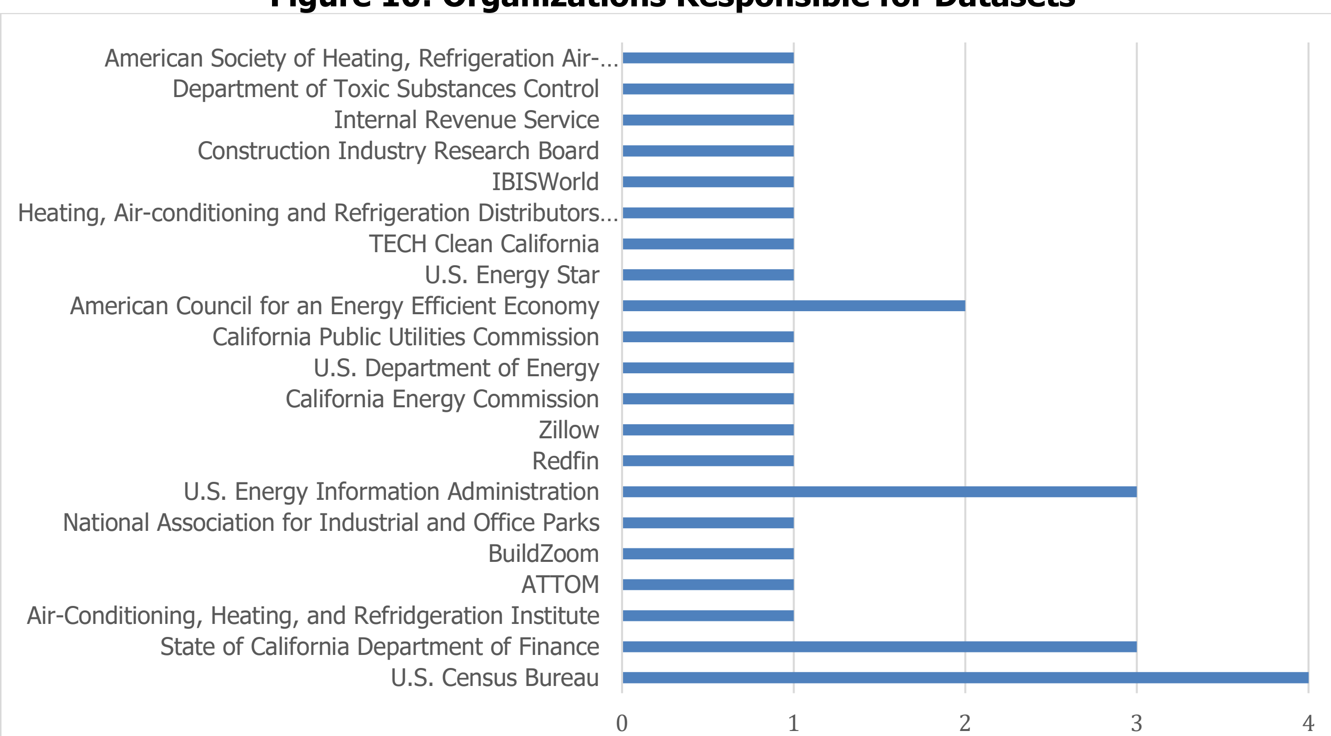
Dataset Characterization

These datasets are characterized in this section. They are described in greater detail in the subsequent section Relevant Datasets. In addition, key findings from each dataset as well as their applicable metrics are summarized in Chapter 2.

Organizations

The datasets reviewed are managed by many organizations, with the U.S. Census Bureau and the State of California Department of Finance being responsible for the most datasets. These datasets were sourced from 18 different organizations, as illustrated in **Figure 10**.

Figure 10: Organizations Responsible for Datasets



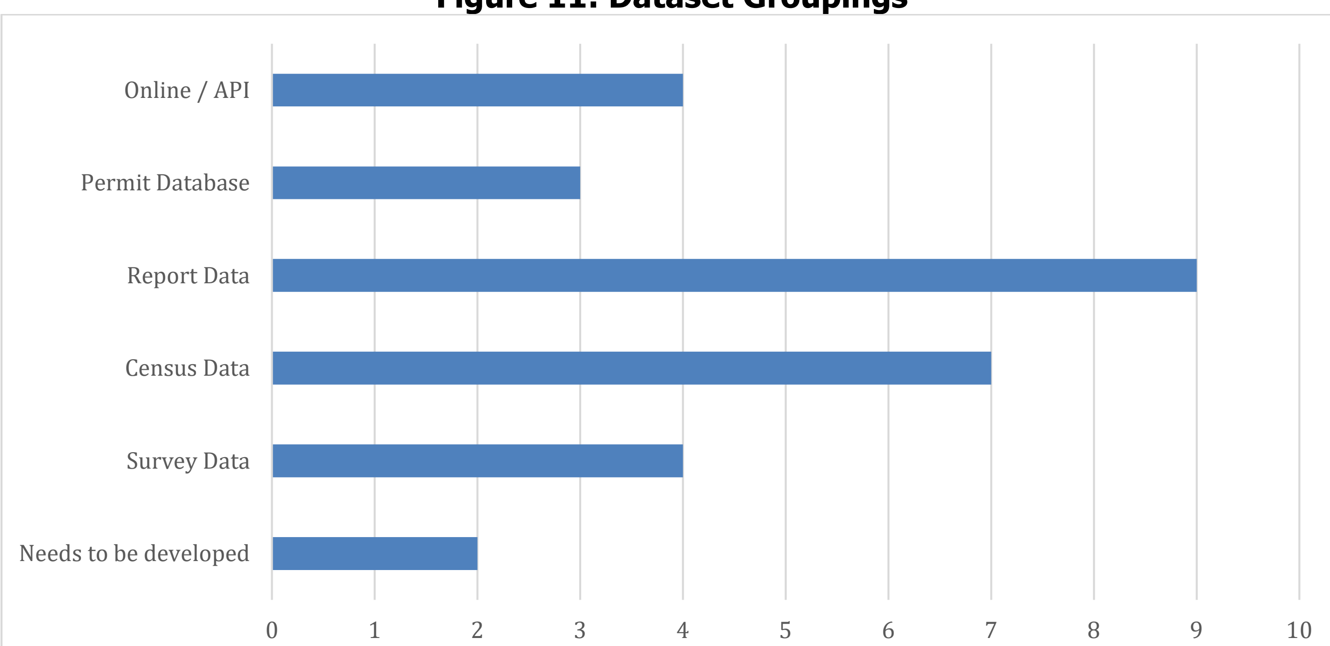
Characterization

Research and discovery focused on datasets with relevance to the installation, construction, and permitting of items requiring Energy Code compliance – HVAC, lighting, and envelope measures – in the State of California or regions in which the State is included (e.g., American Southwest, Pacific Coast, etc.). Datasets identified included permitting databases, survey studies, census data, market data, third-party APIs, and report tables. Arup reviewed these datasets for potential uses and connections to the above variables. Datasets can be characterized as follows:

- **Census Data**: Data taken directly from information collected by the U.S. Census Bureau. Aside from contextual data around population, there is also data around new residential construction and the available supply of houses in California.
- **Online / API**: Data available for download or being visualized on the web. Some of these data sources are also available for direct access via API. Datasets in this category include property data and publicly submitted permit/form/project information.
- **Permit Database**: Data specifically pertaining to construction and renovation permits. Permit data can be accessed through each jurisdiction's own database; however, the permit databases described here centralize permit data for the entire state. Most of the databases in this category investigated by Arup were locked behind a paywall, but any available metadata descriptions or documentation were reviewed to understand what information might be available.
- **Report Data**: Data included within written reports in the form of report text, graphics, or tables. Datasets in this category include estimated equipment lifespans, shipping data, and market estimations.
- **Survey Data**: Data taken from other surveys, particularly around household energy consumption.

The quantities of datasets which fall into these groupings are depicted in **Figure 11**.

Figure 11: Dataset Groupings



Relevant Datasets

Guided by the literature and the CEC, Arup identified datasets involving both direct and indirect measurements as well as proxy data that correspond to the equation variables above and in Chapter 2.

Arup started our research to find datasets that characterize and quantify buildings and construction broadly in California, like how many buildings exist in the state, understanding that KPIs may need to rely on such background information. Changes in the number of buildings, for example, could help inform number of permits required.

The datasets are described in the following subsets.

- Contextual Information
  - Number of Existing Buildings
  - Number of New Buildings
  - Number of Existing HVAC and Appliances
  - Average Building Areas
  - Construction Spending by State
- Number of Permitted Projects
- Total Number of Projects that Should be Permitted
- Non-Compliant Projects
- Energy Use for Average vs Code Compliant Buildings

The most useful datasets were used to create and recommend KPIs described in Chapter 5.

Number of Existing Buildings

Arup sought out these datasets containing quantities of existing buildings to potentially calculate the number of properties pursuing renovations involving the Energy Code. We identified 3 datasets that can be used to estimate the number of existing residential buildings from the U.S. Census Bureau and the State of California Department of Finance, shown in

Table 7 below.

The U.S. Census provides the total residential units whereas the California Department of Finance separates out the occupied units from the vacant ones. This distinction can help refine estimations for the research target metrics, since occupied residential units should consume much more energy than vacant units.

Arup was not able to find any datasets that focused on nonresidential buildings.

Table 7. Existing Building Datasets

References	Name	Source Agency	Relevant Header(s)	Content
(U.S. Census Bureau 2023)	Annual Estimates of Housing Units in California	U.S. Census Bureau	• Housing Unit Estimate (2020-2023), by County • Housing Unit Estimate (2020-2023), by State (California)	• Total residential units by county or state
(U.S. Census Bureau; State of California Department of Finance 2022)	American Community Survey 1-Year and 5-Year Estimates Data Profiles	State of California Department of Finance	• Total Households by State (California)	• Count of total occupied residential units in California from 2010-2022
(State of California Department of Finance 2023)	E-8 Historical Population and Housing Estimates	State of California Department of Finance	• Housing Units by Type and State/County/City • Vacancy Rate by State/County/City	• Total residential units by type (Single, Two-to-Four, Five Plus, Mobile Homes), city, county, and state-wide • Vacancy Rate by city, county and state-wide

Number of New Buildings

The following three datasets from the U.S. Census Bureau and the State of California Department of Finance were found to provide information on the quantity of new buildings, which will require permits. The two datasets from the Census Bureau provide information on the total number of new, permitted residential units in the California. The dataset from the California Department of Finance, on the other hand, covers total residential units as well as percent changes to housing, including but not limited to permitted projects.

Given the increased coverage of the California Department of Finance, Arup recommends tracking percent changes to housing as well as total residential units annually from the California Department of Finance.

Again, Arup was not able to find any datasets that focused on new, nonresidential buildings.

Table 8. New Buildings Datasets

References	Name	Source Agency	Relevant Header(s)	Content
(U.S. Census Bureau 2024)	Building Permits Survey	U.S. Census Bureau	• New Privately Owned Housing Authorized by number of units	• New privately, owned permitted residential units by state
(State of California Department of Finance 2024)	E-4 Population and Housing Estimates for Cities, Counties, and the State	State of California Department of Finance	• City/County/State Housing Estimates with Annual Percent Change, 2023-2024	• Total residential units by county or state • Percent changes to housing
(U.S. Census Bureau 2024)	Historical Time Series of Housing Units Authorized, Started, Under Construction, and Completed	U.S. Census Bureau	• Housing Units Authorized, Started, Under Construction, and Completed, by Year and Geographical Region (Northeast, Midwest, South, West)	• New residential units by state

Number of Existing HVAC and Appliances

Understanding the types of HVAC equipment and appliances related to the Energy Code in existing buildings may help to provide insight into quantity of replacement and alteration projects that require a permit. Tracking such data overtime may also help to forecast trends in the construction of new buildings.

Through the research and consultation with the CEC, Arup identified the Residential Appliance Saturation Study (RASS), which indicates the presence of certain types of energy-using building features and equipment currently installed in residential units. The dataset covers the following applicable systems: space heating, water heating, air-conditioning, lighting, swimming pools, spas and hot tubs, fans, windows, renewable energy technologies. RASS is described in **Table 9**; example datapoints from it are provided in **Figure 12**.

Table 9. Existing Appliances Datasets

References	Name	Source Agency	Relevant Header(s)	Content
(California Energy Commission 2021)	RASS	California Energy Commission	• Unit Energy Consumption (UEC) and Saturation Estimates for Households • Electric Unit Energy Consumption and Saturation Estimates • Gas Unit Energy Consumption and Saturation Estimates	• Estimated Residential Appliance Unit Energy Consumption and Saturation by residence type • Estimated Residential Appliance Unit Energy Consumption and Saturation by Appliance

Figure 12. Example Datapoints from RASS*

Table 15: Electric UECs for Weather-Sensitive End Uses in Forecasting Climate Zones 1-6

	Zone 1 UEC	Zone 1 Saturation	Zone 2 UEC	Zone 2 Saturation	Zone 3 UEC	Zone 3 Saturation	Zone 4 UEC	Zone 4 Saturation	Zone 5 UEC	Zone 5 Saturation	Zone 6 UEC	Zone 6 Saturation
All Household	4,987	7,161 homes	6,346	2,015 homes	8,339	595 homes	7,793	2,948 homes	8,154	1712 homes	5,720	1,536 homes
Conv. Heat	880	0.16	1,518	0.18	1,371	0.11	1,962	0.14	1,353	0.15	1,498	0.18
Heat Pump	773	0.02	1,441	0.03	1,283	0.02	1,515	0.05	1,076	0.03	1,462	0.01
Aux. Heat	224	0.10	566	0.06	545	0.06	1,160	0.06	497	0.09	776	0.10
Furnace Fan	148	0.62	222	0.64	171	0.82	207	0.73	146	0.69	186	0.59
Attic Ceiling Fan	77	0.01	29	0.02	104	0.09	84	0.01	357	0.03	55	0.00
Central Air Conditioning	539	0.40	412	0.35	2,083	0.82	1,134	0.77	2,186	0.74	836	0.19
Room AC	268	0.12	256	0.14	1,331	0.19	723	0.15	1,515	0.20	346	0.05
Evaporative Cooler	337	0.07	261	0.07	1,180	0.12	869	0.15	1,488	0.18	181	0.03
Water Heat	1,142	0.03	1,794	0.14	2,469	0.09	2,579	0.12	2,273	0.04	2,356	0.11
Solar Water Heat	1,275	0.00	1,243	0.00	1,877	0.00	1,161	0.00	1,906	0.00	1,156	0.00

Source: 2019 California Residential Appliance Saturation Survey

*Note: UEC standards for Unit Energy Consumption – the amount of energy an appliance uses in a year (in kWh for electricity and therms for gas)

Average Building Areas

Typical building areas were researched in case they would be needed for the KPIs. Energy use, for example, is typically normalized per square foot of conditioned floor area, i.e., energy use intensity (EUI). As such, one can calculate total energy use by multiplying EUI by gross area.

Average, representative gross areas of buildings were found in the Residential Energy Consumption Survey (RECS) and the Commercial Building Energy Consumption Survey (CBECS), which are described in **Table 10** below.

Table 10. Building Area Datasets

References	Name	Source Agency	Relevant Header(s)	Content
(U.S. Energy Information Administration n.d.)	RECS	U.S. Energy Information Administration (EIA)	• Total square footage of U.S. homes (HC10.1) • Total square footage of West homes (HC10.5) • Average square footage of U.S. homes (HC10.9) • Average square footage of West homes (HC10.13)	• Average square footage of homes per residential unit
(U.S. Energy Information Administration 2018)	CBECS	EIA	• Table B6. Building size, number of buildings • Table B7. Building size, floorspace	• Average square footage of nonresidential buildings per building type

Construction Spending by State

If California data was not identified, Arup looked for datasets to help allocate portions of US datasets specifically to California. Construction spending was seen as one of the ways to do this, assuming that the construction spending in California divided by that for the entire US could serve as a proxy for the ratio of construction projects in California relative to the country.

Arup found construction spending estimates in the U.S. Census Bureau as shown in **Table 11** below.

Table 11. Construction Spending Datasets

References	Name	Source Agency	Relevant Header(s)	Content
(U.S. Census Bureau 2024)	Annual Value of State and Local Construction Put in Place by State	U.S. Census Bureau	• 2023 Construction Spending in California	• The amount of construction spending in California compared to other states and the US as a whole

Number of Permitted Projects

Understanding the number of permitted projects is essential to estimating rates of unpermitted work. Namely, the number of unpermitted projects is in theory equal to the number of projects that should be permitted subtracted by the total number of permitted projects.

Arup identified 4 different datasets that help to provide information on number and type of permitted projects. These datasets include the State of California Department of Finance, Attom, BuildZoom, and CIRB. They are described in **Table 12** below.

The challenge with identifying the number of permitted projects stems from the decentralization of permit approval: Permitting is managed by jurisdictions separately. These datasets centralize permitting data from various jurisdictions through surveys, research, and direct sourcing.

None of these datasets cover all applicable permits. Attom appears to come closest, claiming to cover 99% of the US in its dataset (ATTOM n.d.). BuildZoom accounts for 90% of the US ((BuildZoom n.d.) while CIRB has 539 partnering jurisdictions (BuildZoom n.d.). The Census data only includes authorized residential permits.

Access differs across the sources with Attom and BuildZoom requiring a paid subscription, CIRB requiring users to purchase datasets. The California Department of Finance information is free.

The CEC already has access to CIRB. To complement this data, the CEC can consider purchasing a subscription to Attom, given its superior coverage of building permits.

Table 12. Energy Use Datasets

References	Name	Source Agency	Relevant Header(s)	Content
(State of California Department of Finance n.d.)	Construction Permits Annual Data	State of California Department of Finance	• Single-Family Units (Thousands), Multifamily Units (Thousands), Total units (Thousands), per year	• Authorized building permits for new residential units by year, data collected from 1975-2023
(ATTOM n.d.)	Nationwide Building Permit Data	Attom	• Assessor tax • Building permits • Interior features • Property characteristics	99% coverage for • Assessor tax: public assessor tax estimates per priority • Building permits: types of building permits awarded for a property • Interior features: types of interior features (e.g. appliances, heating and cooling systems) for a property • Property characteristics: size, use, location, condition, ownership
(BuildZoom n.d.)	BuildZoom Building Permit Data	BuildZoom	Data API	90% coverage for the following: Property Permit history

References	Name	Source Agency	Relevant Header(s)	Content
(Construction Industry Research Board n.d.)	CIRB Database	Construction Industry Research Board	• CIRB Building Permit Data • Statewide Permits Issued	Permit Data for 539 jurisdictions (80% coverage) • Permit Data: • Issue Date • Permit No • Class • Builder • Valuation • Description Permits Issued: • # of Permits by Code Number of Units by Code • Valuation by Code

Total Number of Projects that Should be Permitted

Finding the number of projects that should be permitted proves a more challenging task, since many buildings are built or renovated without the required permits. In the literature, two studies – DNV GL 2017 and Mohasci 2006 – used HVAC sales and shipments to approximate total number projects. The DNV GL 2017 study also made use of estimated useful life for HVAC and appliances requiring Energy Code compliance to refine their estimate.

In addition to databases for HVAC sales and useful life, Arup proposed researching property values as a potential indicator for construction projects requiring Energy Code compliance. These three dataset groups are described below.

HVAC Sales

The literature review revealed that HVAC sales have been used to serve as a proxy for the total number of HVAC projects that should require a permit and achieve Energy Code compliance. This method assumes a 1:1 ratio for HVAC sale to project.

Several agencies track HVAC sales. The DNV GL study from 2017 in the literature review relied on AHRI data while the Mohasci study used IHACI data (DNV GL 2017) (Mohasci 2006).

Arup identified the HVAC sales datasets of potential use in **Table 13**. AHRI and HARDI track manufacturer shipments of HVAC; however, neither separates out HVAC sales in California. As such, some post-processing of these datasets would be required to allocate the right amount to California. This post processing could be done through use of the contextual datasets assuming shipments in California, for example, are proportional the total construction spending in California relative to the entire US.

EnergyStar and TECH also provide HVAC quantities shipped and installed as part of their efficiency programs. EnergyStar and TECH only make up a portion of the total HVAC sales in California and thus are not as useful as AHRI and HARDI.

In terms of access, HARDI is only available to HARDI's registered distributors; it is not accessible to the CEC. Arup, thus, recommends using AHRI from the following datasets.

Table 13. HVAC Sales

References	Name	Source Agency	Relevant Header(s)	Content
(Air-Conditioning, Heating, and Refrigeration Institute n.d.)	Historic HVAC Shipments by Type	AHRI	• Monthly shipments • Twenty Year Summary Charts	• Combined U.S. manufacturer shipments of central air conditioning, air-source heat pumps systems, gas and oil furnaces, and gas and electric tank water heaters.
(U.S. Energy Star n.d.)	Energy Star Unit Shipment and Market Penetration Report	U.S. Energy Star	• 2023 Units shipped by Product Category • 2023 Estimated Market Penetration by Product Category	Relevant Product Categories: • Boilers • Furnaces • Heat Pumps • Room Air Conditioners • Windows, Doors, and Skylights
(TECH Clean California n.d.)	Heat Pump Data - Contractor Data	TECH Clean California	• Tech Working Dataset • Greenhouse Gas Impacts Dataset (Not yet released)	• Data on the installed equipment and replaced equipment • Total Project Cost • Incentive provided • Installation details including duration and quality installation measures performed
(HARDI n.d.)	HARDI Annual Benchmarking Survey	HARDI	• Inventory • Product Type	• Average inventory • Average number of orders shipped monthly • Average number of lines per order • Average number of shipments received • Statistics per product type including HVAC unitary, HVAC light commercial, heating & AC supplies, controls and control parts, refrigerants & refrigerant accessories, plumbing & hydronics, sheet metal and sheet metal items and all other products

Useful Life

Data around the useful life of HVAC offers another way to estimate total number of HVAC projects that *should* be permitted for alteration work. At the end of their useful life, HVAC equipment should be replaced. Knowing the amount of HVAC equipment installed and that which is at the end of its useful life paints of picture of how many permits should be expected for HVAC changeouts.

Three datasets on useful life of HVAC equipment are described below. The DOE dataset includes lifetime estimates for residential furnaces. ASHRAE includes effective lifetimes for most HVAC system types while DEER provides effective useful life estimates for various energy savings measures including building envelope.

From a literature review conducted as part of their study on unpermitted residential HVAC changeouts, DNV GL found the DEER database to provide the best estimates for effective useful life, save for central gas furnaces (DNV GL 2017). DEER generates its estimates from a variety of sources, most notably the California IOUs who have conducted research on the lifetime of energy-saving equipment and appliances (California Public Utilities Commission 2022). ASHRAE, on the other hand, bases its estimates on the reported service live of specific equipment from a sample of projects (American Society of Heating, Refrigeration Air-Conditioning Engineers n.d).

Table 14. Useful Life Datasets

References	Name	Source Agency	Relevant Header(s)	Content
(U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy 2024)	Energy Conservation Program: Energy Conservation Standards for Consumer Furnaces	U.S. Department of Energy	• Lifetime estimate for residential furnaces	• The average lifetime for furnaces outside of northern region of the U.S.
(American Society of Heating, Refrigeration Air-Conditioning Engineers n.d.)	ASHRAE: Major HVAC System & Equipment	ASHRAE	• Service Life Data by System Type	• Surveyed data on expected life expectancies of typical HVAC equipment including air distribution, cooling, heat rejection, cooling pumps, heating, heating pumps, controls, and miscellaneous
(California Public Utilities Commission 2022)	Database for Energy Efficient Resources (DEER)	California Public Utilities Commission	• Effective useful life	• Effective useful life estimates for energy saving technologies and measures

To estimate the amount of equipment at the end of its useful life, one can use the contextual datasets discussed earlier. Tracking, for example, dataset updates involving the quantity of residential units in California (State of California Department of Finance 2024) and the saturation of HVAC appliances, i.e., RASS (California Energy Commission 2021), can help approximate the amount and installation date of existing HVAC in homes. Factoring in effective useful life estimates, one can then determine when these pieces of HVAC equipment need to be replaced.

This method is accurate *only if* equipment gets replaced at the end of its effective useful life. At times, pieces of equipment are left in service much longer than their useful life. If on average, equipment is replaced on a longer timeline, this method would result in too high an estimate of projects that *should* be permitted.

Property Value

Arup identified property value as a potential indicator for changes made to a property requiring a permit. While property value reflects the real estate market, it typically changes if certain upgrades or renovations are made once market factors are accounted for.

Tracking real estate values, tax assessor data, and new property listings may help to determine the total number projects that should be permitted. Since many construction and renovation projects may not require Energy Code compliance, the challenge with this method involves separating out real estate value changes due to work involving HVAC, lighting, or envelope.

For this indicator, Arup investigated two real estate databases: Redfin and Zillow. These two databases only cover residential buildings; nonresidential buildings cannot be listed on either website. They are free to access; however, Zillow offers a public API to query data (Zillow n.d.). Redfin does not appear to offer an accessible API; as such, web scraping would be required to collect and aggregate its data (Redfin 2022).

While exploring Zillow's Bridge Interactive API, Arup identified several headers relevant to Energy Code compliance that can help filter changes in real estate data. These headers include items like the heating or cooling systems installed, appliances, insulation, and renewable energy (Zillow n.d.). Tracking changes to these headers along with real estate value across properties in California may help to filter construction projects that warrant Energy Code compliance. For example, if the property value of a building changes along with energy efficient listed items like insulation (see Table 15, **Table 16**, and **Figure 13.** Example Fields for a Property on Zillow (Zillow n.d.) below for relevant fields on sample property on Zillow), it is likely that changes were made to the property that should involve Energy Code compliance.

Table 15. Property Value Assessor Datasets

References	Name	Source Agency	Relevant Header(s)	Content
(Redfin 2022)	Property Tax Information	Redfin	• Sales & tax history • Property details	• Sales & tax history: tax assessed value • Property details: interior features (e.g., rooms, appliances), exterior features (e.g., view), public facts
(Zillow n.d.)	Public Records API	Zillow	See Table 16. Select Headers from Zillow Bridge API for details.	• Assessor tax: public assessor tax estimates per priority • Building features: appliances, heating and cooling systems, renewable energy, energy efficiency measures for a property • Property characteristics: size, use, location, condition

These additional fields apart from real estate value (shown in

Table 16), however, are self-reported. Machine learning or artificial intelligence (AI) would likely be necessary to fill in gaps in the data and analyze the dataset to determine the number of Energy Code compliance related projects.

Table 16. Select Headers from Zillow Bridge API

Name	Type	Description
BridgeModificationTimestamp	string	A timestamp representing when last this record was modified in the Bridge system.
building.airConditioning	string	Air conditioning feature of the building.
building.class	string	The class of the building.
building.condition	string	The condition of the building.
building.heating	string	Heating feature of the building.
building.quality	string	The quality of the building.
building.yearBuilt	number	The year in which the building was built.

Name	Type	Description
Cooling	string	A list describing the cooling or air conditioning features of the property
GreenEnergyEfficient	string	Pick list of general green attributes such as energy efficient doors, or appliances without naming specific elements with ratings that may wane over time.
GreenEnergyGeneration	string	Methods of generating power that are included in the sale or lease.
GreenIndoorAirQuality	string	Pick list of indoor air quality measures without naming specific elements with ratings that may wane over time.
Heating	string	A list describing the heating features of the property.
landUseDescription	string	Description that matches the land use code.
TaxAssessedValue	number	The property value as of the last assessment made by the taxing authority.
TaxYear	number	The year in with the last assessment of the property value/tax was made.
WindowFeatures	string	A list of features or description of the windows included in the sale/lease.

Figure 13. Example Fields for a Property on Zillow (Zillow n.d.)

Construction

Type & style

- Home type: SingleFamily
- Architectural style: Ranch
- Property subtype: Single Family Residence

Materials

- Vinyl Siding
- Foundation: Concrete Perimeter, Raised
- Roof: Asphalt

Condition

- New construction: No
- Year built: 1965

Utilities & green energy

- Sewer: Septic Tank
- Water: Public
- Utilities for property: Cable Available

Green energy

- Energy efficient items: Insulation, Thermostat, Ridge Vents, Doors, Windows

Non-Compliant Projects

The literature review did not reveal any existing datasets that can be used to estimate the amount of non-compliant work. As described in Chapter 3, all the studies investigating non-compliant work relied on data sampling – primarily involving a comparison between site visit data and permit data for a representative sample of buildings.

Arup was not able to identify direct or proxy datasets for the number of non-compliant projects. This lack of datasets prevents Arup from recommending KPIs for non-compliant work that do not involve new methods of data sampling.

Energy Use Values

As detailed in CHAPTER 2:
Methodology, the equations for unrealized energy savings from non-compliant work and unpermitted work, rely on estimates for the EUI of non-compliant work and unpermitted work, respectively. According to the literature review, the energy use and resultant EUIs of these two types of work are district from one another.

Arup was not able to find specific datasets for the energy use of unpermitted work or non-compliant work. Studies in the literature review investigating them used data sampling and energy modeling to estimate their respective energy use.

As an alternative, Arup explored datasets that capture the EUI of an average or baseline building compared to that of code compliant building and/or energy saving measures. Although an average building should not be taken as a proxy for an unpermitted or non-compliant building, it can help narrow in on range of expected EUIs for this type of work. In addition, having the EUIs of average versus code compliant projects can help determine the amount of energy savings that can be attribute to code compliance.

Average Energy Use

Arup identified the three data sources that can be used to estimate an average or baseline energy use intensity: the RECs, CBECs, and RASS. They are described in

Table 17 below.

RECS and CBECs from the EIA includes average energy consumption across the US for a representative sample of buildings – residential for RECS and nonresidential for CBECS. These two datasets offer results for specific Census regions; however, California data cannot be isolated. RECS and CBECs offer results for the western, pacific region of the US, which can serve as a proxy for California.

RASS includes energy consumption of residences in California from a representative sample. Energy in the RASS reflects metered and reported data from meters and the utilities in California. Due to its California specific data, Arup recommends using RASS to represent baseline energy use for residential buildings in California.

Unfortunately, no datasets specific to California were identified for baseline, nonresidential building energy use.

Table 17. Baseline Energy Use Datasets

References	Name	Source Agency	Relevant Header(s)	Content
(U.S. Energy Information Administration n.d.)	Residential Energy Consumption Survey	EIA	• CE1.1.ST – Summary household site consumption and expenditures in U.S. homes by state, 2020 • CE5.3.ST – Detailed electricity end uses by state - consumption – averages • Detailed natural gas, propane, and fuel oil by state - consumption – averages • 2020 RECS microdata	Average energy consumption from a representative sample of housing units
(U.S. Energy Information Administration 2018)	Commercial Building Energy Consumption Survey	U.S. Energy Information Administration	• Table C12. Sum of major fuels consumption totals and gross energy intensities by building activity subcategories • Table C16. Electricity expenditures by census region • Table C26. Natural gas expenditures by census region • Table E4. Electricity consumption intensities (in British thermal units [Btu]) by end use • Table E7. Natural gas consumption and energy intensities (in British thermal units [Btu]) by end use • 2018 CBECS microdata	• Average energy consumption from a representative sample of commercial buildings • 2018 CBECS microdata contains data from individual buildings sampled
(California Energy Commission 2021)	Residential Appliance Saturation Study	California Energy Commission	• Unit Energy Consumption (UEC) and Saturation Estimates for Households • Electric Unit Energy Consumption and Saturation Estimates • Gas Unit Energy Consumption and Saturation Estimates	• Estimated Residential Appliance Unit Energy Consumption and Saturation by residence type • Estimated Residential Appliance Unit Energy Consumption and Saturation by Appliance

Energy Efficiency Measures Savings

Two sources were identified to estimate energy performance associated with code compliance: DEER from the CPUC and the Energy Efficiency in High Renewable Energy Future from ACEEE. Both sources include energy data, such as energy savings potential, of specific efficiency measures from prototypes energy model simulations. DEER also has data to represent baseline energy consumption in line with the Energy Code.

Due to the increased focus on California and Energy Code, Arup recommends using the DEER database to help estimate energy savings and building savings potential from Energy Code compliance.

Table 18. Energy Efficiency Measures Savings Datasets

References	Name	Source Agency	Relevant Header(s)	Content
(California Public Utilities Commission 2022)	Database for Energy Efficient Resources (DEER)	California Public Utilities Commission	• Measure Name/ID, Baseline Characteristics, Measure Characteristics, Annual Energy Savings (kWh, therms), Carbon Emissions Reductions (tons CO_2e), Climate Zone • Claims Data	Energy savings by measures from CASE reports related to: Envelope, HVAC, thermostat, Refrigeration, Lighting
(American Council for an Energy-Efficient Economy 2023)	Energy Efficiency in a High Renewable Energy Future	American Council for an Energy Efficient Economy	Increase in annual energy savings for modeled energy efficiency measures between 2030 and 2050, California Region	Energy savings by measures related to: Envelope, HVAC, thermostat, Refrigeration, Lighting

Figure 14. Example Results from DEER (California Public Utilities Commission 2022)

			Baseline			Measure			UES		
Description	Building Type	Climate Zone	Electric (kWh)	Demand (kW)	Gas (Therms)	Electric (kWh)	Demand (kW)	Gas (Therms)	Electric (kWh)	Demand (kW)	Gas (Therms)
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ01	-	-	149.35	-	-	101.8	-	-	47.52
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ02	-	-	133.30	-	-	87.3	-	-	46.01
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ03	-	-	135.15	-	-	88.4	-	-	46.80
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ04	-	-	127.18	-	-	81.4	-	-	45.77
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ05	-	-	136.94	-	-	90.2	-	-	46.72
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ06	-	-	122.03	-	-	76.2	-	-	45.84
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ07	-	-	119.54	-	-	74.3	-	-	45.29
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ08	-	-	115.45	-	-	70.6	-	-	44.88
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ09	-	-	116.09	-	-	71.3	-	-	44.80
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ10	-	-	115.14	-	-	70.8	-	-	44.35
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ11	-	-	118.94	-	-	74.7	-	-	44.23
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ12	-	-	124.25	-	-	79.2	-	-	45.05
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ13	-	-	115.36	-	-	71.6	-	-	43.77
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ14	-	-	120.72	-	-	76.3	-	-	44.39
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ15	-	-	86.67	-	-	47.8	-	-	38.89
Gas Absorption Heat Pump Water Heating System with Gas Boiler Backup, replacing Gas Boiler Water Heater	MFm	CZ16	-	-	148.28	-	-	102.1	-	-	46.20

Datasets to Explore Further

During discussions with the CEC, Arup came across two datasets that could be of potential use to the calculation of building savings and unpermitted work: IRS Form 5695 and the Orphan

Appliance Report Forms sent to the Department of Toxic Substances Control. Arup did not receive access to either data source. As such, we could not investigate them sufficiently.

U.S. taxpayers use IRS Form 5695 to claim residential energy credits for energy-efficient improvements. This data could provide a representative sample of first costs for energy efficiency measures. Such data could then be mapped to corresponding code compliance measures in California to help determine the cost benefit of building savings.

Orphaned appliances refer to disposed appliances. They can serve as potential proxy for the number of appliances that must be replaced, assuming a 1:1 ratio of disposed appliance to replacement. This method would thus help to determine the amount of alteration / replacement HVAC projects that should be permitted, providing insight into the rate of unpermitted work.

Table 19. Datasets to Explore Further

References	Name	Source Agency	Relevant Header(s)	Content
(Internal Revenue Service n.d.)	IRS Form 5695	Internal Revenue Service	• Qualified Energy Efficiency Improvements • Residential Energy Property Expenditures	• Cost of central air conditioners • Cost of windows and skylights that meet Energy Star Certification Requirements
(California Environmental Protection Agency, Department of Toxic Substances Control n.d.)	Orphan Appliance Report	California Environmental Protection Agency, Department of Toxic Substances Control	• Total number of "orphan" appliances received per month • "Orphan" appliances received by type	Relevant "orphan" appliance types: • Furnaces • Air Conditioners

Blue Sky Idea - Satellite Imagery

During our dataset research effort, Arup also considered out-of-the-box and blue-sky ideas to establish KPIs for unpermitted work, non-compliant work, and building savings. These strategies were not expected to make use of available data, likely relying on collection and/or script development to scrape data.

From this brainstorming effort, one strategy stood out: using satellite imagery for construction. The proposal involves using street view data found on sites such as Google Maps combined with aerial satellite imagery, such as Landsat data, to visually identify evidence of construction or renovation work related to rooftop HVAC systems or building envelopes, which may not have been permitted. This strategy is currently limited, however, due to the lack of API access to historical street view photos, challenges analyzing such a large set of data for the entire region of California, and the fact that many HVAC equipment types are not installed on roofs. There may be opportunities to utilize technology to circumnavigate some of these challenges, such as web-scraping historical street view data and automating review using computer vision or other software techniques.

Discussion

The research identified several useful datasets to establish KPIs and provide values to metrics of this study around unpermitted work and building savings. While examining the datasets together, Arup uncovered a few patterns:

- Residential Buildings: More datasets (14 out of 29) focused on residential construction than nonresidential projects (only 1 dataset focused explicitly on commercial properties while the remaining applied to both residential and nonresidential buildings). Datasets including the U.S. Census, the State of California Department of Finance, and Zillow, for example, only provide information on housing. As such, approximating the target metrics of this study is likely easier for residential buildings.
- Alteration Work: The datasets used to calculate unpermitted work show a slight bent towards alteration work over new construction work. Specifically, those capturing data on useful life of HVAC as well as orphaned appliances can only be used to estimate HVAC changeouts. This finding lines up with the literature review, whose only 2 studies on unpermitted work focused specifically on HVAC changeouts in residential buildings. Alteration work is thought to have higher rates of unpermitted work than new construction. As such, these datasets can be useful to target this issue.
- HVAC and appliances: Although the Energy Code covers a wide range of building features, the datasets focused on HVAC and appliances. Arup identified 7 studies specific to HVAC but no datasets for other Energy Code related features such as envelope or lighting. This trend aligns with that of the literature review, which did not include any studies specific to envelope or lighting. Thus, using these datasets may result in a bias of HVAC-related project work.
- Coverage: Arup's review revealed that datasets differ terms of their coverage and quality of data. For example, in terms of permitted data, Attom offers more coverage (claiming to have data for 99% of the US) than BuildZoom (90% of the US) and CIRB (539 partnering jurisdictions). Databases that rely on self-reported data, like Zillow for certain building features (property data is not self-reported), may include gaps. When using datasets, one must consider coverage and implement strategies to factor it and/or fill in gaps in the data to produce statistically sound results.
- Non-compliant work: As mentioned, Arup was not able to identify any datasets that directly measure or serve as a proxy for non-compliant work. This finding aligns with the literature review, which only included studies involving data sampling to estimate non-compliant work. Additional research may be required to find and test out different types of data to approximate non-compliant work.
- Energy use for unpermitted and non-compliant work: Similarly, Arup was not able to find any datasets that specifically capture or approximate the energy use of unpermitted work or non-compliant work. The studies in the literature relied on data sampling and energy modeling to estimate energy use of these type of projects. We did identify datasets capturing average energy use of both residential and nonresidential buildings. However, according to the literature, unpermitted work and non-compliant should have distinct energy use.

Summary

This chapter identifies existing challenges and opportunities within California's permitting data landscape, focusing on its decentralized nature and the potential to leverage available datasets for energy efficiency and compliance analysis. A diverse array of datasets has been reviewed, covering contextual information on building stock, construction activity, and baseline energy use. These datasets include sources such as the U.S. Census Bureau, California Department of Finance, and the California Energy Commission, among others.

Key datasets include estimates of housing units, building permits, construction spending, HVAC system shipments, and energy consumption surveys. These resources provide valuable context on both existing and new buildings, the scope of permitted and unpermitted projects, and baseline energy performance. While third-party services claim to aggregate some of this data, direct access to these sources remains fragmented.

Additionally, the review highlights innovative possibilities for supplementing existing data with indirect methods, such as geospatial analysis, to identify unpermitted construction activity. Together, these datasets and methodologies form a foundation for understanding energy compliance trends and estimating the scale of unpermitted work.

Recommendations

Some of the most promising data around permitting is currently decentralized across various county and city assessor offices in California. While there are third-party services available that claim to aggregate this data for paying customers, the lack of direct access to a centralized platform makes it challenging to track both renovation and new construction projects that may or may not comply with energy efficiency requirements.

To mitigate these challenges, Arup recommends the following next steps to help estimate and inform the rates of unpermitted work, non-compliant work, and building savings through datasets, ranked roughly in order of priority:

1. Explore Datasets: We recommend that the CEC explores the recommended datasets outlined in Table 20. These datasets can be used in KPIs and the equations established in Chapter 2 to approximate unpermitted work, non-compliant work, and building savings.
2. Data Access: To facilitate future analysis, data should be requested regularly or provided with direct API access from the source organizations mentioned earlier, and stored in a centralized, accessible location, along with relevant metadata about what the data represents and how it may be used.
3. Consider Collecting New Data: Outside of the datasets reviewed, we also recommend considering more indirect approaches for capturing data on unpermitted work. This could involve, for example, the blue-sky satellite imagery idea, which involves the use of earth observation or remote sensing to capture evidence of unpermitted construction or renovation work. The CEC can consider partnering with the private sector for development software or automated workflows to analyze visual geospatial data to provide further insights into non-compliant or unpermitted projects.

Table 20. Recommended Datasets

References	Name	Source Agency	Use
(U.S. Census Bureau 2023)	Annual Estimates of Housing Units in California	U.S. Census Bureau	• Contextual dataset (existing buildings)
(U.S. Census Bureau; State of California Department of Finance 2022)	American Community Survey 1-Year and 5-Year Estimates Data Profiles	State of California Department of Finance	• Contextual dataset (existing buildings)
(State of California Department of Finance 2023)	E-8 Historical Population and Housing Estimates	State of California Department of Finance	• Contextual dataset (existing buildings)
(State of California Department of Finance 2024)	E-4 Population and Housing Estimates for Cities, Counties, and the State	State of California Department of Finance	• Contextual Dataset (new buildings)
(California Energy Commission 2021)	RASS	California Energy Commission	• Contextual Dataset (Number of Existing HVAC and Appliances) • Baseline energy use
(U.S. Census Bureau 2024)	Annual Value of State and Local Construction Put in Place by State	U.S. Census Bureau	• Contextual Dataset (construction spending)
(U.S. Census Bureau 2024)	Building Permits Survey	U.S. Census Bureau	• Number of permitted projects (residential only)
(State of California Department of Finance n.d.)	Construction Permits Annual Data	State of California Department of Finance	• Number of permitted projects (residential only)
(ATTOM n.d.)	Nationwide Building Permit Data	Attom	• Number of permitted projects
(Construction Industry Research Board n.d.)	CIRB Database	Construction Industry Research Board	• Number of permitted projects

References	Name	Source Agency	Use
(Air-Conditioning, Heating, and Refrigeration Institute n.d.)	Historic HVAC Shipments by Type	AHRI	• Total number of projects that should be permitted (HVAC sales)
(American Society of Heating, Refrigeration Air-Conditioning Engineers n.d.)	ASHRAE: Major HVAC System & Equipment	ASHRAE	• Total number of projects that should be permitted (useful life)
(Zillow n.d.)	Public Records API	Zillow	• Total number of projects that should be permitted (property value)
(U.S. Energy Information Administration n.d.)	Residential Energy Consumption Survey	EIA	• Contextual dataset (average area) • Baseline energy use
(U.S. Energy Information Administration 2018)	Commercial Building Energy Consumption Survey	EIA	• Contextual dataset (average area) • Baseline energy use
(California Public Utilities Commission 2022)	Database for Energy Efficient Resources (DEER)	California Public Utilities Commission	• Energy efficiency measure savings

Research Limitations

Arup's examination of the existing data ecosystem, while thorough, encountered certain limitations. Some valuable sources with data pertinent to the KPIs were inaccessible due to paywalls. Additionally, other datasets were either partially accessible or entirely restricted due to general terms of use that Arup could not fulfill. In such instances, we reviewed available documentation and metadata to glean as much information as possible from these more restricted data sources.

Our efforts also included reviewing permitting data directly from city and county assessor offices to understand the available information. Currently, publicly accessible permitting data is decentralized, with each jurisdiction maintaining its own database. The information recorded within these permitting databases varies, and some data fields are reported inconsistently. Although there are third-party vendors who offer the capability to aggregate permitting data across jurisdictions, we were unable to investigate further due to restrictions on paying for data access.

Since many of the reviewed studies concentrated on HVAC alterations, we prioritized identifying datasets related to lighting upgrades and residential building envelopes, which also necessitate Energy Code permitting. However, we were unable to locate any datasets with sufficient information on these two elements to integrate them into the KPIs beyond assessor data.

Some data sources identified as potentially relevant were also found to be outdated, which limited their usefulness. For example, a California Residential Remodeling/Renovation Market Study conducted in 2001 (Primen 2001) was considered too outdated to provide meaningful insights for the current analysis.

CHAPTER 5: Recommended Key Performance Indicators

Based on the literature and data review, we provide recommendations to enhance data tracking and analysis of key metrics including rates of unpermitted work, rates of non-compliant work, and rates of building savings. These methods build on those examined in the studies and attempt to fill in gaps where identified. These KPIs are recommended for further assessment and the most promising will be expanded upon in the upcoming report for Subtask 4: *Identify Improvement Opportunities for Tools, the Compliance Process, and Compliance Indicators*.

KPI Prioritization

The KPIs recommended below were selected and developed in accordance with the following criteria:

- Robustness: The KPIs should be logical and sensible enough to deter scrutiny. Priority was given to those that contain strong research backing that other experts have tested and written about and simple reasonable assumptions.
- Accessible Data: The KPIs should make use of data already existing and available to the CEC to avoid having to collect or generate new data. As such, the KPIs involve the Top-Down methodology rather than Bottom-Up to avoid having to acquire data from site visits, surveys, and interviews.

The KPIs were reviewed by the CEC for inclusion in this report. This list below represents those approved by the CEC. KPIs rejected under the criteria above have been included in Appendix C: Rejected Key Performance indicators.

Note that fully robust datasets are not available for all required variables. This means that there is some level of uncertainty in all KPIs, even those that are recommended. Variables and KPIs that have moderate levels of uncertainty can still be useful for the purposes laid out in this report but is important to clarify for the reader that each of these is meant as specifically that – a KPI to *estimate* various metrics, not to calculate them with perfect accuracy.

Summary

The three metrics of this study inherently cannot be directly measured or calculated. Therefore, we have proposed the following KPIs which are able to be directly calculated and can each be used in combination to estimate the metrics. These are listed in Chapter 2 and explained in greater detail in this chapter below. The metrics derive from examples found in our academic literature review and our review of datasets available. Note that there were several additional KPIs found in the literature review and summarized in

Table 2 above, however most are not recommended in their current form because of their requirements for data sampling, which do not meet that accessible data criteria noted above.

Table 21: Summary of Metrics, KPIs, and Data

Metric	KPI	Dataset Reference
Rates of Non-Compliant Work	No Feasible KPIs Identified[1]	N/A (see Appendix C: Rejected Key Performance Indicators)
Rates of Unpermitted Work	Product to Permit Compliance Ratio	(Air-Conditioning, Heating, and Refrigeration Institute n.d.)
	End of Life Equipment Permitting Gap	(U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy 2024)
		(California Public Utilities Commission 2022)
	Permit Correlation to Real Estate Estimates	(Zillow n.d.)
Rates of Energy Code Compliance Savings	Energy Code Savings Impact of Non-Compliant Work	Site Confirmation Program Field Reporting
		(California Public Utilities Commission 2022)
	Energy Code Savings Impact of Unpermitted Work	N/A (see Appendix C: Rejected Key Performance Indicators)

Notes:

1. Several KPIs were proposed and studied to estimate Rates of Non-Compliant Work. They did not meet the robustness and accessibility criteria. These KPIs are placed in Appendix C: Rejected Key Performance for reference.

Recommended KPI Calculations

We recommend considering the following KPI calculations to better understand and evaluate the key metrics discussed in this report. In all cases, these KPIs should be calculated based on multiple filters including location, permitted scope (e.g., lighting, HVAC, envelope, etc.). The intended result is that a larger conclusion can be drawn from multiple aspects, as opposed to a binary pass-fail metric, which has proven too simplistic to derive sufficient information regarding rates of unpermitted or non-compliant work.

This section outlines the data points used in these KPI calculations. The data points listed overlap with some that are already being tracked in the studies and by the CEC. We recommend consolidation and centralized management to improve the use of these datasets.

KPIs for Rates of Non-Compliant Work

No additional KPIs beyond those described in literature and summarized in **Table 2** have been found at this time which were deemed feasible by the Arup and CEC team. KPIs initially proposed can be found in Appendix C: Rejected Key Performance . These KPIs depend on new or sampled data to be collected.

KPIs for Rates of Unpermitted Work

High level equation:

$$Rate\ of\ Unpermitted\ Work = \frac{Number\ of\ Unpermitted\ Projects}{Total\ Number\ of\ Projects\ that\ should\ be\ Permitted}$$

- **Product to Permit Compliance Ratio**: This KPI estimates the percentage of installations completed without permits by comparing product shipment data (e.g., HVAC systems, appliances) to the number of permits issued. It highlights the compliance gap by identifying the discrepancy between shipped products that should require permits, and the actual number of permits recorded.
  - *Data Source(s)*: The AHRI provides shipment numbers from 2004-2023 in their Historic HVAC Shipments by Type dataset which can be extrapolated to California and referenced to compare with past permits and will ideally be updated over time. Other data sources may be available in the future through HARDI or others.
    - *Limitations*: We have not found consolidated equipment supply chain datasets relating to other permitting types, such as lighting and envelope. This would require further exploration with key industry partners.

Illustrative Example

If sales sources report that 100 residential water heaters were sold in a jurisdiction in the previous year, but only 30 permits have been pulled for water heaters in that jurisdiction, that would imply that there is a 70% rate of unpermitted work for water heaters in that jurisdiction suing the high-level KPI equation above:

$$Rate\ of\ Unpermitted\ Work = \frac{(100 - 30)}{100} = 70\%$$

There are limitations, including the fact that the purchase location and installation location for a piece of equipment are not always the same. Therefore, it would be ideal to perform this calculation wholistically for the state to compare total values in addition to values per jurisdiction.

- **End of Life Equipment Permitting Gap**: This KPI measures the gap between the estimated number of equipment replacements based on typical product life cycles (e.g., HVAC or appliances reaching end of life) and the actual number of permits issued for replacements. It helps identify potential unpermitted work when products likely need replacement but are not reflected in permit data.

  This analysis could be done at a statewide scale by quantifying the typical lifespans of common equipment, and then compiling summaries of the number of related permits that have been pulled by timeframe and jurisdiction. This would need to include individual permits, or larger permits which included multiple system types and pieces of equipment. See the illustrative example below for one case.

  Note that there are some limitations to this calculation which could need to be accounted for if this KPI were to be implemented. In the example below, one valid reason for a reduced number of furnace installations could be that they are displaced by heat pumps. This is somewhat unique within electrification cases and could be accounted for by considering system types (e.g., heating system), in addition to system components (e.g., furnaces).

- *Data Source(s)*: The DOE's Energy Conservation Program: Energy Conservation Standards for Consumer Furnaces, and the CPUCs DEERs both contain product lifetime estimates to be used in this calculation.

Illustrative Example

The construction and engineering industry has multiple sources for lifespan estimations of various equipment. This can be correlated with the frequency between permits pulled for the same piece of equipment in the same building over time.

For this example, let us assume that furnaces have an average lifespan of 22 years. If there are three buildings in a jurisdiction which last had permits pulled to install a furnace 31 years ago, 28 years ago, and 3 years ago, we can calculate that the first two buildings have high likelihoods of needing a new furnace in recent years. One of those buildings has had another permit pulled to install a furnace or equivalent heating system, but the other has not. Therefor we can assume that a replacement was installed without a permit (note that other considerations should be considered, such as is the building located in a climate zone which may not need heating any longer). In summary, two buildings *should* have had related permits pulled, but only one has.

Note that the third two building had a furnace which was installed recently enough that that it should not need replaced in this time period.

Therefor we calculate an estimated rate of unpermitted heating equipment of 50% in this jurisdiction using the high-level equation provided above:

- $Rate\ of\ Unpermitted\ Work = \frac{1}{2} = 50\%$

- **Permit Correlation to Real Estate Estimates**: This KPI compares increases in property values to certain types of alteration or addition permits. By analyzing historical changes in property values, it is possible to identify similar changes in property values and details listed on real estate sites that occurred without a permit.
  - *Data Source(s)*: We have identified the Zillow API as sufficient to access broader real estate information including historical price trends, property value estimates, and property features. This is a paid product and will require CEC subscription.
  - *Limitation(s)*: This calculation relies on property descriptions which have been manually entered by real estate agents or others, and as such is limited by their accuracy and to properties which have been listed for sale in recent history. There will be especially low accuracy for improvements which do not have a significant effect on property value (e.g., water heater electrification) and so this calculation should focus on elements which increase property values or curb appeal, such as the photovoltaic example below.

Illustrative Example

To estimate this, the CEC would conduct a statistical analysis, such as regression, on changes in property values linked to known permits. This historical analysis aims to understand past trends rather than predict future outcomes and therefore the entire dataset can be used without needing to isolate a training set.

Broad factors such as inflation should be considered. One conceivable example may be that singlefamily homes which have pulled permits for rooftop photovoltaic installation have seen a rise in property value by 5%, but only if the real estate database, such as Zillow, specifically mentions rooftop photovoltaics as a feature.

Now that this first task has been completed, we can estimate that any properties for which Zillow has tags for rooftop photovoltaics as a feature, and which show a rise in property value of about 5%, are likely to have installed a photovoltaic system. If there is no corresponding permit for that specific property which would be related to such an installation, we can assume that the work was likely unpermitted. To estimate this, the CEC would conduct a statistical analysis, such as regression, on changes in property values linked to known permits. In the example above, geo-tagged photovoltaic permit data and data from Zillow containing tags to photovoltaic systems would need to be analyzed. The first step is to compare properties for which there were both permits and a reference within Zillow to confirm a consistent correlation in estimated property value increase with photovoltaic system installation. Then, the remaining Zillow data should be filtered for properties which reference a similar installation and show a similar rise in property values. This group of properties contains the likely unpermitted projects in the category of photovoltaic installations.

KPIs for Rates of Energy Code Compliance Savings

- **Energy Code Savings Impact of Non-Compliant Work**: This KPI combines the estimations for the previously discussed KPIs for non-compliant work established in the literature so that building savings implications can be extrapolated. Again, note that this analysis has not identified any KPIs specific to non-compliant work, however, this methodology could be applied to existing or future KPIs that may be identified.

  High level equation:

  $$\text{Unrealized Savings from noncompliant work} = (EUI\ of\ noncompliant\ project - EUI\ of\ code\ compliant\ project) \cdot Area\ of\ noncompliant\ work$$

  The CEC will need to establish an estimate for the average energy impact by system type and location. DEER is a database of energy modeling results which has been created for Energy Code development purposes and can be utilized to estimate those energy impacts. These values should then be extrapolated based on the estimation of the rate of non-compliant work and compared against an idealized scenario in which all permitted work was compliant.

  - *Data Source(s)*: The field confirmation program could provide the initial data for this calculation. This should be supplemented with energy and carbon impacts estimated from a DEER analysis, taking advantage of the large modeling database that has resulted from Energy Code development work over the past several years.

Illustrative Example

A field confirmation program has estimated that 2% of retail buildings in a jurisdiction have installed air-cooled chillers which do not meet the requirements of the Energy Code and on average are 5% less efficient than the prescriptive requirements.

Next, a relevant measure in the DEER database must be identified, such as the screenshot below which is an example of an air-cooled chiller upgrade in a retail building and the appropriate climate zone. For this example, we assume that the area of the test model was 800 ft^2.

FIELD	CURRENT VALUE (SWHC020-05)	PREVIOUS VALUE (SWHC020-04)	CHANGE FROM PREVIOUS TO CURRENT
First Baseline - Peak Electric Demand Reduction (UnitkW1stBaseline)	0.0585	0.0530	0.0055 (10.45%)
First Baseline - Electric Savings (UnitkWh1stBaseline)	139.54	122.51	17.03 (13.90%)
First Baseline - Gas Savings (UnitTherm1stBaseline)	0.0000	0.0000	No change

These results show that for this measure, the electricity savings decreased from 139.54 kWh to 122.51 kWh, or a delta of 17.03 kWh (13.9%) which can be attributed to the chiller efficiency. However, this measure was based on a chiller efficiency improvement of 6% (noted from the measure description). We can extrapolate that the electricity detriment of a chiller which is 5% worse than prescriptive requirements results in an increase of $\frac{5}{6}(17.03\ kWh) = 14.19\ kWh\ (or\ 11.6\%)$ electricity.

This measure is also specific to a prototype energy model of certain size. The total impact on the jurisdiction can be estimated by calculating the area of 2% of the local retail buildings and extrapolating from the area and carbon basis of the prototype energy model. For this example, 2% of local retail buildings accounts for 250,000 ft^2.

Following the high-level question in the example above:

$$\text{Unrealized Savings from noncompliant work} = \left(\frac{139.54kWh}{800ft2} - \frac{122.51kWh}{800ft2}\right) \cdot 250{,}000ft$$

$$= 5{,}322\ kWh$$

Note that there are several points of uncertainty in this process; however, it is consistent with the analysis and modeling procedures used in the CEC's CASE (Codes And Standards Enhancement) reports which inform the Energy Code improvements each cycle.

- **Energy Code Savings Impact of Unpermitted Work**: This proposed KPI was found to be not rigorous or feasible by the Arup and CEC team due to a high amount of uncertainty in the input parameters. This KPI and others initially proposed can be found in Appendix C: Rejected Key Performance .

CHAPTER 6: Conclusions and Next Steps

This report has investigated the current landscape of compliance with California's Energy Code, focusing on unpermitted and non-compliant work as major barriers to energy efficiency and the impact of the Code. Through a literature review and data analysis, several core themes emerged, including gaps in current compliance enforcement, resource limitations, and a need for greater data consistency across jurisdictions. The findings point to actions that can better align compliance practices with California's ambitious climate and energy targets.

Key Findings

High Rates of Unpermitted and Non-Compliant Work

This report highlights that unpermitted and non-compliant work—especially in residential HVAC—presents a major challenge. Some studies estimate permit rates as low as 3% and as high as 29%, significantly limiting the state's potential energy savings and complicating the tracking and enforcement of Energy Code standards. Variations in resource availability among local jurisdictions also contribute to inconsistent permit issuance and compliance rates, particularly in residential renovations and alterations.

Data Gaps and Tracking Limitations

A significant obstacle to comprehensive compliance tracking is the lack of centralized and accessible datasets. Current data collection remains fragmented, with each jurisdiction maintaining its own databases—often in non-standard formats (e.g., PDF files)—making it difficult to aggregate information or identify statewide trends. Even relatively well-organized jurisdictions do not have efficient processes for summarizing permit PDFs into usable data fields without manual effort. Existing Top-Down and Bottom-Up methods for estimating unpermitted and non-compliant work each have drawbacks, such as reliance on indirect indicators or the high resource requirements of site visits.

Unrealized Energy Savings and Savings Potential

The prevalence of non-compliant and unpermitted work directly impacts California's energy efficiency goals by limiting the realization of potential energy savings. The studies reviewed suggest that gaps in compliance contribute to unrealized energy cost savings, which could otherwise be achieved through stricter adherence to the California Energy Code. For example, improved compliance in areas such as HVAC system installations, lighting, and envelope sealing has shown high energy-saving potential. By enhancing compliance in these key areas, California could significantly reduce its GHG emissions and advance toward its sustainability targets.

Recommendations for Improving Compliance Tracking and Enforcement

KPIs for Tracking Unpermitted Work and Energy Code Savings

To achieve a more detailed understanding of compliance, the team proposes the following KPIs which provide insights into the scope of unpermitted work and building Energy Code savings and allow for targeted improvements in specific areas of code adherence. These KPIs focus on existing datasets and statistics to simplify the effort of characterizing these metrics.

- Product to Permit Compliance Ratio: Divides difference between the number of permits (sourced from CIRB or HERS verification certificates) and total number of equipment product sales (sourced from AHRI or HARDI) by the number of equipment product sales to approximate the rate of unpermitted work.
- End of Life Equipment Permitting Gap: Compares the number of permits (sourced from CIRB or HERS verification certificates) to the typical useful life of common equipment (sourced from DOE Energy Conservation Program or the CPUC's DEERs database) to approximate the rate of permitted work.
- Permit Correlation to Real Estate Estimates: Tracks changes to property value and features identified in the Zillow API to determine the total amount of work that should be permitted.
- Energy Code Savings Impact of Non-Compliant Work: Multiplies non-compliant work rates from the literature by energy consumption statistics for certain building measures (sourced in the CPUC's DEER database) to determine the amount of unrealized energy savings of non-compliant work.

Consider Jurisdiction Audits to Assess Non-Compliant Work

Arup found it difficult to estimate non-compliant work through existing datasets. All the studies reviewed in the literature relied on data sampling to approximate non-compliance, in most cases comparing field recorded site visit data to building permit applications and drawings.

Arup was not able to recommend any KPIs for rates of non-compliant work that did not involve data sampling. Nonetheless, we still recommend the process of performing a jurisdiction review, similar to the one BayREN performed in their study, in order to characterize non-compliant work (Benningfield Group, Inc.; BKI; Association of Bay Area Governments 2015). This process involves comparing permits applications and field inspections reports to actual site data for a sample of permitted buildings. It should be repeated every 3-5 years in line with the code cycle to provide a snapshot of the rates of Energy Code compliance.

Next Steps for the California Energy Commission

The findings and recommendations in this report lay out a framework for the CEC to improve Energy Code compliance, enhance energy savings, and support California's objectives. The following steps are proposed to implement these improvements:

1. **Prioritize Energy-Saving Compliance Measures**: Focus compliance efforts on measures with the highest potential for energy savings, such as HVAC systems, envelope sealing, and lighting, aligning with California's GHG reduction goals.
2. **Engage with External Data Sources**: Collaborate with external data providers to explore new ways to estimate unpermitted work, such as integrating third-party datasets like aerial imagery and tax records.
3. **Begin Tracking Proposed KPIs**: Start collecting information to calculate the KPIs proposed in this study.

Summary

This report underscores the need for a more systematic, data-driven approach to tracking and enforcing Energy Code compliance across California. By utilizing targeted KPIs, the CEC can track compliance rates, close gaps in unpermitted work, and achieve meaningful progress toward statewide energy and energy savings goals. The next steps proposed offer actionable measures that will support the state’s broader objectives of sustainable development and energy efficiency. With these enhancements, California is better positioned to meet its climate goals and set a benchmark for Energy Code compliance nationwide.

Glossary

ABAG	Association of Bay Area Governments A regional planning agency for the San Francisco Bay Area, coordinating local governments on issues like housing, land use, transportation, and environmental planning.
AHRI	Air-Conditioning, Heating, and Refrigeration Institute. An industry trade organization that certifies HVAC and refrigeration equipment performance to ensure energy efficiency and reliability standards.
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers. A global professional association advancing HVAC&R standards, technology, and sustainability in building systems, energy efficiency, and indoor air quality.
Attribution Rate	Represents the level of influence a program has on the intended outcome. In the context of this paper, attribution rate reflects the percentage of energy savings that can be attributed to the IOU C&S advocacy programs.
Attom	A real estate data company providing insights on property, neighborhood, and real estate market data, used by industries like insurance, finance, and real estate.
BayREN	Bay Area Regional Energy Network. A collaboration of local governments in the San Francisco Bay Area that offers energy efficiency, water conservation, and green building programs.
BuildZoom	An online platform for finding and hiring contractors, providing project tracking, and access to building permit data, helping homeowners manage and oversee construction projects.
CBIA	California Building Industry Association. An association which represents builders, developers, and contractors in California, advocating for policies that support housing development and affordable housing initiatives.
CEC	California Energy Commission. California's primary energy policy and planning agency, focusing on promoting energy efficiency, renewable energy development, and emission reductions.
CEE	Center for Energy and Environment. A nonprofit organization focused on energy efficiency, renewable energy, and environmental health, providing research, program implementation, and policy support to reduce energy use and emissions.
CIRB	Construction Industry Research Board. A provider of research and statistics resources on the construction industry.

Compliance	Describes the status of meeting the letter of the Energy Code with an error-free, approved permit application.
Conformance	Describes the status of meeting the letter of the Energy Code regardless of whether the project has attained a permit.
CPUC	California Public Utilities Commission. A state agency responsible for regulating public utilities, including electricity, water, and telecommunications, to ensure safe and reliable services.
DEER	Database for Energy Efficient Resources. A public database containing information on energy-saving measures, supporting policymakers and utility programs in planning efficiency improvements.
Delphi Approach	A research technique that involves collecting opinions from a panel of experts to reach a consensus.
DOE	Department of Energy. The federal agency overseeing national energy policy, promoting energy innovation, security, and environmental quality.
DNV GL	Det Norske Veritas and Germanischer Lloyd. A global quality assurance and risk management company that offers certification, consulting, and testing services, specializing in energy, maritime, and renewable sectors.
Effective Useful Life	The age at which a system becomes ineffective. Defined also as the median number of years at which half of the equipment is anticipated to have failed.
EnergyPlus	A U.S. Department of Energy (DOE) open-source software used to model and simulate building energy consumption for heating, cooling, lighting, ventilation, and other energy flows.
EUI	Energy Use Intensity. A metric that compares building energy use to building size, used to evaluate overall energy efficiency.
Existing Data	Datasets already available to use; includes datasets that may have to be purchased.
GHG	Greenhouse Gases. gases like CO_2 and methane that trap heat in the atmosphere, leading to climate warming and affecting weather patterns.
Google Maps	A digital mapping platform by Google providing maps, directions, traffic information, and business locations, widely used for navigation and location-based services.
HARDI	Heating, Air-conditioning, and Refrigeration Distributors International. An organization supporting HVACR wholesalers through resources, advocacy, and education.

HERS	Home Energy Rating System. A standardized assessment system to evaluate and score residential energy efficiency, often used in energy-efficient home programs.
HVAC	Heating, Ventilation, and Air Conditioning. Systems used to control indoor temperature, humidity, and air quality in residential, commercial, and industrial buildings.
IHACI	Institute of Heating and Air Conditioning Industries. A trade organization providing education, certification, and support to HVAC professionals in California.
IMT	Institute for Market Transformation. A non-profit focusing on reducing building energy use through market-based policies, building codes, and performance standards.
KPIs	Key Performance Indicators. Specific, measurable values that assess the success of an organization, project, or individual in meeting objectives.
Landsat	A satellite program by NASA and USGS that captures Earth images for environmental monitoring, used in fields like agriculture, forestry, and urban planning.
NOMAD	Naturally Occurring Market Adoption. A process where products, practices, or innovations gain widespread adoption in the market naturally, without formal incentives or policy interventions, driven by consumer demand, market trends, and perceived benefits.
Non-compliant work	Work that does not fully conform with Energy Code standards, specifically Title 24, Part 6 in this context
NRDC	Natural Resources Defense Council. An environmental advocacy organization that focuses on issues like climate change, pollution, and conservation through research and litigation.
Passing	Describes the advancement of a project to the next stage of the Energy Code compliance process; does not necessarily mean the project complies with the Energy Code.
PG&E	Pacific Gas and Electric Company. A California-based utility company that provides natural gas and electricity to millions of customers across Northern and Central California, focusing on energy delivery, grid infrastructure, and renewable energy integration.
PNNL	Pacific Northwest National Laboratory. A U.S. Department of Energy lab conducting research in energy, environmental science, and national security.
Response Bias	A type of bias in survey responses influenced by factors such as question phrasing or survey method, often skewing the data.

SCE	Southern California Edison. A large electric utility that serves millions in Southern California, focusing on reliable power delivery and renewable energy integration.
Title 24, Part 6	Also referred to as "Energy Code"; California's Building Energy Efficiency Standards, which in the context of this report refers specifically to Part 6 of Title 24. Energy efficiency standards for new and renovated buildings, setting requirements for lighting, HVAC, insulation, and more to reduce energy use and emissions, supporting California's conservation goals.
UEC	Unit Energy Consumption is the amount of energy an appliance uses in a year: kWh for electricity and therms for gas
Unpermitted work	Construction activities performed without obtaining necessary permits, making compliance tracking difficult.

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Appendices

Appendix A: List of Papers Reviewed

Table 22 below provides a summary of the purposes and methodologies of the studies reviewed as part of this analysis.

Table 22. Overview of Studies Reviewed

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
(Pacific Northwest National Laboratory 2023)	Data Analysis of Energy Code Compliance in Commercial Buildings	DOE, PNNL	Analyze the rates of Energy Code compliance in commercial buildings, focusing on the potential energy cost savings from higher rates of compliance.	Site visits, energy modelling	The study involved visiting 230 buildings (6 million square feet of commercial and retail space in climate zones 2A and 5A), collecting data, and using regression analysis to estimate lost energy savings due to non-compliant work. Over 50 measures were investigated in this study from envelope U-values to duct leakage requirements to parking garage lighting controls.	The study found significant potential savings, with a present value average of $2,868 per thousand square feet over the life of the buildings. Only 4 buildings were fully compliant. This study found that 15% energy cost savings can be achieved through improved rates of code compliance.
(Ecotope; Slipstream; Center for Energy and Environment 2020)	Residential Building Energy Efficiency Field Studies: Low-Rise Multifamily	DOE, Ecotope, Slipstream, Center for Energy and Environment	Evaluate the rates of Energy Code compliance in low-rise multifamily buildings and	Site visits, energy modelling	Field studies were conducted in multiple locations to gather information on the energy performance of low-rise multifamily buildings. The research encompassed nearly 100 buildings spread across four states—Illinois, Minnesota,	Most buildings met or exceeded thermal envelope code requirements. Nearly all buildings complied with mechanical system efficiency standards, with some exceeding code requirements. High-efficacy lighting was common in living

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
			identify areas for improvement.		Oregon, and Washington—reflecting diverse climate conditions ranging from mild to very cold continental. The collected data was compiled into a spreadsheet to build a comprehensive database. Furthermore, the data was integrated into an EnergyPlus model to estimate potential energy savings associated with code compliance.	units and often exceeded code, though common area lighting occasionally had higher power densities than allowed. Simulation-based studies suggest that full code compliance could reduce energy use by about 10% of EUI, with modest savings from improvements in windows and lighting.
(Pacific Northwest National Laboratory 2018)	Residential Building Energy Code Field Study - Data Collection & Analysis Methodology	DOE, PNNL	Assess baseline energy efficiency in new single-family residential buildings and quantify related savings potential, aiding states in evaluating and improving their building Energy Codes and energy-efficiency programs.	Site visits, energy modelling	The study proposes a methodology to assess rates of code compliance. It involves sampling, data collection, and analysis of key energy efficiency measures in new homes. It includes stakeholder engagement, training for data collectors, and quality assurance processes. The key items relied upon in the study are (metric): 1. Envelope tightness (ACH at 50 Pa); 2. Windows (U-factor & SHGC); 3. Wall insulation (assembly U-factor); 4. Ceiling insulation (R-	This study only proposes the methodology; it does not apply it. The methodology however was applied in Article 1.4 below. The DOE recommends that the states conduct this study every 3-5 years.

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
					value); 5. Lighting (% high-efficacy); 6. Foundation insulation (assembly U-factor); 7. Duct tightness (CFM per 100 ft2 of conditioned floor area at 25 Pa).	
(Pacific Northwest National Laboratory 2022)	Residential Energy Code Field Studies: Assessing Implementation in Seven States	DOE, PNNL	Quantify energy impacts of code-based measures in single-family residential construction, improve compliance through education and training, and project long-term savings from enhanced Energy Code compliance. Energy code used included 2009 IECC, 2012 IECC, and 2015 IECC.	Site visits, energy modeling	The study, conducted in seven pilot states, evaluated the impact of education and training on code compliance and energy savings across three phases: Phase I: A baseline field study assessed the energy performance of new single-family homes and identified opportunities for improvement. Phase II: Education, training, and outreach addressed compliance issues identified in Phase I. Phase III: A follow-up field study measured the impact of training on compliance and energy performance. To calculate energy savings, researchers used field data (e.g., window SHGC,	Phase I revealed mixed compliance rates across key building measures. While window U-factor and solar heat gain coefficient requirements were largely met, lighting and insulation often fell short. Despite improvements, $18.6 million in potential energy savings remained. Education and training programs drove progress, achieving over $8 million in annual savings from Phases 1 to 3; though the study found $10.6 million in savings opportunities remaining.

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
					insulation, and duct tightness) in an EnergyPlus model of a "pseudo home" representing a typical building. The results were compared to a code-compliant energy model to estimate potential savings.	
(U.S. Department of Energy 2013)	DOE 90 percent compliance pilot studies final report	DOE	Measure and improve Energy Code compliance across states, targeting 90% compliance by 2017 through pilot studies.	Site visits	These studies used DOE-developed procedures and tools to evaluate rates of compliance. The methodology was comprised of collecting data on checklists and jurisdictional surveys. The results of the study were used to tabulate a compliance score using Score + Store – an online tool to collect and analyze field collected data. The study was performed in 6 states: Georgia, Iowa, Massachusetts, Montana, Wisconsin, and Utah. Energy codes involved in the study included 2006 IECC, 2009 IECC, and ASHRAE 90.1-2007.	According to the jurisdictional surveys, residential non-compliance issues were mainly related to envelope sealing and duct sealing, while commercial issues included envelope sealing, duct sealing, and lighting controls. The checklists, however, revealed the least compliant residential requirements to be certificate posting and HVAC load calculations. Missing or inaccurate building plan information was a significant challenge for compliance determination. Residential compliance scores ranged from 20% to 100%, with averages between 62% and 94%. Commercial studies showed

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
						averages above 80%, with most buildings scoring at least 50%.
(DNV GL 2017)	DNV GL Report 2017 HVAC Permit and Code Assessment	DNV GL, CPUC	Assess state permitting and compliance rates and evaluate energy efficiency in correlation with permitting for HVAC residential upgrade installations governed by 2008 and 2013 Energy Code.	Site visits	This study used a Top-Down approach analyzing secondary HVAC market data and a Bottom-Up approach through homeowner surveys to estimate statewide permit rates for HVAC replacements. To assess energy efficiency differences between permitted and unpermitted work, researchers conducted field assessments of 196 installations, initially sampling homes randomly and later focusing on permitted homes for comparison. Additionally, HERS raters were interviewed to evaluate code compliance enforcement and effectiveness.	The permitting rate in California is low, ranging from 8% (calculated using Top-Down Approach) to 29% (calculated using Bottom-Up approach). While permitted and non-permitted installations showed few statistically significant differences in energy efficiency, non-permitted cases exhibited a wider performance range. The study attributes low permitting and compliance rates to homeowner and contractor knowledge gaps and inconsistencies among building departments, as confirmed through interviews with HERs raters and homeowners.
(KEMA n.d.) (Cadmus; DNV GL; CPUC 2014) (Cadmus,	CASE Impact Evaluations	Cadmus, Energy Services	Validate the electric and gas savings that can be attributed to Investor-Owned	Site visits, interviews, energy modelling	For building efficiency, the process involves estimating “potential standards energy savings:” energy savings from all projects meeting the	The 2006-2008 report estimated the following: 117% realization rate and 373.2 GWh savings for electricity usage, 85% and 73.2 MW for electricity demand, 77%

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
Energy Services Division; DNV GL 2017) (Opinion Dynamics; CPUC., Market Logics; J. Mitchell Analytics 2023)		Division, DNV GL, CPUC	Utility (IOU) statewide Codes and Standards (C&S) Building Code Advocacy Program for program years 2006-2008, 2010-2012, 2013-2015, 2016-2018 (same analysis performed multiple times, published in several reports).		California Energy Code. These are then adjusted to create "gross standard energy savings," which account for observed code compliance rates, i.e., how many buildings projects comply with the code. Gross savings are then attributed to the IOUs by factoring in naturally occurring market adoption (NOMAD) and attribution rates to determine "net savings," are compared against the savings claimed by the IOU to determine a realization rate (100% means that the IOU claimed savings are 100% verified). For "potential standards energy savings," the study uses permit and new construction data to determine amount of buildings / alteration work. Compliance rates and actual energy savings are estimated using field data from a sample of buildings, entered into a prototype energy model to provide comparison against an Energy Code baseline model.	and 5.1 million therms for gas usage. The 2010-2012 report estimated the following: 98% realization rate and 2,203 GWh savings for electricity usage, 94% and 374 MW for electricity demand, 64% and 20.4 million therms for gas usage. The 2013-2015 report estimated the following: 81% realization rate and 653.1 GWh savings for electricity usage, 59% and 114.9 MW for electricity demand, 119% and 3.83 million therms for gas usage. The 2016-2018 report estimated the following: 70% realization rate and 217.5 GWh savings for electricity usage, 69% and 97.2 MW for electricity demand, 50% and 8.8 million therms for gas usage.

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
					NOMAD is approximated using the Delphi approach: an iterative questionnaire sent out to industry experts. Attribution rates are deduced from Code Change Savings Report (CCSR) conducted by the IOUs.	
(Itron, Inc 2004)	Residential New Construction: Baseline Study of Building Characteristics - Homes Built After 2001 Codes	Itron, Inc., PG&E	Examine the status and determine rates of Energy Code compliance for a representative sample of California single-family residential new construction (RNC).	Existing datasets/census data	At least 800 low-rise residential buildings were surveyed in California. The results of these surveys were placed into a MICROPAS Title 24 energy model to determine the status of compliance: non-compliant, indeterminant, compliant, or high efficiency. Additionally, telephone surveys were conducted with 77 builders and 41 Title 24 Energy Code Consultants throughout California to gain an understanding of building and compliance practices of single-family new home builders as they relate to the current 2001 Title 24 energy efficiency standards.	The results from the compliance analysis indicate that 27% of all homes built in the study period were non-compliant, 34% of homes fell within the compliant group, and 13% fell in the high efficiency (better than Energy Code) group. The percentage of glazing area and climate zone were most directly correlated factors with compliance rates. Coastal properties tended to have higher rates of compliance. From 2000 to 2003, the study showed significant changes in fenestration, space heating systems, and space cooling systems correlating with updates in the code.

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
(Mohasci 2006)	Enforcement of T-24 Compliance Pertaining to Residential Alterations	Unknown	Investigate the lack of enforcement of T-24 compliance requirements for residential alterations in California.	Existing datasets/census data	This study focuses on HVAC retrofits. It used equipment sales to represent how many permits should be issued and the number of HERS verifications to represent the number of permits actually issued. It differentiates new housing from retrofits by using information from the census (existing residences) as well as new construction for CBIA (new developments)	They study estimated that only 3.2% of the residential alteration work had been permitted.
(Quantec 2007)	Statewide Codes and Standards: Market Adoption and Noncompliance Rates	Quantec, SoCal Edison	Refine the original estimates made of non-compliance with Title 20 (appliances) and Title 24, Part 6 (buildings), initial market penetration, and naturally occurring market adoption rates. Evaluate the 2006 California Energy Efficiency Evaluation	Site visits, existing datasets/census data	This study evaluates California Energy Code noncompliance rates of building energycode and appliance efficiency standards (Title 20). For Energy Code, researchers collected data via a combined approach of reviewing building department records and conducting site visits at a sample of buildings to estimate the noncompliance rates at different stages of the code compliance process. 418 records were examined from nine building departments across the state, representing	For residential, hardwired lighting showed the lowest rate of non-compliance (21%) while duct improvement yielded the highest rate (73%). For nonresidential, lighting controls under skylights showed the lowest rate of non-compliance (44%). Ducts in both existing and new buildings had the highest rate (100%), i.e., no ducts were compliant. In terms of NOMAD, unit heaters / duct furnaces showed the highest rate of market adoption (50% initial market penetration

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
			Protocols (Evaluation Protocols) as it applies to determining net savings resulting from Program activities.		437 measures. In addition, to noncompliance, researchers estimated the Naturally Occurring Market Rate Adoption (NOMAD) of the building efficiency and appliance measures, i.e., rate of market adoption irrespective of building codes and standards. It was estimated using a questionnaire sent to experts in the field to solicit a market diffusion curve.	and 58% NOMAD in 2015) while ducts in existing nonresidential buildings had the lowest rates (2% initial market penetration and 7% NOMAD in 2015).
(Institute for Market Transformation; Natural Resources Defense Council 2017)	Evaluating Energy Code: Compliance in Cities	City Energy - Joint Project of NRDC (National Resource Defense Council) & IMT (Institute for market Transformation	Overview of City Energy Project (CEP), a public methodology that enables any city to conduct a code compliance assessment.	No study conducted. Establishes a framework to determine Energy Code compliance.	The steps in the framework included: 1) review submittals of construction plans to building department, interview plan reviewers, assess intake and plan review process, 2) assess plans that have been reviewed and approved, 3) conduct on-site inspection of buildings under construction, interview inspectors, assess inspection process, 4) analyze findings and develop compliance improvement plan	There are no findings from this report. It only proposes a framework.

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
(Benningfield Group, Inc.; BKI; Association of Bay Area Governments 2015)	BayREN Codes & Standards: Permit Resource Opportunity Program -PROP Final Report and Energy Code Resource Guide	BayREN, Benningfield Group, Inc., BKI, Association of Bay Area Governments	Use BayREN's Energy Code experts to implement a survey of stakeholders and conduct a series of visits to Bay Area building departments to learn about Energy Code enforcement barriers and challenges, identify successful enforcement strategies, and gather data about the impact of discrepancies on building performance.	Existing datasets/census data	This study involved visiting 15 building departments, spending 2 days with the departments to interview key personnel, observe permitting processes, conducting plan reviews and field inspections of several permitted projects, summarizing discrepancies between permitted and installed energy features, and scoring projects based on permitting findings.	Full compliance is rare (16%), with original submissions being more correct than revisions or inspection documents. Many compliant buildings still contain errors, and 51% of projects perform worse than documented, especially alterations. Local governments, though influential in promoting compliance, often lack staff. Building departments use varied procedures for permit reviews and inspections, with Energy Code enforcement often deprioritized compared to structural, fire, electrical, plumbing, and mechanical codes. None of the jurisdictions enter Energy Code information into permit tracking systems. Review processes are inconsistent across jurisdictions.
(California Energy Commission 2008)	CEC 2008 Strategic Plan to Reduce Energy Impact of Air Conditioners	CEC	Improve the energy efficiency and reduce the peak energy use of central air-conditioning systems in	No study conducted. Strategy and roadmap discussions and	No study conducted. This strategic plan was developed through a working group of HVAC industry professionals who created detailed roadmaps and strategies. The group focused on quality control	There are no findings from this report. It only proposes a framework.

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
			California, as mandated by Assembly Bill 2021.	literature research	during installation and maintenance, public education, and regulatory changes.	
(U.S. Department of Energy 2024)	Webinar from Corrie Anderson on "Best Practices for Understanding and Improving Compliance	DOE	Overview of 4 case studies on understanding and improving Energy Code compliance rates nationwide by the DOE's Building Energy Code Program (BECP).	Site visits	This webinar presented by the DOE's Building Energy Code Program (BECP) discussed 4 case studies on understanding and improving Energy Code compliance nationwide: the Midwest Energy Efficiency Alliance (MEEP), Mozingo Code Group, Colorado Energy Office, and Green Coast Enterprises. The DOE's Building Energy Codes Program aids in the development, adoption, and enforcement of energy-efficient building codes for residential and commercial structures. It provides technical support, educational resources, and collaborates with stakeholders to enhance energy savings and reduce emissions.	Key challenges include unsealed air handling units (AHUs), resistance to air and duct leakage testing in rural areas, and a shortage of skilled labor in critical regions. Local agency enforcement of codes enhances compliance compared to state-level enforcement, and integrating tax credits with code rollouts improves acceptance and adherence.
(Pacific Northwest National Lab 2023)	A Review of the Evaluation of Building Energy Code	PNNL	Review and compare methodologies and metrics used	Site visits	The paper reviewed multiple studies, emphasizing building types, sampling strategies, data collection approaches,	Compliance evaluation methodologies have shifted from binary compliance rates to energy-consumption-based

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
	Compliance in the United States		in building Energy Code compliance rate evaluations in the U.S. over the past three decades.		evaluation techniques, and compliance metrics. It outlined the progression of methodologies and identified recurring challenges. The methodology established in the pilot study includes three key stages—sample design, data collection, and compliance evaluation—supplemented by interviews with design professionals and code officials.	approaches, highlighting the need for standardized methods to address gaps and reduce costs. On-site evaluations were found to be costly, limiting sampling and data collection efforts, prompting recommendations for more statistically rigorous and cost-effective approaches to measure real-world energy performance. The study emphasized that effective code compliance evaluation is essential for achieving energy savings and emission reductions. While compliance rates remain useful for assessing enforcement, energy-based metrics are now recognized as more accurate for evaluating the energy impacts of non-compliance. Future studies should focus on refining methodologies and addressing existing gaps.
(Pacific Northwest National Lab 2018)	Assessing overall building energy performance of a large	PNNL	Assess the overall energy performance of a large population of residential	Site visits, energy modelling	In this study, researchers collected limited field data from new homes in eight US states. They used prototype buildings and bootstrap sampling to	The study showed that the energy performance of large populations of new homes can be effectively assessed using a novel framework, even with

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
	population of residential single-family homes using limited field data		single-family homes using limited field data.		create models and draw inputs from the limited data.	limited data. It emphasized the potential of building energy simulation as a valuable tool for evaluating Energy Code compliance and identifying energy savings opportunities in residential buildings.
(Pacific Northwest National Lab 2022)	Falling Short: Does Energy Code Compliance and Enforcement Vary by Income?	DOE, PNNL	Investigate whether Energy Code compliance rates and enforcement vary by income levels across different jurisdictions in the U.S.	Site visits, existing datasets/census data	In this study, data from residential code compliance field studies in 19 states were analyzed, focusing on compliance rates and socioeconomic characteristics at the county level. The seven key items in the sample included: 1) foundation R-value and insulation installation quality (IIQ), 2) wall R-value and IIQ, 3) ceiling R-value and IIQ, 4) window U factor and solar heat gain coefficient (SHGC), 5) envelope air tightness (ACH50), 6) duct tightness (CFM25/100 ft2), and 7) percentage of high-efficacy lighting. 87,000 observations. The approach was to collect 3 years of residential permit data at the municipal level and weight the number and	The study revealed that lower-income counties exhibit higher rates of non-compliance with Energy Codes compared to higher-income counties, particularly in areas such as duct tightness and roof insulation. Compliance rates were 67% for lower-income counties and 73% for higher-income counties, with an overall compliance rate of 70%. Counties using older Energy Codes, such as IECC 2009, demonstrated higher compliance rates regardless of income levels. The findings highlight a clear link between income levels and compliance, emphasizing the need for targeted education and training programs to improve compliance in disadvantaged communities.

Reference	Publication Title	Organization	Purpose Summary	Study Methodology Type	Study Methodology Summary	Findings
					location of samples based on number of permits and then randomize the locations.	

Appendix B: List of Datasets Reviewed

Table 23. Dataset Review Findings

References	Name	Source Agency	Relevant Header(s)	Content	Relevance to KPIs and Metrics	Access
(U.S. Census Bureau 2023)	Annual Estimates of Housing Units in California	U.S. Census Bureau	• Housing Unit Estimate (2020-2023), by County • Housing Unit Estimate (2020-2023), by State (California)	Total residential units by county or state	Contextual dataset (existing buildings): • Tracking historic (annual) changes can separate out new construction from alteration work for residential buildings	Free
(U.S. Census Bureau 2024)	Building Permits Survey	U.S. Census Bureau	New Privately Owned Housing Authorized by number of units	New residential units by state	Contextual dataset (new buildings): • Separates out new construction from alteration work for residential buildings Number of permitted projects (residential only)	Free
(State of California Department of Finance 2024)	E-4 Population and Housing Estimates for Cities, Counties, and the State	State of California Department of Finance	City/County/State Housing Estimates with Annual Percent Change, 2023-2024	• Total residential units by county or state • Percent changes to housing	Contextual dataset (existing buildings): • Separates out new construction from alteration work for residential buildings	Free
(U.S. Census Bureau 2024)	Historical Time Series of Housing Units Authorized, Started, Under Construction, and Completed	U.S. Census Bureau	Housing Units Authorized, Started, Under Construction, and Completed, by Year and Geographical Region (Northeast, Midwest, South, West)	New residential units by state	Contextual dataset (new buildings): • Separates out new construction from alteration work for residential buildings	Free
(U.S. Census Bureau; State of California	American Community Survey 1-Year	U.S. Census Bureau, State of California	Total Households by State (California)	Count of total occupied residential units in	Contextual dataset (existing buildings):	Free

References	Name	Source Agency	Relevant Header(s)	Content	Relevance to KPIs and Metrics	Access
Department of Finance 2022)	and 5-Year Estimates Data Profiles	Department of Finance		California from 2010-2022	• Provides residential occupancy rates, which can be used to inform energy use in residences given that unoccupied residential units use less energy than occupied ones.	
(State of California Department of Finance 2023)	E-8 Historical Population and Housing Estimates	State of California Department of Finance	• Housing Units by Type and State/County/City • Vacancy Rate by State/County/City	• Total residential units by type (Single, Two-to-Four, Five Plus, Mobile Homes), city, county, and state-wide • Vacancy Rate by city, county and state-wide	Contextual dataset (existing buildings): • Provides additional granularity on the types of residential units, which can be used to inform residential energy use since larger unit consumer more energy than smaller ones. • Provides residential vacancy rates, which also can be used to inform energy use given that unoccupied residential units use less energy than occupied ones	Free
(U.S. Census Bureau 2024)	Annual Value of State and Local Construction Put in Place by State	U.S. Census Bureau	• 2023 Construction Spending in California	• The amount of spending for construction in California • The amount of construction spending in the U.S.	Contextual dataset (construction spending): • Can serve as an estimate for the amount of construction in California relative to the entire U.S. • Allocate portions of datasets for the US to California	Free
(Air-Conditioning, Heating, and Refrigeration	Historic HVAC Shipments by Type	AHRI	Monthly shipments Twenty Year Summary Charts	Combined U.S. manufacturer shipments of central air conditioning, air-source heat pumps systems, gas	Total number of projects that should be permitted (HVAC sales): • Provides total HVAC shipments, which can characterize the total amount	Free

References	**Name**	**Source Agency**	**Relevant Header(s)**	**Content**	**Relevance to KPIs and Metrics**	**Access**
Institute n.d.)				and oil furnaces, and gas and electric tank water heaters.	of HVAC installation work that should involve Energy Code compliance	
(State of California Department of Finance n.d.)	Construction Permits Annual Data	State of California Department of Finance	Single-Family Units (Thousands), Multifamily Units (Thousands), Total units (Thousands), per year	Authorized building permits for new residential units by year, data collected from 1975-2023	Contextual dataset (existing buildings): • Tracks residential construction activity, which can be used to approximate the ratio of new construction to alteration work for residential buildings	Free
(ATTOM n.d.)	Nationwide Building Permit Data	Attom	• Assessor tax • Building permits • Interior features • Property characteristics	Assessor tax: public assessor tax estimates per priority Building permits: types of building permits awarded for a property • Interior features: types of interior features (e.g., appliances, heating and cooling systems) for a property • Property characteristics: size, use, location, condition, ownership	Number of permitted projects: • Has a record of permit data for 99% of the US	Subscription
(BuildZoom n.d.)	BuildZoom Building Permit Data	BuildZoom	Data API	Property Permit history	Number of permitted projects: • Has a record of permit data for 90% of the US	Subscription
(National Association for Industrial and Office Parks 2022)	Development Approvals Index	National Association for Industrial and Office Parks	Transparency Score, Accountability Score, Pillar Score	Scores reflects permitting procedures surveyed across different jurisdictions. Calculated using a systematic method to evaluate and	N/A: • No data was collected for California, so this data is not relevant to the KPIs.	Free

References	Name	Source Agency	Relevant Header(s)	Content	Relevance to KPIs and Metrics	Access
				compare approvals processes	• Provides some context into the differences between jurisdiction approval processes	
(U.S. Energy Information Administration n.d.)	Residential Energy Consumption Survey	U.S. Energy Information Administration	• CE1.1.ST – Summary household site consumption and expenditures in U.S. homes by state, 2020 • CE5.3.ST – Detailed electricity end uses by state - consumption – averages • Detailed natural gas, propane, and fuel oil by state - consumption - averages	Average energy consumption from a representative sample of housing units	Baseline energy use (residential only): • Tracking historic changes (every issuance of the survey) can help determine the rate of decarbonization for residential buildings as well as the average energy use for a typical residence	Free
(U.S. Energy Information Administration 2018)	Commercial Building Energy Survey	U.S. Energy Information Administration	• Table C12. Sum of major fuels consumption totals and gross energy intensities by building activity subcategories • Table C16. Electricity expenditures by census region • Table C26. Natural gas expenditures by census region • Table E4. Electricity consumption intensities (in British thermal units [Btu]) by end use • Table E7. Natural gas consumption and energy intensities (in British thermal units [Btu]) by end use	• Average energy consumption from a representative sample of commercial buildings • 2018 CBECS microdata contains data from individual buildings sampled	Baseline energy use (nonresidential only): • Provides the average energy performance for commercial buildings, which can be used to inform an energy performance baseline. • Tracking historic changes (every issuance of the survey) can help determine the rate of decarbonization for commercial buildings	Free

References	Name	Source Agency	Relevant Header(s)	Content	Relevance to KPIs and Metrics	Access
			• 2018 CBECS microdata			
(Redfin 2022)	Property Tax Information	Redfin	• Sales & tax history • Property details	• Sales & tax history: tax assessed value • Property details: interior features (e.g., rooms, appliances), exterior features (e.g., view), public facts	Total number of projects that should be permitted (property value): • Tracking changes to properties (e.g., interior features, green features) along with property value can help estimate the total number of construction projects that should be permitted.	Free but involves creating a script for web-scraping
(Zillow n.d.)	Public Records API	Zillow	BridgeModificationTimestamp, building.airConditioning, building.class, building.condition, building.heating, building.quality, building.yearBuilt, Cooling, GreenEnergyEfficient, GreenEnergyGeneration, GreenIndoorAirQuality, Heating, landUseDescription, TaxAssessedValue, TaxYear, WindowFeatures	• Assessor tax: public assessor tax estimates per priority • Building features: (e.g., appliances, heating and cooling systems, renewable energy, energy efficiency measures) for a property • Property characteristics: size, use, location, condition	Total number of projects that should be permitted (property value): • Tracking changes to property values can help estimate the total number of construction projects that should be permitted.	Free
(California Energy Commission 2021)	Residential Appliance Saturation Study	California Energy Commission	• Unit Energy Consumption (UEC) and Saturation Estimates for Households • Electric Unit Energy Consumption and Saturation Estimates	• Estimated Residential Appliance Unit Energy Consumption and Saturation by residence type • Estimated Residential Appliance Unit Energy Consumption and	Contextual Dataset (Number of Existing HVAC and Appliances) • Presence of appliances and replacement rate Baseline energy use • Estimate HVAC and appliance energy consumption.	Free

References	Name	Source Agency	Relevant Header(s)	Content	Relevance to KPIs and Metrics	Access
			• Gas Unit Energy Consumption and Saturation Estimates	Saturation by Appliance • Covers the following applicable systems: space heating, water heating, air-conditioning, lighting, swimming pools, spas and hot tubs, fans, windows, renewable energy technologies		
(U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy 2024)	Energy Conservation Program: Energy Conservation Standards for Consumer Furnaces	U.S. Department of Energy	Lifetime estimate for residential furnaces	The average lifetime for residential furnaces outside of northern region of the U.S.	Total number of projects that should be permitted (useful life): • Understand equipment lifespans to predict HVAC and appliance replacements that require Energy Code compliance.	Free
(California Public Utilities Commission 2022)	Database for Energy Efficient Resources	California Public Utilities Commission	• Measure Name/ID, Baseline Characteristics, Measure Characteristics, Annual Energy Savings (kWh, therms), Carbon Emissions Reductions (tons CO_2e), Climate Zone • Claims Data	Energy savings related to specific energy efficiency measures and technologies in California	Energy efficiency measure savings: • Determine the energy savings associated with specific Energy Code measures	Free
(American Council for an Energy-Efficient	Energy Efficiency in a High Renewable Energy Future	American Council for an Energy Efficient Economy	Increase in annual energy savings for modeled energy efficiency measures between 2030 and 2050, California Region	Energy savings by measures related to: Envelope, HVAC, thermostat, Refrigeration, Lighting	Energy efficiency measure savings: • Determine the energy savings associated with specific Energy Code measures	Free

References	Name	Source Agency	Relevant Header(s)	Content	Relevance to KPIs and Metrics	Access
Economy 2023)						
(American Council for an Energy-Efficient Economy 2022)	2022 State Energy Efficiency Scorecard	American Council for an Energy Efficient Economy	Scoring for appliance efficiency standards and clean lighting policies	Energy savings from state standards and clean lighting through 2035 (MMBtus/capita)	Energy efficiency measure savings: • Determine the energy savings associated with specific Energy Code measures	Free
(U.S. Energy Star n.d.)	Energy Star Unit Shipment and Market Penetration Report	U.S. Energy Star	• 2023 Units shipped by Product Category • 2023 Estimated Market Penetration by Product Category	Number of shipments for: • Boilers • Furnaces • Heat Pumps • Room Air Conditioners Windows, Doors, and Skylights	Total number of projects that should be permitted (HVAC sales): • Provides total HVAC installation, which can characterize the total amount of HVAC installation work that should involve Energy Code compliance • Limited to the EnergyStar program	Free
(TECH Clean California n.d.)	Heat Pump Data - Contractor Data	TECH Clean California	• Tech Working Dataset • Greenhouse Gas Impacts Dataset (Not yet released)	• Data on the installed equipment and replaced equipment • Total Project Cost • Incentive provided • Installation details including duration and quality installation measures performed	Total number of projects that should be permitted (HVAC sales): • Provides total HVAC installation, which can characterize the total amount of HVAC installation work that should involve Energy Code compliance • Limited to the TECH Clean California program	Free
(HARDI n.d.)	HARDI Annual Benchmarking Survey	HARDI	• Inventory • Product Type	• Average inventory • Average number of orders shipped monthly • Average number of lines per order	Total number of projects that should be permitted (HVAC sales): • Provides total HVAC installation, which can characterize the total amount of HVAC installation work that	Free for participating HVACR distributors

References	Name	Source Agency	Relevant Header(s)	Content	Relevance to KPIs and Metrics	Access
				• Average number of shipments received • Statistics per product type including HVAC unitary, HVAC light commercial, heating & AC supplies, controls and control parts, refrigerants & refrigerant accessories, plumbing & hydronics, sheet metal and sheet metal items and all other products	should involve Energy Code compliance	
(IBISWorld 2024)	Remodeling in California - Market Research Report	IBISWorld	Remodeling in California industry statistics	• California Remodeling Market Size • Number of Remodeling Businesses in California • California Remodeling Industry Employment • Contribution or Remodeling Industry to California Economy	N/A: • Provides a picture of the amount of remodeling work in California; does not appear to separate out types of remodeling projects, e.g., structural from energy work. As such, may not be helpful to the KPIs.	Purchased report
(Construction Industry Research Board n.d.)	CIRB Database	Construction Industry Research Board	• CIRB Building Permit Data • Statewide Permits Issued	Permit Data: • Issue Date • Permit No • Class • Builder • Valuation • Description Permits Issued: • # of Permits by Code	Number of Permitted Projects: • Data centered on permits issued across the state of California with some information on what projects were permitted and where.	Purchased Database (CEC already owns)

References	**Name**	**Source Agency**	**Relevant Header(s)**	**Content**	**Relevance to KPIs and Metrics**	**Access**
				• Number of Units by Code • Valuation by Code		
(Internal Revenue Service n.d.)	IRS Form 5695	Internal Revenue Service	• Qualified Energy Efficiency Improvements • Residential Energy Property Expenditures	• Cost of central air conditioners • Cost of windows and skylights that meet Energy Star Certification Requirements	Energy Efficiency Measure Savings: • Provides cost data around decarbonization-focused home improvements shared with the IRS to claim energy credits. Can potentially be used to approximate the cost benefit associated with specific Energy Code measures	Arup could not access data source
(California Environmental Protection Agency, Department of Toxic Substances Control n.d.)	Orphan Appliance Report	California Environmental Protection Agency, Department of Toxic Substances Control	• Total number of "orphan" appliances received per month • "Orphan" appliances received by type	Relevant "orphan" appliance types: • Furnaces • Air Conditioners	Total number of projects that should be permitted (end of life) • Indicates the potential quantity of renovation or replacement work based on number of appliances processed for recycling	Arup could not access data source

Appendix C: Rejected Key Performance Indicators

The initial list of KPIs were reviewed with the CEC team to agree on feasibility. The following KPIs in this appendix were rejected due to either a lack of feasibility of data sources, or an unacceptable degree of uncertainty in input parameters. They are listed here for reference only.

Rate of Non-Compliant Work

- **Initial Permit Compliance Rate**: Percentage of issued permits that achieve compliance on the first submission relative to the total compliant permits: This KPI can be useful to understand discrepancies between various jurisdictions. For example, if a jurisdiction shows a very high percentage compliance on initial permit applications, that might suggest it is not as rigorous in its review indicating a higher potential of non-compliant work.
    - *Data Source(s)*: This data would need to be aggregated from all California jurisdictions. We recommend standardizing the data and formatting that these jurisdictions retain to simplify this aggregation going forward. Attom, an aggregator of property permit history among other things, may be a broader source of this data however it is unclear if they aggregate information on the iterations of permits.
- **Average Total Permit Iterations**: Average number of iterations permits went through before being approved: This value should be referenced together with the previous KPI to understand the 'difficulty' of successful compliance in a particular jurisdiction, scope of code, or point in time.
    - *Data Source(s)*: As above, this data would need to be aggregated from all California jurisdictions. We recommend standardizing the data and formatting that these jurisdictions retain to simplify this aggregation going forward. BuildZoom may be a broader source of this data, however it is unclear if they aggregate information on the iterations of permits.

Illustrative Example

Note: several of these illustrative examples are provided to provide context for the KPI definition, however they do not reflect real world data or situations.

Three imaginary jurisdictions have calculated the above KPIs as follows:

Table 24: Example data for KPI's

Jurisdiction	**Initial Permit Compliance Rate**	**Average Total Permit Iterations**
A	95%	1.1
B	75%	2.0
C	50%	3.5

Upon reviewing these data, we can infer that Jurisdiction A either has a cursory permit review process, thus passing projects through with minimal review, or is in a situation with especially astute designers, engineers, and contractors. For the sake of this example, we assume the former. In contract, Jurisdiction C only approved half of permits upon initial submission, and on average requires over three revisions by permit submitters. Jurisdiction B is between these two.

One way to estimate potential rates of non-compliant work would be to take the difference in initial compliance between the two jurisdictions. For example, between A and C: 95% - 50% 45%. This could be used to estimate that there is a rate of non-compliant work in Jurisdiction C of 45%, because if those same permits had been submitted to officials in jurisdiction A, there is a higher likelihood that they would have been rejected and required revision.

This of course is only an estimation, however if calculated in bulk across jurisdictions, between types of permits, at different points of time, or using other relevant factors, there may be broader trends that emerge and can reduce the uncertainty of the estimation. Note also that this example simplified permit approval into a single transaction, however also understanding when in the compliance process (during plancheck or site verification/acceptance testing), the estimations can be further broken down.

The key limitation in this calculation is that it can only consider situations in which a permit has been pulled in the past, and so will inherently be an under predictor.

- **Historical Permit Compliance Trends**: This KPI analyzes historical trends in permit compliance by tracking permit issuance over time. It evaluates whether unpermitted work is increasing or decreasing, providing insights into the effectiveness of enforcement measures and policy changes on compliance rates.
    - *Data Source(s)*: The CIRB data that the CEC already has access to provides a history and summary of permit issuance over time. This dataset can be filtered down into jurisdiction and permit type.

Illustrative Example

This KPI is useful to understand if there are factors in the market or code update process which may be triggering changes in rates of unpermitted work. Let's assume that in the past 10 years in a particular jurisdiction, there have been the following total number of envelope alteration permits pulled: 100, 105, 98, 100, 95, 99, 103, 106, 129, 62. Without any other knowledge, one interpretation may be that one year ago the Energy Code was updated and became much more stringent. The year before that, the 129 permits may have been preemptive, and projects rushed to permit in the old code cycle. However, we can see that the increase in permits in that year compared to the average prior (129–100= 29 more permits than average) does not equate to the reduction in the following year (100-62 = 38 permits less than average). One possible explanation is that more people have done work without a permit, equating to 9% ([38-29]/100) unpermitted work for those last two years.

One limitation of this approach is that is does not consider the fact that people may have simply delayed construction projects until the new strict code settles out. Another limitation is that there were other motivators for a change in construction patterns that influenced projects. This is best mitigated by performing these calculations broadly to identify patterns that may be statewide (e.g., from an economic downturn), or isolated locally or within a specific type of permit (e.g., lighting but not envelope).

- **Rate of Field Confirmed Compliance**: This metric is a KPI, but more importantly a recommendation to establish a program to confirm Energy Code compliance in the field a set time after a permit has been completed. These field confirmations should be done randomly and consistently and then the resulting data extrapolated to estimate broader rates of non-compliant work.
    - *Data Source(s)*: This confirmation would need to be done by a very expert and critical team of CEC staff to perform a secondary review of both plancheck and field verification/acceptance testing. The purpose here would not explicitly be to point out errors to the building owner, contractor/installer, or local jurisdiction staff, but rather to generate a dataset and understand trends. Many of the research papers reviewed and summarized in Chapter 3 of this report conducted similar field confirmations and should be used as reference to design such a program and adjusted to meet the specific requirements of California and its Energy Code.

KPIs for Rates of Energy Code Compliance Savings

- **Energy Code Savings Impact of Unpermitted Work**: This KPI estimates the likelihood that unpermitted work conforms to Energy Code requirements. While unpermitted work is often assumed to be non-compliant, some projects may meet or exceed code standards despite the absence of a permit. By using NOMAD models, the CEC can estimate the probability that unpermitted projects align with code by assessing market behavior and identifying trends in "natural" compliance without regulatory influence.
    - *Data Source(s)*: NOMAD Estimates (e.g., DNV GL 2017): Provides data on market adoption rates of energy-efficient practices without external enforcement, offering baseline compliance estimates for various measures (e.g., HVAC systems, insulation upgrades).
    - CEC Site Confirmation Program (if implemented): Can be used to validate NOMAD predictions or reveal areas where compliance rates deviate.
    - DEER Database: Supplies energy and carbon impact values to quantify the broader decarbonization impacts of compliant and non-compliant work, following the same methodology used for non-compliant work analysis.

Illustrative Example

The calculation of this KPI follows the same procedures as the previous KPI for Energy Code Savings Impact of Non-Compliant Work. The distinction is the applicability. Whereas Non-Compliant work relates to buildings in which permits have been pulled and approved, but have unidentified conformance issues, Unpermitted Work applies to buildings and projects which have not completed the permitting process at all.

Estimating the energy and EUI impacts for this KPI is only possible in situations where NOMAD models can provide sufficient specificity of certain building attributes. For example, if the NOMAD model is only able to provide the binary likelihood of conformance of wall insulation, that is not sufficiently specific. However, if the model can provide the likelihood of wall insulation at a specific R-value, then that is sufficiently specific.