Final Report: 2014-16 HVAC Permit and Code Compliance Market Assessment (Work Order 6) Volume I – Report

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Report Glossary

Provided are definitions of key words used in this report. Several definitions are direct citations from the California Energy Commission (CEC) California Building Energy Efficiency Standards or "Standards."[1]

Additional duct insulation refers to a supplemental threshold—required in some climate zones—of increasing the R-value of the duct insulation beyond the typical minimum of R-4.2. Depending on the climate zone, the Standards require that duct insulation must be increased to a minimum of R-6 or R-8.

Additions are changes to an existing building that increase both conditioned floor area and volume. These were excluded from the study. Installations that involved additions at the same time as the HVAC changeout were also excluded from this study.

Airflow is the volume of air per minute that central, forced-air system fans maintain across the return air intake; it is measured in cubic feet per minute (cfm). When entirely when new or replacement HVAC system changeouts (including new/replacement duct systems) are installed in climate zones 10-15, the system must be tested and field-verified to have an airflow greater than 350 cfm per nominal ton of cooling capacity to comply with the Standards. This requirement does not apply, however, when only some of the HVAC components are new/replaced—a more common occurrence than changeouts. Additionally, a separate protocol dictates that the airflow must be greater than 300 cfm when measuring and verifying refrigerant charge. Therefore, at projects with new/replacement components that have less than 300 cfm of airflow, the project is—by definition—out of compliance with the refrigerant charge requirement.

Alterations are not additions, but rather changes to a building's envelope, space conditioning system, water heating system or lighting system. This building modification category was the focus of this study.

Building permit is an electrical, plumbing, mechanical, building, or other permit or approval issued by an enforcement agency and that authorizes any construction that is subject to Title 24, Part 6 Building Energy Standards (Standards).

California Building Energy Efficiency Standards, also referred to as the Standards, are the regulations and requirements contained in Title 24, Part 6 Building Energy Standards (Standards).

Changeout is a HVAC replacement of an existing component or system or installation of a new central system when a central system was not previously installed. These system types are the focus of the study. The study excludes HVAC installations that are part of a building alteration and portable space heating or cooling installations.

Climate region is a region made up of combined California climate zones (defined below) for the purpose of this study. Each region is made up of groups of climate zones that have relatively similar characteristics related to heating and cooling needs. For the top-down permit rate estimation, we used five climate regions: North Coast (zones 1, 2, and 5), North Inland (zones 2, 11, and 16), Central Inland (4, 12, and 13), South coast (6 and 7), and South Inland (8, 9, 10, 14, and 15). To evaluate the smaller on-site sample, we futher consolidated the zones into two regions comprised of similar climate characteristics: a Coastal region (zones 1, 3, 5, 6, and 7) and an Inland region (zones 2, 4, and 8-16).

[1] CEC, 2012.

Climate zone (CZ) is one of the 16 geographic areas of California for which the CEC has established for use with the California Building Energy Efficiency Standards. Typical weather data, prescriptive requirements, and energy budgets are established for each climate zone. Climate zones are defined by ZIP code: http://www.energy.ca.gov/maps/renewable/building_climate_zones.html.

Codes and Standards Enhancement (Case) Initiative Reports are detailed studies used to inform CEC rulemaking.

Compliance forms (CFs) are any of the documents specified in Section 10-103(a) of the Standards that demonstrates compliance with Title 24, Part 6 Building Energy Standards (Standards). Examples include a certificate of compliance, certificate of installation, certificate of acceptance, and certificate of verification.

Database for Energy Efficient Resources (DEER) is a CEC and California Public Utilities Commission (CPUC) sponsored database designed to provide a source of well-documented estimates of energy and peak demand savings values, measure costs, and effective useful life (EUL).

Duct insulation is wrapped around or integral with all ductwork in located in unconditioned spaces. Unless ducts are installed entirely within conditioned spaces, the minimum duct insulation allowed by the Standards is R-4.2.

Duct leakage is the air leaked from the duct system when it is tested as required by the Standards. When a HVAC system is altered by the installation or replacement of components (including replacement of the air handler, outdoor condensing unit of a split system air conditioner or heat pump, cooling or heating coil, or the furnace heat exchanger), or if at least 40 feet of ductwork in unconditioned space is replaced, or if the entire duct system is new/replaced, the duct system must be tested and confirmed through field verification to have no more air leakage than is allowed by the Standards. Compliance requirements for the 2008 building code cycle include: either ≤6% total leakage (for new ducts), ≤15% total leakage (for existing ducts), ≤10% leakage to outside, ≥60% measured improvement compared with existing leakage conditions, or demonstration—confirmed through a smoke test—that all accessible leaks have been sealed. See Section 152(b)E (CZs 2 and 9-16) for the 2008 Standards.

Enforcement agency is the city, county, or state agency responsible for issuing a building permit.

Fan power index is the measure of the wattage drawn by the central system air handler fans divided by the airflow at the return air intake, in W/cfm. To comply with the Standards at entirely new or replacement duct systems, the system must be tested and field-verified to have an air-handler fan power index of less than 0.58 W/cfm for CZs 10-15. The requirement does not apply to the much more common occurrence of replacement of the entire duct system.

Field verification and diagnostic testing (FV/DT) is a term used to describe the actions taken HERS Raters when performing inspections.

Final permit is used to describe an installation with documentation of a mechanical permit having been both issued and finalized—or signed off on—by an enforcement agency. Throughout the report, we sometimes refer to final permits as “permitted” or “closed permit.”

HERS is the California Home Energy Rating System (HERS) as described in California Code of Regulations Title 20, Chapter 4, Article 8, Sections 1670 – 1675.

HERS Provider is business entity that administers a home energy rating in compliance with the HERS regulations.

HERS Registry is a registry maintained by a HERS Provider that contains field diagnostic test results performed by HERS Raters. HERS inspections primarily apply to residential installations, but some commercial equipment types—such as split systems—require HERS testing. Registries process the HERS Rater rating, store the documents, and issue the certification. The registry (by project level) is accessible to HERS Raters, building department officials, and HVAC contractors.

HERS Rater is a person who has been trained, tested, and certified by and is subject to the oversight of a HERS Provider to perform field verification and diagnostic testing required for demonstrating compliance with Title 24, Part 6 Building Energy Standards (Standards). Raters are typically independent contractors. Raters charge customers a service fee to rate the contractor's HVAC inspection and a portion of this fee is paid to Registry. HERS rater inspections are not limited to HVAC changeouts.

HVAC installation efficacy (HIE) is a weighted average of the requirement-level compliance (see definition) results for each energy efficiency requirements at a given site. DNV GL developed this metric for the purpose of this study. We established the weights for each requirement based on their relative influence on the energy impacts attributable to the HVAC alteration. Each requirement has its own set of weights that vary by climate zone and the building code in effect at the time of the alteration.

Load calculations are used for estimating building cooling and heating loads and, ultimately, for equipment sizing. According to the Standards, load calculations must be calculated in accordance with a method based on any one of the following: American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Handbook, Sheet Metal & Air Conditioning Contractors' National Association (SMACNA) Residential Sheet Metal Manual, or Air Conditioning Contractors of America (ACCA) Residential Load Calculation: Manual J.

Mandatory measures are requirements that are mandatory and apply to any installed HVAC equipment.

Measurement access is a measure of access to the refrigerant charge port and to the supply and/or return plenums. Access to the refrigerant charge port is necessary to measure the amount of refrigerant in the system and to adjust as necessary. Measurement access holes are required to facilitate insertion of temperature or pressure probes into the supply or return plenums. There are three options: temperature measurement access holes (TMAH), saturation temperature measurement sensor (STMS), or permanent install static pressure probe (PSPP). Access must be in the plenum on either side of the evaporator coil to allow non-intrusive measurement of supply and return air temperature and humidity. This requirement applies in CZs 10-15.

No permit is an installation where there is no documentation of a mechanical HVAC by an enforcement agency permit from the local jurisdiction. Throughout this report we refer to unpermitted changeouts as "no permit" or "non-permitted".

Performance standard describes a compliance path whereby the energy budget calculated for the Proposed Design Building under Subsection 2 is no greater than the energy budget calculated for the Standard Building under Subsection 1. Installations that followed the performance path were excluded from the on-site sample fram for this study.

Prescriptive measures are those that are used in lieu of performance standards to comply with the Standards. It should be noted that different prescriptive requirements apply to 1) alterations that install/replace specific components of HVAC systems and 2) alterations that install/replace entire HVAC systems, including all components and ducts.

Refrigerant charge is the amount of refrigerant gas that a cooling system must contain. For a cooling system to perform properly, the correct refrigerant charge is required. To comply with the Standards, proper refrigerant charge must be tested and field-verified (home energy rating system or HERS) and diagnostic testing using procedures in the Reference Residential Appendix SA3.2 or the cooling unit must have a charge indicator display. HERS verification of refrigerant charge is required only in CZ 2, and CZs 8-15. The refrigerant charge verification includes requirement for verification of minimum system airflow rate. For alterations, a 300 cfm/ton minimum is required and 350 cfm/ton is required for entirely new or complete replacement systems.

Refrigerant line insulation is required around refrigerant lines in HVAC systems. The Standards require cooling system line insulation of a minimum thickness determined using Equation 150-A from the Standards.

Requirement-level compliance is scored by using a scale from zero to 100%. Some of the requirements used in this study are pass/fail and, hence, the requirement-level compliance receives a score of 100% or zero, respectively. The remainder of the requirement-level compliances each use a scale, from zero to 100%, to gauge the extent to which the installation falls short of the threshold dictated by the Standards. Meeting the threshold for a given requirement yields a compliance rate of 100%; no bonus is given for conditions that exceed a given threshold. To establish appropriate ranges for these scales, lower limits were selected to be represented by a zero on the scale (e.g., 150 cfm/ton for airflow and 60% for total duct leakage). This was done to account for the fact that no installation could reasonably be expected to have conditions below those lower limits.

Title 24, Part 6 Building Energy Standards (Standards) are the California Code of Regulations that dictate energy efficiency standards for buildings: http://www.bsc.ca.gov/Codes.aspx.

Un-final permit is used to describe an alteration where documentation exists of a mechanical permit issued by an enforcement agency, but the permit was either allowed to expire or remain open without sign-off from a building department. Throughout this report, we refer to un-final permits as “open.”

1 EXECUTIVE SUMMARY

This report presents DNV GL's 2014-16 assessment of state permitting and compliance rates for specific heating, ventilation, and air conditioning (HVAC) replacement installations in residential dwellings in California. We performed this work under contract with the California Public Utilities Commission (CPUC). We limited our assessment to HVAC installations governed by the two most recent state building energy efficiency standards: 2013 and 2008 Title 24, Part 6 Building Energy Standards (Standards).

The CPUC created a Long-Term Energy Efficiency Strategic Plan to help guide the state toward greater energy efficiency through research and programs.[2] The Plan emphasizes market transformation and comprehensive approaches to energy savings. To assist the CPUC in evaluating these, Commission staff collaborated with investor-owned utilities (IOUs) and other program administrators to provide long-term research and evaluation planning for a number of specific sectors and topic areas ("research roadmaps").[3]

One of the roadmaps defined the need to assess standard practices for HVAC permitting and compliance in residential installations and to inform policymakers and stakeholders of the results. The focus of this study is the permitting rate and the energy efficiency of HVAC replacements of existing components or systems, and new HVAC equipment in existing spaces. The study focused on single family homes within the IOU service territories with recent central heating or air conditioning replacements. The study initially focused on the 2008 Standards, but ultimately combined installations subject to the 2008 and 2013 Standards. The primary difference for residential HVAC installations is that the 2013 Standards made some previously prescriptive requirements mandatory and expanded the applicable climate zones for some requirements.

1.1 Background

Since 2005, the Standards require new and replacement HVAC components and systems be installed by state-licensed contractors. When installing or replacing an HVAC system, the homeowner, resident, or HVAC contractor must obtain a building permit from the local city or county building department. The Standards require certified evaluators (called Home Energy Rating System [HERS] Raters) to perform on-site testing and verification as part of the permit process. The goal of this requirement is to reduce the incidence of installation defects that result in wasted energy.

Generally, the energy efficiency industry in California assumes that compliance with permitting requirements for HVAC replacements is low. The potential downsides of non-permitted installations may include defective installation, safety hazards for homeowners and installation contractors, higher energy usage (and thus higher energy costs), and higher maintenance costs. The industry does not know the extent or degree to which these issues occur because bypassing the permit process avoids the HERS verification requirements. Building departments can penalize property owners for failure to obtain permits with fines and corrective repair requirements. A relatively small number of building departments concentrate efforts on enforcement of HVAC permits, and there are ongoing efforts to pilot strategies for improved enforcement.

California has focused on increasing the permitting rate for nearly a decade based on the assumption that increased permitting would result in a decrease in energy usage and peak demand. In 2011, the CPUC set

[2] CPUC , 2011.

[3] CPUC, 2016.

goals to increase the permit rate to 50% by 2015 and to 90% by 2020.[4] Several of California's IOUs offer programs that claim savings for HVAC installation code compliance. In addition, some offered a residential pilot program in 2013-15 that provided incentives for obtaining HVAC changeout permits in certain regions in the state. While legislation and programs require permits, there are no recent large-scale permit rate estimates of the market or studies that measure energy impacts for permitted versus non-permitted installations. Notably, California Senate Bill 1414 (SB1414) requires that participants in energy efficiency programs for air-conditioning and heat pump installations provide proof that their equipment has been properly installed and permitted. The IOUs had to address this new legislation in program designs submitted as part of their 2017 business plans.

1.2 Research objectives

This project had three broad objectives:

- Estimate the percentage of HVAC installations that are permitted versus non-permitted
- Estimate the energy efficiency of permitted and non-permitted residential HVAC installations
- Assess the effectiveness of the HERS verification process

We examined all of these within existing residential dwellings (excluding new construction) in California. We focused on two HVAC installation types: (1) installations involving replacements of existing components or systems; and (2) installations of new central systems that do not replace existing systems.

For this study, DNV GL developed and used transparent and replicable methods to measure the level of permitting and relative energy efficiency implications related to permitting. To reduce the potential response bias for survey and site visits with non-permitted homeowners, the study used techniques to disguise the primary intent of the research (to learn about permitting). Activities included:

- Obtained customized permit data and analyzed secondary HVAC market data to estimate overall statewide permitting rates for HVAC replacements
- Completed 1,421 web-based and telephone surveys to identify HVAC replacements
- Looked up permit status for 364 identified replacements
- Initiated follow-up case studies and analysis across all available data to further test results
- Completed 196 installation assessments at 193 sites across California, and obtained the HERS documentation (CF-3R) for 54 of 103 permitted installations
- Surveyed 122 and interviewed 57 HERS Raters and reviewed documentation to understand the reasons for the permit rate and energy efficiency assessment results

The study developed information for the CPUC and its stakeholders to inform policy decisions with a broader and deeper understanding of the HVAC replacement market. We collected additional data that may not directly inform code compliance but is relevant to future energy efficiency program planning and expected savings workpapers.

Prior to this study, there was no relative estimate of the efficiency increase associated with obtaining a permit—a leading indicator that energy impacts can be attributed to a permit. This research did not question the merits of obtaining permits from a broader societal perspective, but tested the hypothesis that obtaining

[4] CPUC, 2011.

permits alone results in more efficient installations. This was very important to inform programs and policies that aim at increasing energy efficiency by increasing permitting of HVAC installations.

1.3 Findings and Discussion

The study examined residential single family central HVAC replacements in IOU service territories. At a high level, findings from the study suggest that:

- **Permitting rates are low**, with permits pulled for less than one-third of all change-outs that require them.
- **Under current market and enforcement conditions[5], permitting does not lead to increased energy efficiency** of HVAC changeouts. We found similar levels of efficiency for equipment at permitted and non-permitted sites in a representative statewide sample.
- **There were documentation gaps for permitted installations.** Three-quarters of permitted installations had the required HERS compliance forms. Among the forms submitted, only a subset contained a complete set of the required tests. Additionally, performance tests replicated by DNV GL found some systems out of compliance while HERS documentation indicated that these units were in compliance.

Below, we provide more detail regarding these findings as they relate to each of the study's key objectives.

1.3.1 Estimated permit rates for residential HVAC installations

The study's first objective was to estimate the proportion of projects that follow the required mechanical building permitting process. Permit types are characterized as either open (not completed), or non-permitted (no records existed).[6] The permit rate analyses do not distinguish between open and closed permits; all permitted projects are treated as "permitted." The compliance analysis distinguishes open and closed permits.

We estimated the rate of permitting using two separate approaches that produced considerably different outcomes: 8% for the top-down approach and 29% for the bottom-up approach. While the two do not align, this was not unexpected; we used two approaches because of the high levels of uncertainty and potential bias inherent in each approach. The true permit rate likely lies within the range represented by the two estimates; in other words, the top-down approach underestimates the permit rate whereas the bottom-up approach overestimates it.

To put our findings in context, we reviewed a number of previous permitting studies. In 2014, DNV GL used a bottom-up approach to estimate permit rates for central cooling equipment on behalf of PG&E.[7] Although the 2014 study differed from the current one in several ways, we used a method similar to the current bottom-up approach.[8] Results from the 2014 study suggest that PG&E customers obtained permits for 38% of residential cooling equipment purchased without energy efficiency program incentives, although the findings from that study were not statistically significant.

Two earlier sources provide lower estimates of permit rates:

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[5] The data collection spanned 2015 and 2016 and focused on changeouts in 2013 through 2015.

[6] See Report Glossary for permit type definitions, pg. V

[7] PG&E, 2014.

[8] The 2014 study included a tighter geographic scope and focused on cooling equipment versus heating equipment.

- In 2013, the Institute of Heating and Air Conditioning Industries asserted only 10% of the work that is supposed to be regulated under the Standards is permitted.[9]
- In 2012, Proctor Engineering Group conducted a study that estimated that customers obtained permits for less than 30% of air conditioning units in the Sacramento region.[10]

Despite the uncertainties associated with the current analyses, we are confident that the true permit rate lies between the two estimates we developed as part of this study (8% and 29%). Even at 29%, the permit rate is far below the 2015 goal of 50%. What is clear is that the state has a long way to go to meet a 50% permitting rate and will be challenged to get to 90% by 2020.

After completing the top-down and bottom-up analyses we further investigated the drivers of the permit rate. We completed case studies with some of the study participants to ask about their experience with permit process. The consensus among respondents was that contractors drove whether or not the permit was obtained. We then performed a regression analysis using data from the 2009 Residential Appliance Saturation Survey (RASS) and survey data collected for this study. The regression analysis did not find correlations between demographic and other RASS variables and permit status. These additional analyses helped to support our overall conclusions that the bottom-up represents an upper limit of the permit rate and the top-down represents a lower limit for permit rate.

1.3.2 Energy efficiency of permitted and non-permitted residential HVAC installations

The second objective of this study was to determine the energy efficiency of residential HVAC installations and determine the correlation between permitting and efficiency.[11] The study sampled homes randomly in a first phase and then oversampled permitted and HERS rated homes in the second phase to develop a comparative sample. The replacement scope (e.g., unit replaced or unit and ducts replaced) and climate zone determined the applicable individual code requirements from the Standards. Different replacement scopes trigger different installation and HERS testing requirements. Because we could not control samples sizes at the requirement level, some results have smaller samples and thus greater associated uncertainty. We assumed our sample of 196 installations would characterize the most common replacement scopes of single family HVAC replacements in IOU service territories. Briefly, we found that:

- **Complete/full compliance requirements:** Regardless of permitting status, there was 100% compliance with the mandatory requirements for minimum efficiency, duct insulation, and additional duct insulation requirements.
- **Programmable thermostats:** A total of 87% of permitted installations had programmable thermostats while only 71% of non-permitted installations had them. This is a statistically significant difference.[12] Field staff reported that it was common for homeowners in both samples to request non-programmable thermostats because of their simpler operation.
- **Refrigerant line insulation:** Nearly all sites had refrigerant line insulation in place (at least where field staff could observe it. At permitted sites, 93% of the installations had the necessary insulation whereas at non-permitted sites, 100% had it. This is a statistically significant difference.

[9] Institute of Heating and Air Conditioning Industries, 2013.

[10] Proctor Engineering Group, Ltd., 2012.

[11] We summarize the requirement-level results, detailed by each requirement, in Table 13 of the report and in greater detail in Appendix I.

[12] We report statistical significance at the 90% level of confidence unless otherwise stated.

- **Refrigerant charge:** Refrigerant charge was within the proper range for almost two-thirds of the systems we tested. We did not measure refrigerant charge for packaged systems, however. The sample sizes were relatively small because few sample sites required refrigerant charge tests.
- **Airflow:** Overall, less than one-fifth of installations met the minimum airflow requirement. Among permitted sites, 26% met or exceeded the minimum requirement; among non-permitted sites, only 14% did so; and among sites with open permits, none did so. The extent to which the open permit sites differed from both the final permitted and non-permitted sites is statistically significant. Some homeowners remarked to field staff that they had asked their contractors to reduce fan speed to minimize noise or drafts from the system. These data suggest the possibility that—at those sites with open permits—contractors decided not to close the permit when it became evident that the site would not be in compliance. The sample sizes were relatively small because few sample sites required airflow tests.
- **Fan power index**: About two-thirds of both the permitted and non-permitted installations met the maximum fan power index. The sample sizes were relatively small based on frequency of applicability.
- **Duct leakage:** A little more than half of permitted sites in the sample passed the duct leakage tests as did slightly fewer than half of non-permitted sites. The actual rate of compliance may be higher, however, if any contractors opted to use the alternative smoke testing compliance path at the sites we visited. The sample sizes were relatively small because fewer than expected sample sites required duct testing.

For the purposes of this report, we developed an approach to scoring the relative energy efficiency of each HVAC installation on a scale of 1 to 100.[13] We found somewhat different results for electric installations versus gas installations:

- For electric installations, regardless of where they were located in the state, only a handful met all of the energy efficiency requirements. There was no clear pattern based on permit status, but results suggest that potential impacts from improved compliance may be low in many areas.
- For gas installations, there was also no clear pattern of meeting requirements based on permit status. The average scores were lower than electric for both permitted and non-permitted cases, but like electric, potential impacts from improved compliance may not be large.

In summary, we concluded that the permitted and non-permitted installations in this study had similar rates of compliance with requirements related to their electric and gas energy efficiency. Furthermore, both the requirement level results and efficiency scale results were higher than generally expected for non-permitted installations. Since the potential bias identified for the bottom-up permit rate analysis also applies to the on-site findings at non-permitted installations, both results have greater inherent uncertainty than those for the permitted installations. There was no evident reason for people with permitted projects to avoid our study. Our additional case studies and modeling also supported the conclusion that the onsite sample was not significantly biased.

Our assessments suggest that the potential energy impacts from improved compliance in installations may not be substantial under current market and enforcement conditions. The value of achieving the state's permitting rate goals becomes less clear from an energy efficiency perspective. There may be value in

[13] We developed a scoring method that we refer to as "HVAC installation efficacy (HIE)." HIE is a weighted average of the results of up to 12 different energy efficiency requirements for each installation. We established the weights for each requirement based on their relative influence on the energy savings attributable to the HVAC alteration, and each has its own set of weights that vary by climate zone and relevant building codes. We provide more detail on HIE in Section 5 of the report.

pursuing intervention strategies that improve all installation practices or in pursuing interventions that both improve the efficacy of permitting and the permitting rate together. The results from this study suggest that market interventions that focus solely on the permitting rate may not be successful in increasing the energy efficiency of residential HVAC change-outs in California. Additionally, the barriers we documented with regard to further improving installation practices suggest that achieving energy impacts by improving compliance may pose substantial challenges. The barriers range from inadequate installer training to lack of oversight from building departments. Additional barriers specific to the HERS verification process are provided in the following section.

1.3.3 Effectiveness of the HERS verification process

The third research objective was to assess the effectiveness of the HERS verification process. This involved interviews with HERS Raters to test eight categories of potential barriers. The study generally confirmed the expected barriers to permitting and compliance experienced by homeowners, contractors, and HERS Raters. These barriers included lack of knowledge on the part of contractors and homeowners and inconsistency among and within building departments. The study also found gaps and some discrepancies in the documentation for some of the permitted sites we visited as part of our study. HERS Rater interview results provided insights into the reasons for certain deficiencies in the energy efficiency of permitted installations. However, they do not speak to the findings for the larger population of installations without permits. HERS Rater interviews suggested that contractors drive the decisions about permitting in most cases, and our limited interviews with homeowners suggested the same.

The results of our tests suggest that even with HERS inspections, there are significant deficits in duct leakage, airflow, and refrigerant charge only a few years after installation. Of the units we tested, only 77% passed the duct leakage test, 57% passed the airflow test, and 43% passed the refrigerant charge test. However, because these deficits could be due to any combination of explanations from poor documentation to testing errors, it is not obvious how to remedy the situation.

The HERS Rater online survey asked questions regarding three categories of regulations: regulations for HERS Rater training and testing (including specific topics on which training should focus), regulations for contractors, and regulations as they relate to quality assurance (QA). HERS Raters perceive opportunities to improve regulations regarding field training requirements and, in particular, cite deficiencies with support provided by the Registry. The HERS Raters accounting for the majority of projects agreed that "most HVAC jobs are installed without a permit and there is little a HERS Rater can do to change that." This suggests that, even with additional regulation, compliance gaps will persist due to low levels of enforcement. Respondents agreed that a contractor rating system might improve contractor installations and improve transparency. Last, HERS Raters suggested that the QA process may be an effective way to hold HERS Raters accountable for performing all required tests.

Our research found varying levels of contractor awareness and knowledge of the Title 24 energy efficiency requirements for HVAC installations. Results also suggested that enforcement of these requirements varied among local building departments. Given these findings, it is not surprising that despite HERS inspections, many HVAC projects fail to meet the Standards' energy efficiency requirements. These results call into question whether the permitting process—including HERS verification—is effective in increasing the energy efficiency of residential HVAC installations in California. The findings from our energy efficiency testing of permitted and unpermitted installations further underscore the uncertainty regarding the permitting process's effects on increasing residential HVAC installation efficiency.

1.4 Summary Conclusions

With regard to the study's research objectives Section 1.2, DNV GL concludes the following:

- The permitting rate remains quite low—between 8% and 29%. While results from our two permit rate assessment methods did not converge, they provide a feasible range and support the conclusion that enforcing permitting remains a persistent challenge in California.
- There are few statistically-significant differences in the energy efficiency of permitted and non-permitted installations. There were few significant differences at the requirements level and none at the aggregate level across installations. Non-permitted cases had a wider range of performance, but, like permitted cases, compliance rates were nonetheless fairly high in coastal areas and moderate inland.
- We hypothesized that lack of homeowner and contractor knowledge as well as inconsistency among building departments contribute to low rates of permitting and compliance with the energy efficiency standards. Interviews with HERS Raters and homeowners confirmed our hypothesis. The study also found some gaps and discrepancies in the documentation for some of the permitted sites we visited.

1.5 Recommendations for IOUs

Given the findings and conclusions, we offer the following recommendations for IOU program planners and staff:

- Evaluate current residential pilot programs that aim to increase permit rates in light of this study's findings and current regulations aimed at addressing permitting within energy efficiency programs (e.g., SB1414). In particular, we recommend that such programs:
- Inform homeowners that the permitting responsibility is theirs and that they must hold contractors accountable.
- Have program contractors emphasize other potential benefits of permitted installations for customers, and consider literature for homeowners that does the same. Given that the Standards already dictate permits for IOU program participants, programs that incentivize system efficiency improvements (such as Home Upgrade or Quality Installation) should raise permitting rates to some degree.
- Leverage local government partnerships and non-IOU program administrators where feasible. Community Choice Aggregators (CCAs) and Regional Energy Networks (RENs) can administer energy efficiency programs under the same guidelines and funding mechanisms as the IOUs. However, these local program administrators could work directly with the building departments in their regions to improve their enforcement processes over multiple years. Because of the large number of building departments in each IOU's service territory, it may be less feasible for the IOUs to work directly with the building departments.
- Based on findings from the HERS interviews, we recommend the IOUs continue to support workforce education and training (WET). Studies from the early 2000s identified a number of issues related to HVAC changeouts. The 2005 update to the Standards addressed these issues. We also know the IOUs have supported WET during the same timeframe. As an example, the Standards require temperature measurement access, and we found this at over 80% of non-permitted installations. This would indicate installer knowledge of some aspects of the Standards. We believe that in the current market these IOU and CEC trainings affect contractors that perform both permitted and non-permitted installations. Future

studies on permit rates and compliance should account for any changes in WET efforts as they may affect installation quality regardless of permit status.

- Leverage this study's performance test results to support workpaper inputs for measures addressed in the Home Upgrade and Quality Installation programs. This includes information regarding cases in which code requirements are not triggered, such as equipment-only replacements or system airflow in certain climate zones. The appendices of this report (Volume II) include summaries of data collected at sites that go beyond the analysis of compliance and energy efficiency associated with compliance. There are specific opportunities where code is not triggered based on installation scope and some limited opportunities for improvement above code where code is triggered. While we did not find statistically significant differences based on permit status, current practice (permitted or not) on average does not meet full compliance.

1.6 Recommendations for key stakeholders

Continued collaboration between the California Energy Commission (CEC) and CPUC is essential to continue improving the energy efficiency of HVAC installations in California. This could take the form of simultaneous improvement in permitting and enforcement processes, improvement in efficacy of the inspections process, or through other means. We also recommend the following:

- The CEC and CPUC should consider developing energy modeling software or approaches for existing residential buildings to estimate the energy saving potential for changeouts in single family residential dwellings. The California Technical Forum may be a venue for this collaboration since it includes the IOUs and the largest publicly-owned utilities in California. The absence of a functioning model prevents stakeholders from making realistic predictions about the impacts associated with the required set of compliance measures. The absence of such a model also necessitated the creation of metrics by this study using secondary information. We recommend the model include features such as a cost calculator to factor average cost estimates for permit and compliance requirements including HERS certification.
- Assuming the HERS process will continue to be used in compliance enforcement, the following recommendations could improve the State's oversight of the HERS Registries and improve the efficacy of the HERS verification processes:
    - If stakeholders pursue further research regarding HVAC permitting and compliance, the CEC and HERS Registries should take action to ensure access to information collected by HERS Raters. For instance, terms for sharing compliance data with researchers, including results of HERS tests, could be added as condition for certification of registries in future Title 24 updates.
    - Additionally, the CEC and HERS Registries should take action to ensure public access to information collected by HERS Raters for the benefit of homeowners. The documentation required in the HERS process includes measurements of home performance, but these documents are not required to be provided to the homeowner or to the building department for later access. Streamlined access could be achieved by mandating building departments retain the compliance forms, by the CEC retaining the forms, or by Registries responding to requests for information. Information regarding a current or prospective home's performance characteristics could be valuable to homeowners.
    - The CPUC and IOUs should inform stakeholders of energy efficiency requirements currently being met for permitted installations, including the results of this study and general research in HVAC performance.

- HERS Registries should evaluate HERS Rater training for field-testing procedures intended to assess prescriptive measures. Also, consider developing mentoring programs for new Raters. Efforts should include finding creative ways to reiterate diagnostic testing requirements periodically.
- The CEC and Contractors State License Board (CSLB) should evaluate a complaint hotline to be used by contractors, HERS Raters, and homeowners who believe building departments are not providing adequate enforcement or other HERS Rater issues. Currently, the CSLB hotline[14] handles contractor issues, but the CEC Title 24 Building Energy Efficiency Standards hotline does not field building department or HERS complaints. The CEC and CSLB could also consider a contractor rating system to improve contractor installations and improve transparency.

- The CEC and HERS Providers should improve the marketing and branding of the HERS compliance process. Improve customer awareness of permit and compliance requirements for HVAC changeouts. Presently, there are very few relatively recent articles online to promote the program.
- The CEC should take action to streamline and simplify statewide codes for mandatory and prescriptive HVAC requirements throughout California. Contractors and building departments may not have the resources to understand or enforce the nuances of the code therefore deprioritizing or eliminating verification. The CEC should also consider designing forms that reduce the paperwork required for code compliance.
- The CEC, Building Departments and HERS Registries should pursue an improved process for submitting HERS forms and provide technical training on new methods. Explore ways to provide information in mobile-based or web-based forms so that data enters a database directly, allowing specific forms to be populated electronically, and kept for all parties. An additional potential benefit would be to allow homeowner access to information about their HVAC system performance.
- The CEC should take action to reevaluate, from an energy efficiency perspective, codes that effectively provide no energy impacts or verification benefits. This includes requiring calculations for sizing without a corresponding requirement to reduce size whenever possible. The CEC should consider new cost calculations that explicitly show non-energy cost savings or extended equipment life to improve the value proposition.
- To increase the incidence of HVAC inspections, building departments should consider requiring duct testing and performance measurement for air conditioners at the time of sale for existing homes. Homes should be required to be "to code" when sold. Such a requirement would be easier to enforce than permitting at time of replacement and would be difficult to ignore, as several other inspections are ordered at time of sale. The City of Davis has already adopted this model for existing home sales. Another option would be to provide homebuyers with a path to order a HERS rating just as they can order other inspections during sale negotiations.
- The CEC could work with building departments to have HERS Raters perform all HVAC inspection points with marginally increased fees and then offload building department staff from doing HVAC replacement inspections. This would allow homeowners to only pay for a single inspection instead of one from the building department and another from a HERS Rater.
- Building departments should eliminate inconsistent enforcement of the Standards among employees through more routine training and internal auditing.
- Building departments and HERS Registries should improve coordination to eliminate open permits.

[14] The CSLB offers a Building Permit Complaint form that can be downloaded from the web or by calling to request the form. The form must mailed or faxed to the Sacramento Intake & Mediation Center

- The Contractors State License Board should consider requiring workforce education and training credits for C-20 contractors to verify knowledge of the Standards and HERS process.

1.7 Future research needs and priorities

Additional research on residential HVAC compliance can provide additional insights and also provide indications of changes in market and enforcement conditions. Specific research topics and approaches could include the following:

- Study whether spillover savings may exist for the CEC's and IOUs' workforce education and training efforts. The relatively high rates of compliance and energy efficiency at non-permitted installations among non-participants in energy efficiency programs may be indirectly attributable to these efforts. This study did not pursue evidence suggesting this connection, but such a connection is plausible. It may be important to acknowledge that these trainings are being taken by contractors who are not pulling permits. This implies the education and training to improve compliance affects the broader HVAC replacement market and not just permitted installations.
- Perform a "secret shopper" study where researchers pose as homeowners in need of HVAC replacements in regions of California with high uncertainty of permitting and compliance. Consider working with Contractors State License Board and specific building departments to identify the worst installation cases that may avoid scrutiny. The actual volume of the extreme cases is a particular research question to answer.
- Continue analyzing performance data; If data access is improved as recommended in the previous section, compliance data collected by HERS Raters can be mined and analyzed to help target insufficient installation practices. Reviewing detailed data can help to track progress toward improving compliance of HVAC replacements.

2 INTRODUCTION

This report presents DNV GL's assessment of state permitting and compliance rates of specific Heating, Ventilation, and Air Conditioning (HVAC) replacement installations in residential dwellings in California. We performed this work as part of the California Public Utilities Commission (CPUC) Energy Division (ED) 2013-15 Work Order 6 (HVAC6): HVAC Market Assessment - Existing Conditions and Code Compliance. This assessment is limited to the HVAC installations that must comply with the 2013 and 2008 Title 24, Part 6 Building Energy Efficiency Standards (Standards), the California Code of Regulations that provides energy efficiency standards for buildings.[15] The study focused on single family homes within the IOU service territories with recent central heating or air conditioning replacements. The study initially focused on the 2008 Standards, but ultimately combined installations subject to the 2008 and 2013 Standards. The primary difference for residential HVAC installations is that the 2013 Standards made some previously prescriptive requirements mandatory requirements and the lists applicable climate zones for some requirements were expanded.

2.1 Background

California's Standards require newly installed and replaced HVAC components and systems be permitted and installed by a state-licensed contractor.[16] When installing or replacing an HVAC system, the homeowner, resident, or HVAC contractor must obtain a building permit from a local city or county building enforcement agency. To ensure that the systems are not wasting energy due to installation defects, the Standards require certified evaluators to perform on-site testing and verification as part of the permit process.

The level of compliance with permitting requirements is believed to be very low; so low that the energy efficiency industry refers to contractor business in unpermitted installations as an "underground economy."[17] The potential consequences of non-permitted installations include defective installation, homeowner and worker safety hazards, higher energy costs, and higher maintenance costs, and could result in fines and correctional repairs required by building enforcement agencies. The industry does not know the extent or degree to which these issues occur.

Increasing the rate of permitting has been a concern for the state for nearly a decade. In 2008, the California Energy Commission (CEC) published a report that estimated 130 MW of additional peak demand reduction could be achieved annually assuming there is 90% permitting and proper installation of replacement HVAC equipment. Several of the California investor-owned utilities (IOU) offer programs that claim savings for HVAC installation code compliance, and some currently offer a residential HVAC changeout pilot program that provides incentives for obtaining permits in certain regions in the state. While legislation and programs require permits, there are no recent large-scale permit rate estimates of the market or studies that measure energy impacts for permitted versus non-permitted installations.

The CPUC created a Long-Term Energy Efficiency Strategic Plan to help guide the state toward greater energy efficiency through research and programs.[18] The plan emphasizes market transformation and comprehensive approaches to energy savings. To assist the CPUC in evaluating these Commission staff

[15] For more information regarding California Building Standards Code (California Code of Regulations, Title 24), please refer to the California Building Standards Commission's website at http://www.bsc.ca.gov/Codes.aspx.

[16] Residents or contractors can also apply for HVAC installation permits.

[17] Pennington, G. W., 2014.

[18] CPUC , 2011.

collaborated with the IOUs and other program administrators on an Evaluation, Measurement and Verification (EM&V) Plan to provide long-term research and evaluation planning for a number of specific sectors and topic areas ("research roadmaps").[19] Two of the HVAC roadmap's goals are that 50% of HVAC installations in existing buildings comply with codes via permits by 2015 and that 90% of HVAC systems are installed to code and optimally maintained for systems' useful life by 2020.

As part of the HVAC market assessment work addressed in the HVAC Roadmap, the CPUC asked DNV GL to assess and inform policymakers and stakeholders regarding the current standard practices for HVAC permitting and compliance in residential installation projects that occurred between 2014 and 2016. The focus of this report is on the energy efficiency of both permitted and non-permitted installations for HVAC changeouts, defined as either replacement of an existing component or system or installation of a new central system when the home has no existing a central system. The study excludes HVAC installations completed prior to the 2008 Standards (i.e., installed 2009 or later), installations in high-rise buildings or new construction, residential additions with HVAC changeouts, portable space heating or cooling equipment, and buildings or equipment exempt from the permit process.

2.2 Objectives

This study has three primary objectives:

- **Estimate the percentage of permitted changeouts.** The permit rate is a simple ratio of the number of permitted HVAC changeouts to the number of total changeouts (permitted and unpermitted). We used two different approaches that generated two separate estimates of the permitting rate. First is a top-down approach that paired state-level estimates of total HVAC units installed with statewide estimates of total permitted units. The second is a bottom-up approach that used a customer web and telephone survey to identify HVAC changeouts, an independent search to verify their permit status, and analysis to extrapolate the results to the population. We also discuss the strengths and weaknesses of these two estimates to draw conclusions on the likely estimated range of the 2014 permit rate in existing California homes.
- **Estimate the energy efficiency of residential HVAC changeouts.** There is a common assumption that permitted HVAC installations are more energy efficient than non-permitted installations. Prior to this study, the degrees to which permitted and non-permitted installations comply were largely unknown. Furthermore, it is known that enforcement of permitted installations varies by building and by enforcement agency. Therefore, we performed on-site inspections of permitted and non-permitted HVAC changeouts to analyze two metrics of the energy efficiency of residential HVAC changeouts: requirement-level compliance, which is the percentage of changeouts that comply with each of the specific requirements in the Standards, and HVAC installation efficacy, a weighted average of the requirement-level compliance scores across requirements for each changeout.
- **Assess the effectiveness of the Home Energy Rating System (HERS) verification process.** Because HERS Raters are critical to the HVAC changeout compliance process, we assessed the prevalence of systematic issues, knowledge gaps, and barriers to HERS inspections on HVAC installations that result in HERS-compliant residences. We also examined barriers and awareness of HERS Raters on the code requirements and inspection processes to identify knowledge gaps where training could help HERS Raters to better impact compliance with Standards HVAC requirements.

[19] CPUC, 2016.

The data we collected for this market assessment provide an initial measurement of the permit rate goal set in the Strategic Plan and additional insights into the HVAC changeout market. Additionally, stakeholders can leverage the study results to inform future program planning, policy decisions, and areas requiring further study.

2.3 Organization of the report

The report includes the following sections:

- Section 2 provides the background for this study, reviews its objectives and methods, and provides an overview of the report's organization.
- Section 3 presents our assessment of the current rate at which consumers obtain permits for residential HVAC changeouts in existing California residences.
- Section 4 investigates permit rate influences.
- Section 5 addresses the energy efficiency of residential HVAC changeouts.
- Section 6 reviews the prevalence and completeness of HERS Compliance Forms and assesses whether HERS inspections of residential HVAC installations produce the intended result of HERS-compliant residences.
- Section 7 assesses HERS Rater effectiveness and identifies knowledge gaps among HERS Raters, contractors, and inspectors and examines HERS Rater awareness and understanding of code requirements and inspection processes.
- Section 8 reviews DNV GL's conclusions and recommendations based on the research.
- Section 9 provides complete citations for all of the sources that we reference throughout the report.

We provide the following report appendices in Volume II, HVAC WO6 Report Appendices:

APPENDIX A. Top-down permit rate methodology

APPENDIX B. Count of changeouts by building departments (data source: HERS registry)

APPENDIX C. Count of permits by building department (data source: CIRB)

APPENDIX D. Methodology to merge HERS registry and CIRB data

APPENDIX E. MAPC online screener survey instrument

APPENDIX F. Demographic comparison of MAPC sample frame to respondents

APPENDIX G. Bottom-up reported changeout rate and the possibility of strategic non-response/misreporting

APPENDIX H. Logit modeling detailed results

APPENDIX I. Detailed results: energy efficiency of residential HVAC changeouts

APPENDIX J. Methodology for measuring compliance

APPENDIX K. Source references for measuring compliance

APPENDIX L. On-site field data collection instrument Phase 1

APPENDIX M. On-site testing protocol

APPENDIX N. Comparison of results for HERS and DNV GL field tests

APPENDIX O. HERS Rater compliance form (CF3R) templates

3 PERMIT RATE

The current rate at which consumers obtain permits for residential HVAC changeouts in existing California residences is unknown, but believed to be low. In 2011, the CPUC set goals increase the permit rate to 50% by 2015. DNV GL undertook analyses to estimate the permit rate and measure progress toward that goal.

The permit rate is a ratio. The numerator represents the number of permits that California building departments issued for residential HVAC changeouts in a given period, and the denominator represents the total number of residential HVAC changeouts that occurred in the same period (with or without permits). We show this calculation in Equation 1 below.

Equation 1. Permit Rate Calculation

$$Permit\ Rate = \frac{Permitted\ Changeouts}{Total\ Changeouts}$$

This study estimates the annual permit rate for residential HVAC changeouts in existing dwellings based on two methods: a top-down approach and a bottom-up approach.

1. **Top-Down.** This approach assesses "the big picture" and involves a stock[20] turnover analysis for HVAC units in California residences. Because this method relies primarily on records maintained by building departments, HERS Providers, and other entities rather than information obtained directly from individuals involved in the permitting process (e.g., contractors or consumers), it has the advantage of lower potential response bias than the bottom-up approach. However, the top-down approach has several disadvantages including generating only a coarse estimate of the permit rate, its reliance on interpolation and extrapolation to fill in missing data, and its reliance on many assumptions.
2. **Bottom-Up.** This approach estimates the permit rate based on analysis of a representative sample of changeouts. The bottom-up approach has the advantage of providing site-specific information (such as the type of permit, location, and equipment type) but has the disadvantage of potential response bias.

This chapter contains the following sections:

- Section 3.1 presents the top-down analysis
- Section 3.2 presents the bottom-up analysis
- Section 3.3 compares the results from both sets of analyses and provides DNV GL's conclusions based on these results

For each of the two approaches (top-down and bottom-up) we review our methods for estimating the total number of total and permitted HVAC changeouts and provide a summary of results.

3.1 Top-down permit rate analysis

Researchers used a top-down method that paired state-level estimates of total HVAC units installed with statewide estimates of total permitted units. For the permit estimate, we aggregated permit data from building departments and HERS certificate data from the largest HERS Provider. We then compared those values to the estimated number of replacement units sold during the same period using overall household population data. In developing an estimate of total units sold, we considered the average equipment

[20] Annual estimates of residential HVAC units currently installed within the state.

lifecycles and how lifecycles vary by the 16 California climate zones. This top-down approach resulted in a coarse permitting rate estimate that had the advantage of not being subject to response bias. However, the approach has limitations. We describe these limitations in Section 3.1.1 to help provide context for the analytical steps. The primary analytical steps include:

1. Estimating the total number of residential HVAC changeout units (Section 3.1.2)
2. Estimating the number of permitted changeout units (Section 3.1.4)
3. Calculating the permit rate (Section 3.1.5)

Step 1 and step 2 consists of multiple analytical steps, which we discuss in detail in the relevant sections.

3.1.1 Scope and limitations of the top-down approach

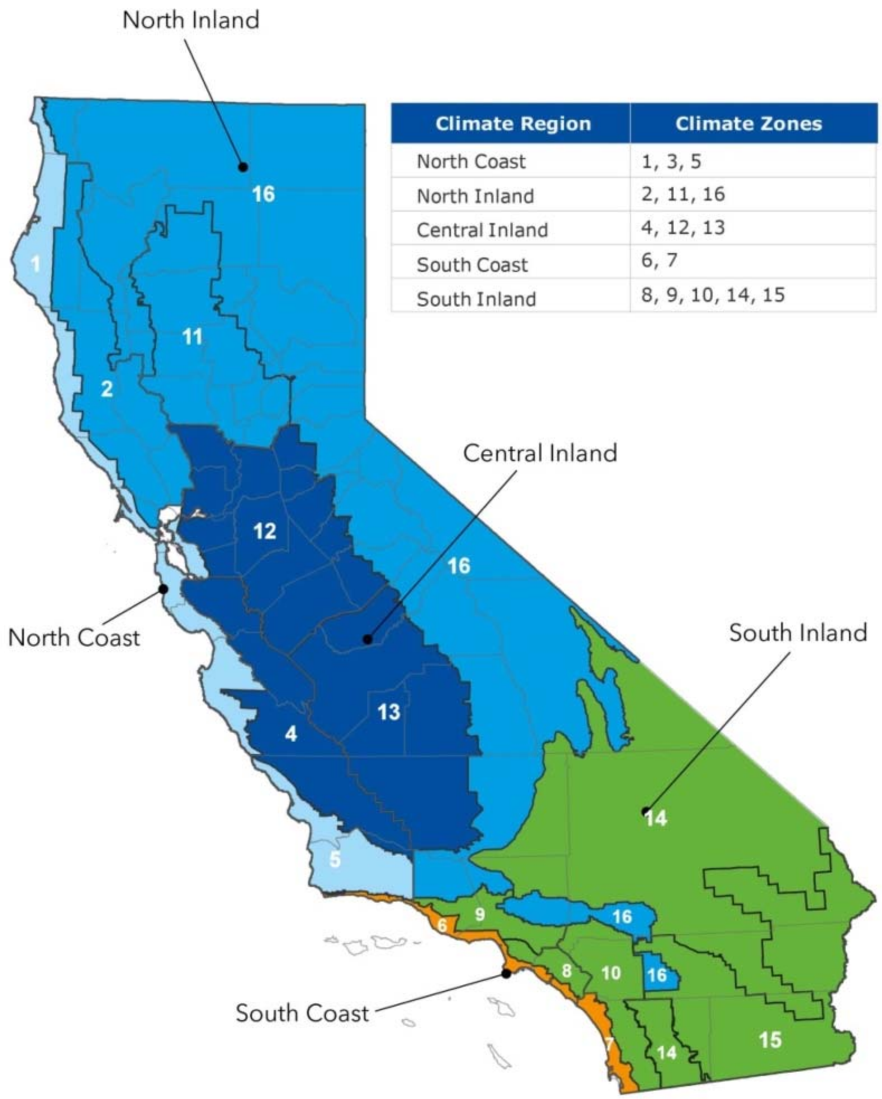
The top-down approach estimated permitting rates for 2014, a period that included a Standards code cycle change.[21] The 2008 Standards applied during the first six months of the year and the 2013 Standards applied during the rest of the year. A key change to the changeout code requirements is that on July 1, 2014, the 2013 code expanded duct testing requirements to all climate zones. Under the 2008 Standards, duct testing was only required in the state's more severe climate zones (2 and 9-16). For the top-down analysis, this meant that certain data sources considered for the study provided only partial coverage during the first half of the year. We also had to consider the possibility that homeowners and contractors, anticipating the code change, may have accelerated obtaining the permit for planned work to avoid the additional cost of complying with the new code.

The California Industry Resource Board (CIRB) began collecting consistent HVAC changeout permit volume data from building departments in 2014. The CIRB data availability ultimately drove our decision to choose 2014 as the analysis year despite the added challenge of the code cycle change.

Due to limitations in the disparate data sources being used in the analysis, we could not obtain statistically reliable data for all 16 climate zones to determine the number of HVAC systems installed. Instead, we used data and evaluated results of five consolidated climate regions comprised of climate zones that share similar geographic characteristics (North Inland, South Inland, Central Inland, South Coast, and North Coast) shown in Figure 1.

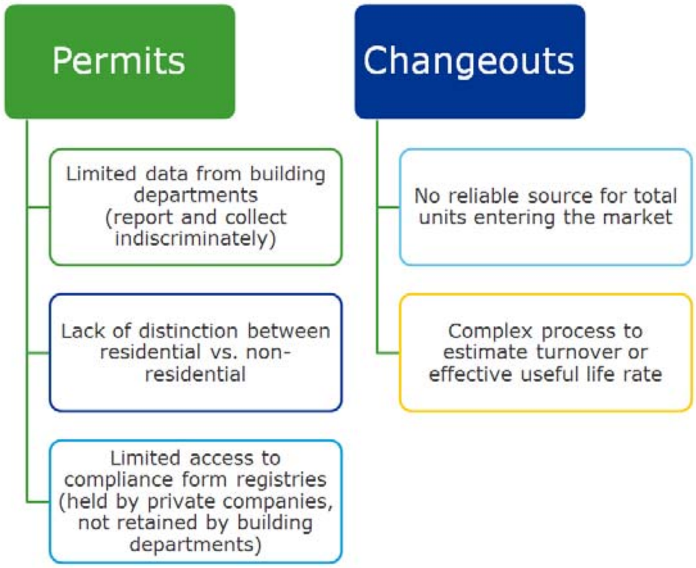
[21] In contrast, the bottom-up analysis below focuses on the extended period 2010 to 2016.

Figure 1. Five climate regions used in the top-down permit rate analysis



Data limitations were a key factor in the design of the top-down methodology. For the calculation of total permits, all the available data sources had significant gaps and limitations. A key element of the study was merging data from the various sources to create the most complete and reliable dataset possible. For the calculation of total permits, the lack of reliable statewide equipment shipment data led us to adopt a complex stock turnover methodology. Figure 2 summarizes the limitations inherent in the permit and changeout data.

Figure 2. Limitations of the data sources in the top-down approach



3.1.2 Estimating the number of residential HVAC changeout units—the denominator

We used an HVAC equipment stock turnover model to estimate the total number of residential HVAC changeout units. The concept involves beginning with annual estimates of residential HVAC units currently installed within the state (stock), then using information about average equipment lifetimes, changes to equipment saturations, and changes to housing stocks to approximate the number of new HVAC units installed annually in both existing and new homes. We used data from the following four sources:

- HVAC equipment saturations from the 2003 and 2009 California Residential Appliance Saturation Surveys (RASS)[22,23]
- The number of California households by county in 2010 and 2014 from the California Department of Finance[24] and total California households from 2000 to 2014 from US Census Data[25]
- Estimated useful lifetimes (EUL) of HVAC equipment from the California Database for Energy Efficiency Resources (DEER) and the US Department of Energy (DOE)[26]
- US historic HVAC shipments by type from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) from 1995 to 2014[27]

The approach gets us from the four sources above to estimated shipments of HVAC equipment over time by type and climate region, disaggregated by new construction, replacement units, and new units in existing buildings (the latter two categories comprising changeouts). This process involves four steps:

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[22] KEMA-XENERGY *et al.*, 2004.

[23] KEMA, Inc., 2010a—d.

[24] California Department of Finance Demographic Research Unit, 2016.

[25] US Census Bureau, 2015.

[26] California Public Utilities Commission, 2016 and Database for Energy Efficiency Resources. http://www.deeresources.com/ and US DOE, 2015.

[27] Air-Conditioning, Heating, and Refrigeration Institute, 2016.

1. Develop estimates of equipment stocks over time by climate region
2. Estimate equipment shipments over time by climate region and equipment type using EUL estimates and assuming that equipment survival rates follow a Weibull distribution[28]
3. Use national-level shipment data to adjust shipments estimates for business cycle effects
4. Disaggregate 2014 shipments into replacement HVAC, HVAC additions to existing construction, and HVAC shipments to new construction

We discuss these steps in detail below.

3.1.2.1 Estimating equipment stocks over time

The 2003 and 2009 RASS studies were an ideal starting point for estimating equipment saturations over time. The large sample size of 25,000 households provided statistically reliable estimates by climate region and equipment type. Having two comparable studies at different points in time let us estimate the change in the saturations of each equipment type over time. The two RASS studies cover most, but not all, of California. They include the service territories of California's four investor-owned utilities (IOUs) and the Los Angeles Department of Water and Power (LADWP). These utilities represented 86% of California households in 2008 when we drew the sample for the 2009 RASS. Lacking an alternative data source for the remainder of the state, we extrapolated the equipment ownership patterns from the regions included in the RASS study to the rest of the state by climate region.

From the RASS data, we estimated the saturation of four key equipment types in 2003 and 2009. Because our primary source of permit data was HERS duct testing, we felt that focusing on ducted systems would provide the appropriate population for comparison. The saturations represent homes with that equipment as their primary heating or cooling system as a percent of the RASS household population for the region.

Taking into account the change in equipment saturations between 2003 and 2009, we interpolated and extrapolated equipment saturations backward to 1984 and forward to 2014. The time series needed to extend so far back in time to accurately represent the mix of vintages present in 2014. For example, a unit sold in 1984 that survived 30 years (a possibility in both real life and the model) would still be present in the stock in 2014.

To get from saturation to the number of units, we combined county-level data from California Department of Finance (for 2010 and 2014) with state-level household counts from the US Census Bureau (2000-14). We aggregated the county-level data up to climate regions, then interpolated to estimate housing stocks between 2010 and 2014 and extrapolated backward to 1984. We combined these estimates with the corresponding saturation estimates to estimate the number of households, by climate region, having each type of equipment of interest from 1984 to 2014. We used the estimate of the number of households as a proxy for the number of HVAC units (assuming one unit per household) for the remainder of the top-down changeout analysis.

3.1.2.2 Estimating equipment shipments based on equipment stocks

Given historic equipment stocks, we can infer shipments given sufficient information regarding equipment lifetimes and survival distributions. In this step of the analysis, we first estimated median equipment lifetimes by equipment type and climate region, then used them to develop probability distribution functions of time to equipment failure. Using these, we disaggregated each year's equipment stock by vintage.

[28] Weibull distribution identifies the probable distribution associated with the lifetime characteristics of system parts or service elements. Reliability engineering often relies on Weibull distribution to predict equipment wear and failure.

3.1.3 Estimating HVAC equipment lifetimes

Available data on equipment lifetimes provides a rough estimate of median equipment lifetime.[29] We conducted a literature review to identify recent retention studies, utility workpapers, and related literature to obtain the necessary lifetime values, but generally found that the DEER captured the best available estimates for most equipment types. The exception, central gas furnaces, have particularly long lifetimes; for instance, DEER caps them at 20 years. For gas furnaces, we used a national-level EUL estimate of 22 years from the DOE.[30]

HVAC usage, however, varies substantially across California's diverse climate zones, which would suggest that HVAC lifetimes should vary as well. We used estimates of full-load hours in each climate zone compared to the state average to modify the state-level EULs up or down to reflect climate region usage. The result was a separate EUL estimate for each type of equipment in each climate zone (CZ). While this is an approximation, we believe it results in more accurate turnover estimates at the climate region level. Table 1 shows the regionally-adjusted EUL that we used for the stock turnover calculations.

Table 1. EULs by climate region and equipment type

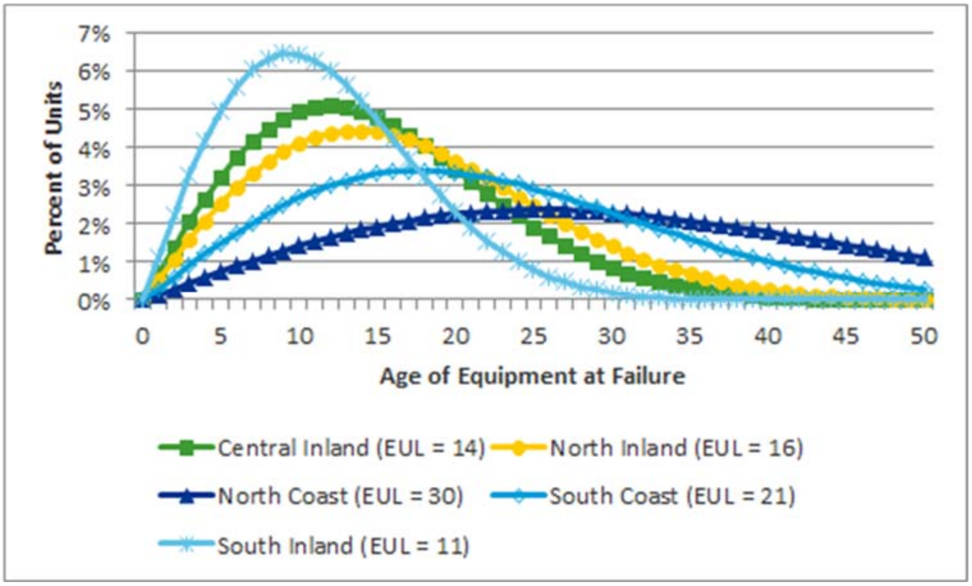
Climate regions	Equipment type			
	Central Air Conditioner	Central Heat Pump	Central Natural Gas Furnace	Central Electric Furnace
North Coast: CZ 1, 3, 5	30	30	17	15
North Inland: CZ 2, 11, 16	16	16	17	16
Central Inland: CZ 4, 12, 13	14	14	23	21
South Coast: CZ 6, 7	21	21	19	17
South Inland: CZ 8, 9, 10, 14, 15	11	11	27	25

The EULs were only a starting place for equipment lifetimes in the analysis. In real life, the lifetimes of individual units vary widely, with some units failing soon after installation while others keep operating for decades. Rather than assume a simplified point estimate for equipment life, we assumed that equipment lifetimes followed a probability distribution.

The Weibull distributions used in the analysis have two parameters: a shape parameter and a scale parameter. For all equipment types and climate regions, we set the shape parameter to 2 for a distribution showing few failures initially, increasing to higher levels near the EUL, and then declining. The distribution is skewed, with the mean higher than the median. The scale parameter determines how stretched out the distribution is over time. We set the scale parameter for each equipment type and climate region so that the median of the distribution matched the EUL in that region. Figure 3 shows the probability distributions used for central air conditioners and heat pumps, by region. We provide similar charts for the other equipment types in Appendix A.

[29] The estimated useful life (EUL) for equipment represents the age at which half of units are expected to have failed.
[30] US DOE, 2015.

Figure 3. Probability distribution of lifetimes for central air conditioners and heat pumps



If the HVAC population were in equilibrium, we would estimate the expected number of changeout units for a given year by multiplying the stock by the average failure rate. However, the number of HVAC units within California is growing, due to both increases in the housing stock and in equipment saturations in existing homes (especially cooling equipment). Therefore, we needed to take into account the mix of equipment ages in the current stock to accurately assess the expected failure rate in 2014. Fortunately, the two RASS surveys provide the data necessary to estimate the change in saturations over time. This, combined with changes to the overall housing stock over time, allowed us to extrapolate both the equipment stocks (by type) and mix of equipment vintages in 2014.

The first year of our stock turnover model was 1984, which was older than the highest median equipment lifetime used in the analysis. For 1984, we estimated a mix of equipment vintages to be consistent with our assumed Weibull distribution. From that point forward, the model tracked the equipment stocks by vintage, replacements, and new equipment. Equipment that was new in 1984 became 1985's one-year-old equipment, after subtracting out the (very few) failures of that new equipment in the first year as predicted by the Weibull distribution. The stock turnover model tracked each cohort over time, reducing the number of surviving units each year according to the Weibull distribution. We calculated the number of new units (shipments) each year as the estimated stock in that year minus the total of the surviving units.

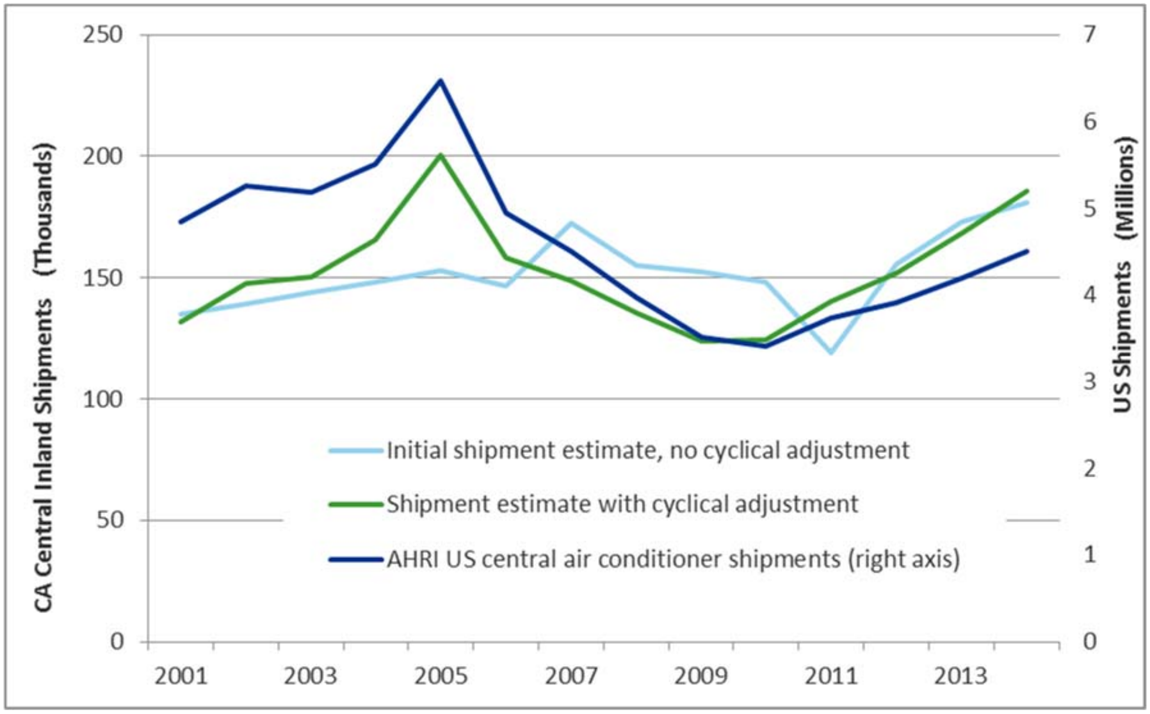
3.1.3.1 Accounting for cyclical sales of HVAC equipment

Like other durable goods, HVAC equipment sales tend to be cyclical. During bad economic times, people often choose to repair rather than replace large equipment such as HVAC when there is an equipment failure. Also, in economic downturns, homeowners are less likely to make major renovations or additions to their homes. Conversely, in good economic times, the decision might be to replace rather than repair. The result is that sales of HVAC equipment can vary widely from the peak of a sales cycle to the trough.

The stock turnover approach discussed above produced annual estimates of total changeout units based on a typical distribution of equipment lifetimes. These estimates show some cyclicality because they are based on historic housing stocks (which reflect the effects of past business cycles). But the year-to-year variation in changeout units predicted by the stock turnover model was out of sync with real-world business cycles because they were based on an algorithm that ignores economic factors.

We used US shipments by equipment type from 1995 to 2014 from AHRI[31] to capture cyclicality in HVAC shipments. We developed statistical models to bring the out-of-sync cycles from the stock turnover shipment estimates in line with the real-world cycles represented by the AHRI data. Appendix A presents the details of these analyses. Figure 4 shows the result of this process for a sample combination of equipment type and climate region (central air conditioning in the South Inland climate region).

Figure 4. Cyclical shipment adjustment, central air conditioning in the South Inland climate region



3.1.3.2 Categorizing changeout units: replacements vs. additions

Our stock turnover analysis provided the means to create credible estimates of replacements in existing homes, new equipment in existing homes (since the model incorporated changing equipment saturations over time), and equipment installed in new construction. We used this approach to disaggregate estimates of new units installed in new homes, replacement units installed in existing homes, and new units installed in existing homes, including altered space.

31 These data are available to the public and represent shipments from 300 US manufacturers for central air conditioners and air-source heat pumps. The total number of US HVAC shipments is available per month and per year by rated capacity ranges (Btuh bins, e.g., 22–26.9 Btuh). AHRI data does not represent all manufacturer shipments; according to AHRI's statisticians, approximately 93% of their 300 members report shipments and membership is limited to manufacturers that produce of a certain volume of equipment. Small manufacturers are not eligible, although the threshold for AHRI acceptance is not publicly available.

3.1.3.3 Total changeout unit results

Total changeout units include replacement units, new units to existing space, and altered space HVAC systems. While our analysis did not distinguish altered space units from units added to existing spaces, we captured both in our estimate of new units installed in existing homes. To determine total changeout units, we simply added our estimate of replacement shipments to our estimate of units added to existing homes, excluding only shipments to new construction.

Table 2 summarizes total changeout units by system type and climate region in 2014. Central cooling in the South Inland region accounted for the largest share of total changeouts in 2014 at 34% across all equipment types. This is not surprising: not only did the South Inland climate region represent the largest share of households of all the climate regions at 40%, but it is also the hottest of the five climate regions. It represented 59% of all central cooling changeouts in the state in 2014.

Because furnaces have longer lives than central cooling or heat pumps, they represented a smaller share of 2014 changeouts (37% of total changeouts statewide) than of total equipment (about 52% of total changeouts).

Table 2. Summary of total changeout units by system type and climate region for 2014

Climate regions	Central Air Conditioner	Central Heat Pump	Central Natural Gas Furnace	Central Electric Furnace	All System Types
North Coast: CZ 1, 3, 5	8,001	5,180	46,872	6,124	**66,177**
North Inland: CZ 2, 11, 16	47,043	1,240	41,266	5,578	**95,126**
Central Inland: CZ 4, 12, 13	168,823	11,578	82,557	8,979	**271,937**
South Coast: CZ 6, 7	37,386	3,844	51,392	6,167	**98,790**
South Inland: CZ 8, 9, 10, 14, 15	370,024	23,813	130,748	19,074	**543,659**
Total	**631,277**	**45,655**	**352,835**	**45,922**	**1,075,689**

3.1.4 Estimating the number of permits issued—the numerator

We used two data sources for estimating permitted HVAC changeouts: HVAC changeout permit data from CIRB Reports[32] and data on HVAC alteration certificates from the primary HERS Provider, CalCERTS:[33]

- The CIRB Reports include an organized dataset of HVAC changeout permit counts, including counts of HVAC units installed, sourced from building departments throughout the state, but it has some limitations. The annual permit changeout report does not distinguish residential from commercial permits or replacements from building additions. In some cases, building departments did not provide HVAC permits to CIRB separately from other types of mechanical permits; these are characterized as "mechanical only."

[32] The CIRB Report, a research service provided by the California Homebuilding Foundation (CHF), provides current and historical statewide building permit data by city, county, and metropolitan statistical area. For more information, visit http://www.mychf.org/about-cirb.html.

[33] CalCERTS, Inc. was the HERS Provider sourced for this study. We requested the same data from USERA, but were unable to obtain it.

- The HERS certificate data, in contrast, focuses on precisely the subset of HVAC installations of interest for this study: residential changeouts. Like the CIRB data, it provides counts of permits and of HVAC systems. However, the HERS data has its own limitation: it covers only part of the state for the first half of 2014. Additionally, the HERS Registries did not provide every HERS certificate for 2014 to support this study.

Table 3 summarizes the advantages and disadvantages of each of these two sources.

Table 3. Overview of CIRB and HERS data sources

	CIRB Permit Report Data	HERS HVAC Certificate Data
Source	California Home Building Foundation CIRB Reports	HERS Providers (Residential HVAC Alteration Certificate Counts for 2014)
Description	2014 annual permit statistics reported by city and county building departments to CIRB	2014 HERS Certificate counts from the HERS Registry collected from field inspections (HERS Raters) as required under Standards
Advantages	•Substantial coverage of the state building departments •Provided affordable and efficiently organized data •Active engagement by CIRB staff •Permit data directly from building departments without the cost of direct collection •Systematically collected and organized permit records non-standard formats	•Inspection data is specific to the residential sector •Data only includes changeouts, not new construction
Disadvantages	•Permit statistics were not available for all building departments •Permit statistics not consistently reported •Reported data may not identify residential vs. non-residential or HVAC permits vs. mechanical permits more generally •Permit activity cannot be isolated to a specific type of HVAC replacement (e.g., due to an addition vs. a one-for-one replacement)	•Data is for inspections, not permits •Incomplete coverage for the first half of the year •Limited accessibility, only one of two HERS Providers supplied Registry data •Certificates are not required for all installation types*

*The Standards require HERS inspections for ducted systems (all CZs under the 2013 code; zones 2 and 9 to 16 only under the 2008 code). Inspections were required for split systems (refrigerant charge in zone 2 and 8 to 15; minimum airflow and maximum fan wattage inspections were required only in zones 8 to 15 under the 2008 code, but that was expanded to all zones under the 2013 code). The Standards do not require inspections for non-ducted systems e.g., wall furnaces, ductless split-systems, room air, and boilers.

Due to the mix of advantages and disadvantages associated with each dataset, we opted to use a combination of data from HERS Providers and CIRB. The HERS data became our primary data source for the climate zones (CZs), and aggregated climate regions, and timeframes for which it offers complete coverage (CZ 2 and 9 to 16 have full-year data; CZ 1 and 3 through 8 have reliable data only for the second half of the year). We filled in the data gaps using CIRB data.

Appendix B presents the raw HERS Registry data and the extrapolated statewide values.[34] Appendix C presents permit counts sourced from CIRB data, the supplemental data collected through calls to non-reporting building departments, and our estimate of residential changeouts based on the CIRB data. Both appendices provide some additional information about the nature and coverage of the data.

The next two sections provide more detail on the two datasets and how we used them. Then we discuss in detail how we combined the data from the two sources to estimate total permits for 2014.

3.1.4.1 Permit rate estimates using HERS HVAC certificate data

A HERS certificate is a good proxy for a finalized permit and, unlike CIRB data, HERS data focuses on residential dwellings. However, due the timeframe of the study and a change in the Standards code, HERS data for the first half of 2014 only covers part of the state.

We purchased data from CalCERTS, Inc. (the leading HERS Provider), which represents 95% of HERS inspections performed in the state. The data represented the total number of HVAC alteration certificates by building department separately for the first and second halves of 2014. To extrapolate to the entire state by climate region, we first estimated the number of omitted inspections (CalCERTS inspections divided by 0.95 minus the number of CalCERTS inspections). We then distributed those permits proportionately to building departments in CZs 10, 12, 13, and 15 based on the number of households. USERA, which holds the majority of the remaining 5% market share for HERS Providers, is most active in those four climate zones.

We believe that the HERS data provides a reasonable estimate of permits (and corresponding unit counts) for the full year for CZs 2 and 9 through 16, and for the second half of the year in the remaining zones. To fill in the missing data, we turned to the CIRB data, discussed in the next section.

3.1.4.2 Permit rate estimates using CIRB permit report data

CIRB Reports contain HVAC changeout permit statistics for a significant volume of city and county building departments. The initial CIRB dataset included data for 69% of the building departments in California, representing 72% of households.

To address the coverage limitation of the CIRB data, we provided funding for a CIRB staff member to follow up with a prioritized list (based on number of households) of building departments to expand the coverage of the data. The final dataset covered 81% of building departments and 75% of households in California.

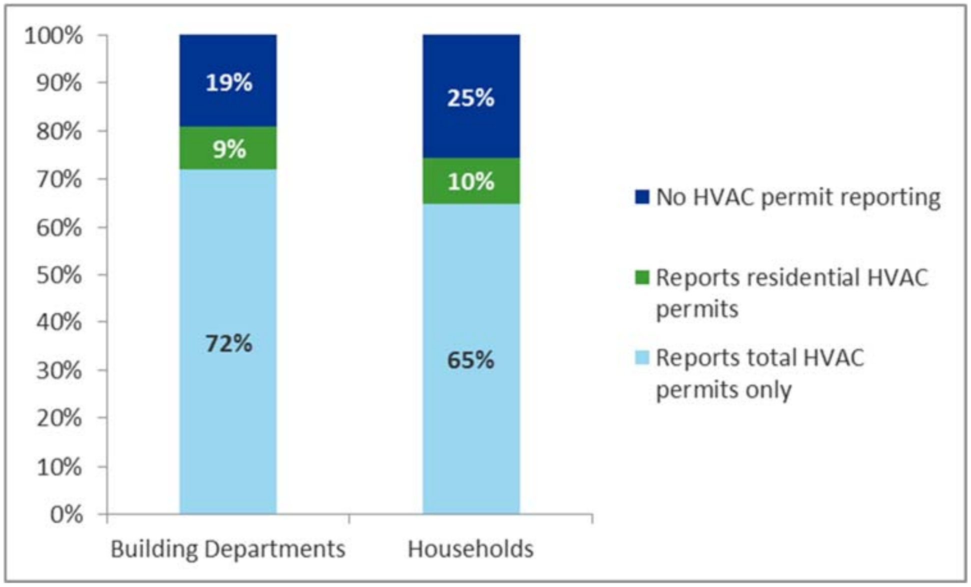
The level of detail provided by the reporting building departments was mixed: some provided only permits for new construction or for undifferentiated mechanical permits, for example. We considered trying to apply some assumption to break out the mechanical permits into HVAC and other, but ultimately decided that process would add complexity without adding any real improvements to the overall estimates. We combined the two groups as “No HVAC permit reporting”. The remaining building departments reported either residential or commercial HVAC permits separately or only total HVAC permits.

Only 48 of the total 538 building departments reported residential permits separately. For the 387 building departments that only reported total HVAC permits, it was necessary to break out residential permits. For each of the 48 building departments that provided residential and commercial HVAC permits, we calculated the percent of combined HVAC permits that were residential. We then calculated the simple average of these

[34] We only received HERS inspection data from CalCERTS, which covers 95% of the state. We extrapolated that data to the remaining 5% of the state.

values and applied the resulting ratio to total HVAC changeout units for the remaining building departments to estimate residential changeouts.

Figure 5. Building departments reporting to CIRB by type of permit data



Because we used the HERS data as our primary source, the missing CIRB data only became a problem if it coincided with a gap in the HERS data. We discuss the combined coverage of the two datasets in the next section.

3.1.4.3 Combining the HERS certificate and CIRB permit data

Using the CIRB and HERS datasets, we developed five sets of overlapping estimates of permitted units at the building department level and combined them into a final estimate. For consistency with the denominator, we used the data on the number of permitted units rather than the number of permits.[35] The estimates included:

1. **CIRB-based permitted unit count for the full year:** Reliable counts of residential permitted equipment for 48 building departments and estimates of residential permits for another 387 building departments
2. HERS-based permitted unit count for the first half of the year: Reliable estimates for CZs 2 and 9 through 16
3. **CIRB-based permitted unit estimate for the first half of the year:** Same as the full year data, but estimating the share of permits issued in the first 6 months of the year (to use in combination with half-year HERS data)
4. HERS-based permitted unit count for the second half of the year: Reliable estimates for all climate zones

[35] There can be multiple units per permit in cases where cooling systems and heating systems are replaced simultaneously, or when a permit covers work in multiple units of a multifamily building. Statewide, there were 1.09 units installed per permit.

5. **CIRB-based permitted unit estimates for the full year based on mechanical permits:** The least reliable of the various estimates, as it required estimating the share of unspecified mechanical permits that were for residential changeouts (used only for a small number of building departments with no other data)

Each of the five estimates provided only a partial picture of total permitted units. Some represent only part of the year while others have gaps and omissions. For example, HERS might report zero inspections for a building department, while CIRB reports that permits were issued from that department. Appendix D shows the values for each of the five components for each building department. We used a combination of all these estimates to create the most comprehensive estimates possible.

Section 3.1.4.2 above discusses the estimates numbered 1, 2, and 4 in the above list. To develop estimate number 3 (partial-year permitted units using the CIRB data), we leveraged the data from the many building departments for which we had HERS data for both the first and second half of the year. For each building department with a full year of HERS data, we calculated the percent of permitted units that were issued in the first half of the year. We aggregated from building departments to climate zones and climate regions. Because the HERS requirements are by climate zone, we were unable to calculate a ratio for climate zones 1 and 3 through 8, or for the North Coast or South Coast climate regions. For CZs 4 and 8, we assigned those zones the average value for their regions (Central Inland and South Inland). For the remaining climate zones, we assigned the average value for an adjacent climate region (North Inland for North Coast, and South Inland for South Coast). We then assigned each building department a "first half of the year share" based on its climate zone.

We applied these shares to our estimates of 2014 residential HVAC changeout units from CIRB to get an estimate of residential permitted units in the first half of the year.

To estimate component 5, we assumed that building department reporting only unspecified mechanical permits had reported both HVAC changeouts and other mechanical permits under that combined value. We looked at building departments that reported changeouts separately from unspecified mechanical permits and estimated the ratio of residential changeouts to total HVAC and mechanical permits for those building departments. We applied the resulting ratios, averaged by climate region, to the unspecified mechanical permit counts to create a rough estimate of residential changeouts for those building departments.

Once we had calculated all five estimates, we combined them into what we believe are reliable estimates for each building department. Our initial estimate of full-year permitted units combined the HERS data for the second half of the year with the HERS permitted unit estimate for the first half of the year for CZs 2 and 9 through 16, and with CIRB permitted unit estimates for the first half of the year for CZs 1 and 3 through 9. However, this initial estimate left 35 building departments with zero permitted units for the year. For these remaining building departments, we filled in data using the full-year CIRB data and mechanical permit data using a process described in detail in Appendix A.

Based on this analysis, Table 4 shows the estimated number of permitted residential HVAC changeout units in 2014 by climate region.

Table 4. Estimated 2014 permitted residential HVAC changeout units by climate region

Climate region	2014 Permits
North Coast: CZ 1, 3, 5	2,986
North Inland: CZ 2, 11, 16	10,606
Central Inland: CZ 4, 12, 13	33,369
South Coast: CZ 6, 7	7,554
South Inland: CZ 8, 9, 10, 14, 15	31,082
Statewide	**83,241**

3.1.5 Summary permit results using the top-down method

In sections 3.1.2 and 3.1.4 above, we estimated the total number of residential HVAC changeout units and the number of permitted residential changeout units issued in California in 2014 by climate region. Using those estimates, it is fairly straightforward to calculate the corresponding permit rates using Equation 1, above.

Table 5 shows the estimated number of permits, total changeouts, and the calculated permit rate by climate region. The permit rates are low, ranging from 4.5% in the North Coast region to 12.3% in the Central Inland region. The low permitting rate supports the widespread beliefs among stakeholders regarding the low level of compliance with code requirements for HVAC changeouts.

Table 5. Residential permits, total HVAC changeouts, and permit rate by climate region, 2014

Climate region	2014 Residential HVAC Changeout Permits	2014 Residential HVAC changeouts	Permit Rate
North Coast: CZ 1, 3, 5	2,986	66,177	4.5%
North Inland: CZ 2, 11, 16	10,606	95,126	11.1%
Central Inland: CZ 4, 12, 13	33,369	271,937	12.3%
South Coast: CZ 6, 7	7,554	98,790	7.6%
South Inland: CZ 8, 9, 10, 14, 15	31,082	543,659	5.7%
Statewide	**85,597**	**1,075,689**	**7.9%**

3.2 Bottom-up estimation approach

Our second approach to estimating the permit rate involved a bottom-up approach. This method relies on customer surveys that asked respondents to identify whether they changed out an HVAC unit in 2010 or later. We then extrapolated this permit rate to the population. The bottom-up permit rate calculation relies on two key metrics:

- The total number of HVAC changeouts (denominator)
- The total number of permitted HVAC changeouts (numerator)

The surveys served two purposes:

- Providing the denominator for the bottom-up permit rate calculation
- Identifying households eligible to participate in the on-site compliance inspections[36]

We estimated the numerator (total number of permits) through permit record requests from local building departments. We estimated the denominator (total number of units installed) using customer self-reports.

3.2.1 Survey methodology

To estimate total changeouts, we conducted mixed-mode surveys (telephone and online) that asked respondents about a list of home improvement projects completed after January 1, 2010.[37] The sample of residential investor-owned utility (IOU) customers reported whether their HVAC system or unit had been changed out (replaced or newly installed). Given the typically low incident rate of a changeouts (equipment can last at least 15 years), DNV GL opted to use survey results collected from the 2009 Residential Appliance Saturation Survey (RASS) to identify households that were more likely to have changeouts requiring permits and qualify for this study's survey. As the implementation contractor for the 2009 RASS study, we were able to target households within the RASS survey respondents based on data about their heating and cooling equipment (including system type, fuel type, approximate age and whether the household paid for their gas and/or electricity).

Once we identified eligible participants from the RASS survey, we fielded the survey in phases over a 16-month period from May 2015 through mid-September 2016. More than 1,400 households participated in the survey, with almost 1,000 completing the survey online and the remaining by telephone. The survey targeted eligible equipment and approximately 24% of the respondents claimed to have an HVAC changeout of one type or another during or after January 2010.

While we reference this research effort within the study team as the Market Assessment Permit and Compliance survey (MAPC), we presented it to survey respondents as the "California Home Improvement Survey." We were concerned that if potential respondents knew the survey intent was to measure the rate of permitting for HVAC changeouts and compliance with the Standards, it would bias their responses. We also rejected the idea of using the survey to ask whether the respondent had obtained a permit for eligible changeouts. Our specific concerns about response bias included:

- Households that completed unpermitted home improvements would be less likely to respond
- Households might not report improvements that were not permitted

As a result of these concerns, the survey was designed and administered without mentioning permitting in any way, and focused only on collecting data on total changeouts of eligible equipment. We collected permitting data through an independent search using web-based lookups and calls and visits to building departments. The primary means used were public records requests via phone or email with web-based options available some times and visits only required in select cases (very busy and rural).

To further reduce potential bias, the survey included a short list of home improvement projects (e.g., building shell improvements and efficient hot water heaters) to detract from the study's focus on permitting for HVAC changeouts. The complete set of survey questions is provided in Appendix E.

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[36] For the on-site compliance inspections, we supplemented the MAPC sample frame with a sample of general population households, as described in the section of the report that covers the compliance inspections.

[37] On January 1, 2008, New Title 24, Part 6 Energy Efficiency Standards came into effect. The requirement to initiate permitting for HVAC changeouts has been clear sine the 2005 code cycle. Title 24, Part 6 has been updated on a 3-year to-5-year cycle since the 1990s and major HVAC measures were added in 2001, 2005, and 2008, and 2013 cycles.

If respondents reported that they replaced an existing heating or cooling system or added a new one, we asked the following questions:

- Did you replace or add a heating system, cooling system, or both?
- [If applicable] What type of heating system(s) did you replace or add?
- [If applicable] What type of cooling system(s) did you replace or add?
- Was the new heating (or cooling) system(s) a replacement or an additional unit added to the existing system?
- When you made improvements to your heating (or cooling) system(s), did you or your contractor select similar equipment, or did you install a different type of equipment?
- Did you receive a rebate from your utility provider for the improvement(s)?
- Please indicate the year in which you made the upgrades.
- Please indicate which season in which you made the upgrades.

We used this information to identify whether the changeout likely required a permit.

3.2.2 Sample frame

We based the initial sample frame on information obtained on residential dwellings from study participants in the 2009 RASS.[38] RASS survey respondents included 25,721 households representing the electric customers of Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), San Diego Gas and Electric Company (SDG&E), LADWP, and LADWP with Southern California Gas Company (SCG) services.[39] To obtain the desired MAPC households, we removed some RASS respondents from the MAPC sample frame based on specific criteria that would exclude households from permit requirements or change the requirements, as described below:

- Electric master-metered households

  Households not within IOU service territory (i.e., LADWP electric customers without gas service from SCG)

  Mobile homes, as permitting requirements for this housing type is beyond the scope of this study

  Homes having no qualified equipment (i.e., without at least one of the following: natural gas or electric forced air heating system or central forced air cooling system)

- Homes with LADWP electric service without gas heating system
- Gas master-metered households without central forced air cooling systems
- Households currently without an active service agreement with at least one of the four IOUs, and thus, no contact information was available
- Households on the "Do Not Contact" list for their IOU

Table 6 shows the exclusions we applied in developing the MAPC survey sample frame from all 2009 RASS respondents. The table shows the number of households removed from the original RASS population with each refinement to the sample frame, the number of remaining RASS households, and the corresponding weighted number of households that the sample households represent. The initial RASS population included

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38 We implemented the 2009 RASS study as a mail survey with an option for respondents to complete the survey online. The survey requested households to provide information on appliances, equipment, and general consumption patterns. We completed data collection in early 2010. For more information, visit http://energy.ca.gov/appliances/rass/index.html.

39 The RASS dataset comes from IOU and LADWP customer accounts active in 2008. The sample strata included electric service provider, presence of electric heat and energy forecasting zone.

25,721 households (which weight up to 11,523,719 households at the population level). After removing the households in the categories listed above from the RASS population, the resulting MAPC survey sample frame included 16,526 households (representing 7,236,650 households at the population level).

Table 6. MAPC sample frame development

Description and Steps	Number of Households Removed from Sample Frame (Unweighted)	RASS	
		Unweighted Number of Households	Weighted to Population
Total RASS population	-	25,721	11,523,719
Removed electric master-metered	1,257	24,464	11,093,798
Removed LADWP customers without SCG service	239	24,225	10,954,075
Removed mobile homes	857	23,368	10,751,580
Removed homes without any qualified equipment	6,414	16,954	7,473,364
Removed LADWP customers with SCG service, but no gas heat	264	16,690	7,342,055
Removed gas master metered without qualified cooling system	37	16,653	7,327,842
Removed households with no current active service account	50	16,603	7,289,049
Removed households on IOU Do Not Contact list	77	16,526	7,236,650

Using the 2009 RASS survey data helped us to identify households with eligible equipment and reduced the cost of screening customers for the MAPC study. We leveraged information collected by the RASS about the household heating and cooling equipment types and vintages to target the MAPC households with equipment of interest (i.e., equipment requiring a permit for a changeout). Recognizing that since the 2009 RASS survey was conducted, occupant turnover should be expected, we requested current customer account information from the four IOUs.

Initially we targeted households with older equipment, expecting them to be more likely to have replaced their aging equipment. However, due to low initial replacement rates, we removed this restriction and attempted to contact all households with eligible equipment regardless of vintage.

The RASS survey also provided sample weights that could be applied to the MAPC survey data. The RASS weights date to 2008 when we developed the RASS strata. Due to changes in the number and distribution of California households, we assessed the value of updating the RASS weights to better align with the current California population before applying them to the MAPC responses. Ultimately, we decided to proceed with using the RASS weights without updating for a couple of reasons. The sampling plan for the RASS was complex, and updating the weights would be a large project in its own right. Also, researchers expected the error introduced by using the original weights to be small relative to other sources of uncertainty in the bottom-up permit estimate.

3.2.3 Permit record search

Once we identified the households that reported eligible HVAC changeouts during the MAPC survey, we independently verified the permit status for each installation (excluding portable units) through public records requests to local building departments or through online permit records, telephone calls, and/or in-person visits. We trained the rresearchers charged with investigating permits to ensure that they performed the assessments consistently. There were two possible dispositions for each search performed:

- Mechanical permit found - with subcategories of open/closed status (final)
- Mechanical permit not found - no evidence of a HVAC changeout permit on file

In this section, the bottom-up permit rate does not distinguish between closed and open permits; all permitted projects are treated as "permitted" regardless of their status as open or closed. The permit identification process *for the entire study* represents more than 200 unique city and county building departments with more than 400 installations researched for the presence of a permit (although not all were included in the bottom-up data set). Among the installations, permit searches were performed through the following methods: filing public record requests (45% of the population), online searches (38%), telephone (15%), mixed-mode and/or in person (3%).

Another approach to identifying HVAC installations that began the permit process is through a review of HERS Registry data. We cross-referenced the MAPC sample with the largest HERS Provider Registry. However, a project's absence from the Registry did not guarantee that a permit was not issued, as some building departments were either not actively enforcing the HERS certifications, Installers were claiming the "sampling" approach, or the installation would not have triggered a HERS certificate. Additionally, a few projects were identified as existing in the HERS Registry but the initial searches for a permit resulted in "permit not found" and for these cases, we reversed the permit status. This gap occurred among online permit searches, as some building departments are still in the process of uploading their permits to online systems. We omitted the installations identified solely through the HERS Registry from the bottom-up permit rate extrapolation since they were not tied to the RASS sample weights. For consistency, we only counted permits associated with self-reported changeouts.

To facilitate the discussion of the bottom-up permit rate results, Figure 6 illustrates the relationship between the RASS sample frame, RASS respondents, the MAPC sample frame, and the two sets of responses of interest (changeouts and permitted changeouts).

Figure 6. Populations of interest in the analysis

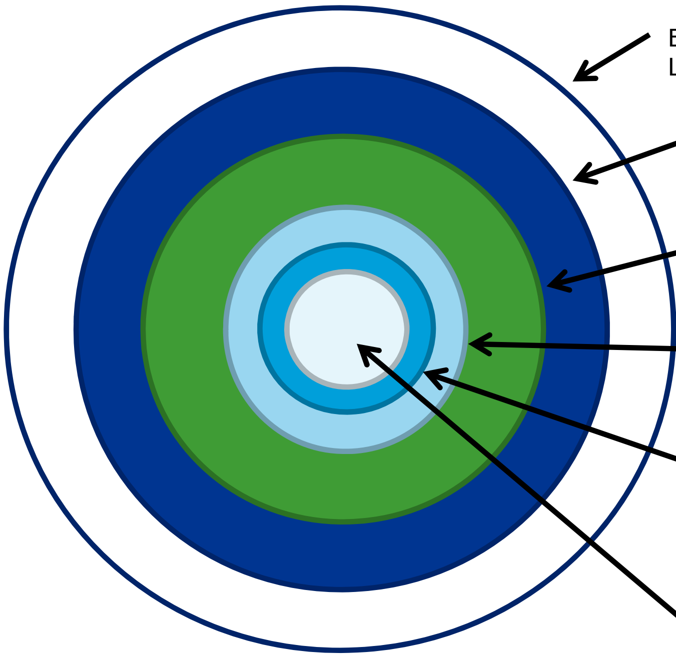


Table 7 presents the unweighted sample and weighted populations associated with the RASS study, the MAPC sample frame, MAPC respondents, eligible equipment changeouts, and permitted changeouts.

Table 7. MAPC sample frame, eligible changeouts, and permit search results

Description	RASS Sample and Weighted Population	
	Sample	Weighted
Total RASS population	25,721	11,523,719
MAPC sample frame	16,526	7,236,650
Number of completed MAPC survey respondents	1,461	532,924
Number of respondents with verified and eligible changeouts	324	108,071
Number of changeouts with permits found	95	31,034

3.2.4 Summary permit results using the bottom-up method

We calculated the permit rate by dividing the weighted number of respondents with self-reported permitted changeouts by the weighted total number with changeouts.

Equation 2. Bottom-up weighted permit rate results

$$Permit\ \ Rate = \frac{Permitted\ \ Changeouts}{Total\ \ Changeouts} = \frac{31{,}034}{108{,}071} = 28.7\%$$

3.2.5 Limitations to the bottom-up approach

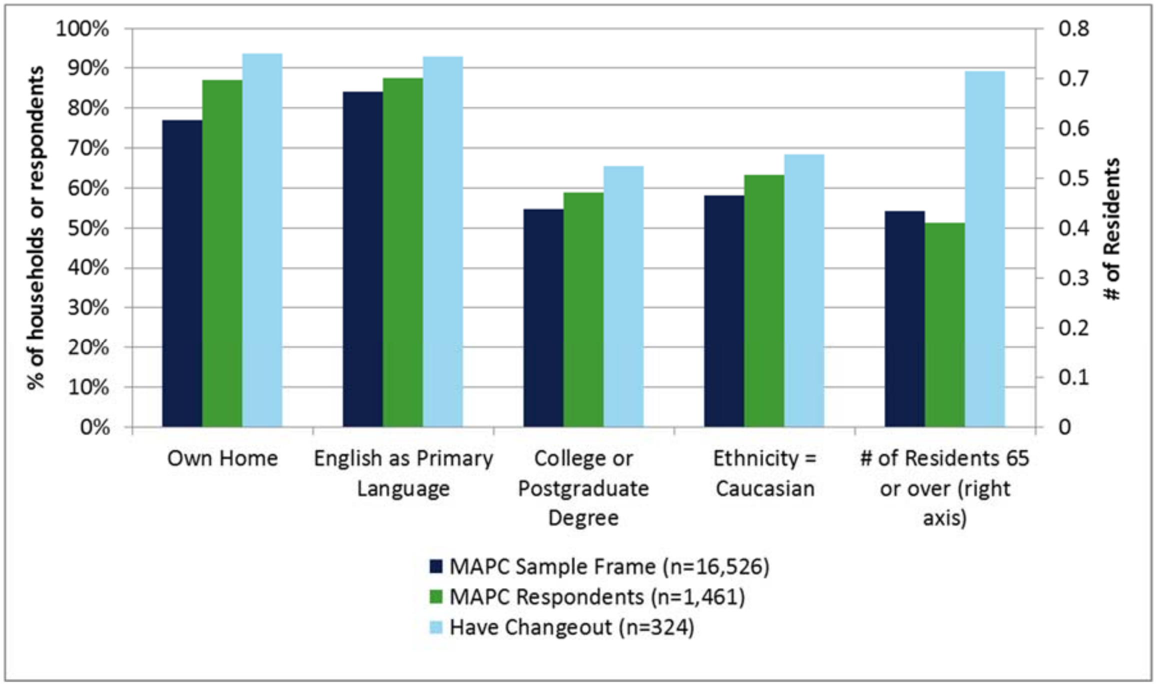
The most important limitation to the bottom-up approach was the possibility of response bias. We looked at the possibility of response bias in two key areas:

- Response bias related to respondent demographics (such as differences in income, age, and/or primary language)
- Strategic response bias (permitting scofflaws either refusing to do the survey or lying on the survey about any unpermitted changeouts

To investigate demographic response bias, we compared the demographic characteristics of the MAPC sample frame to both the MAPC survey respondents and to the survey respondents who reported a changeout. We found differences in demographics across the three groups, as Figure 7 shows. Using RASS respondents as the sample frame may have exacerbated the bias. The MAPC survey reflects its own internal response bias on top of whatever response bias may have been embodied in the RASS respondents. Appendix F presents the full results of the demographic analysis.

The over-represented groups may be more likely to obtain a permit than under-represented groups, and may be more likely to report having a changeout as well. Compared to renters, homeowners may be more likely to remember and report a changeout due to lower resident turnover and also greater willingness to invest in the replacement process (the financial investment as well as time and effort in locating a contractor). Higher resident turnover in rental units may suggest that the survey respondent was not present for the full period of interest, and may not be aware of past work. Higher rates of home ownership and higher education levels could skew the permit rate upward. Response rates also skew away from households where English is not the primary language. Since language is a potential barrier to both understanding permitting requirements and navigating the permitting process, underrepresenting these households may further overstate the permit rate.

Figure 7. Demographic characteristics of MAPC sample frame vs. respondents



In addition to typical concerns about demographic response bias, we were also concerned that the subject matter of code compliance would introduce bias into the responses. We designed the survey to conceal our interest in permits in order to avoid, to the extent possible, underreporting of changeouts by those who had performed work without a permit. Despite our efforts, it is possible that homeowners with unpermitted work were less likely to respond, or responded but were dishonest in their answers related to unpermitted work.

Determining if, or the degree to which, systematic non-responses or misreporting biased the implied changeout rate or the estimated permit rate proved to be challenging. There are four factors that can all cause similar effects:

- Strategic non-response. Households with unpermitted work decline to respond to the survey
- Strategic misreporting. Survey respondents with unpermitted work do not report the unpermitted changeout
- Accidental misreporting. Survey respondents do not report changeouts either because they do not remember (either the changeout or the date of the changeout) or were not aware of the changeout (for example, due to resident turnover)
- Sample bias. As we have discussed earlier, the characteristics of the respondents could result in different changeout and permitting rates than the population

Of the four possible explanations, strategic non-response and strategic misreporting would lead to an overestimate of the permit rate. The omission of these changeouts decrease the denominator in the permit rate calculation, while the permit count stays the same.

Accidental misreporting would reduce the rate of reported changeouts. The survey relies on respondents accurately reporting work done up to six-and-a-half years previously. Even if the respondent has been in the home for the full period of interest, he or she may not recall work that was done, or may not include it because they misremember the date. If the respondent was not present in the home for the full period of interest, they may be unaware of changeouts done prior to their occupancy.

While it would definitely affect the estimated changeout rate, accidental misreporting would not introduce bias into the permit rate estimate, as long as such misreporting was proportional across all changeouts, permitted and unpermitted. However, due to sample bias, that may not be the case. The differential turnover rates between renters and homeowners, combined with the overrepresentation of homeowners among respondents, opens the possibility of bias in the permit rate. However, it is unknown which group is more likely to obtain a permit: owner/residents or owners of rental units. While there may be a systematic distortion, we do not know the direction or magnitude.

Sample bias, as we have discussed could skew the permit rate upward. Its effect on the changeout rate are less clear. Replacements due to equipment failure are unlikely to be affected by demographics, but new equipment in existing spaces, or changeout due to major remodels, could be higher for some demographic groups.

To cast some light on the possibility of strategic response bias (both non-response and misreporting), we looked at the changeout rate implied by the MAPC survey. Based on the survey results, just over 20% of households had a changeout between the beginning of 2010 and the time of the survey, which is approximately six years.[40] For respondents misreporting that they had no changeout (whether strategically or accidentally) or strategic non-response to explain a significant portion of the difference between the top-down and the bottom-up permitting rate, the actual changeout rate in the survey sample would have had to be much higher than 20%.

To assess whether that was the case, we compared the reported changeout rate from the MAPC survey to an independent estimate of changeouts. We used the stock turnover analysis of the top-down permit rate analysis to estimate a statewide changeout rate. Appendix A details the methodology we used to develop comparison values.

Of households with eligible HVAC equipment (the MAPC sample frame from Table 7 extrapolated to the entire state), the stock-turnover model changeout rate over six years was 59%. Due to the high level of uncertainty in the top-down estimate of total changeouts, we also calculated the changeout rate assuming that our estimate was too high by 20% (as discussed earlier in this section, we received comments suggesting that our estimate of total shipments is too high due to and underestimate of equipment life).

With that change, we estimated 48% of homes with eligible equipment had a changeout over the six-year period based on the stock-turnover model. Even using the more conservative 48% estimate suggests that the MAPC survey under estimates changeouts by 58% (comparing the 48% changeout rate to the 20% changeout rate implied by the MAPC results).

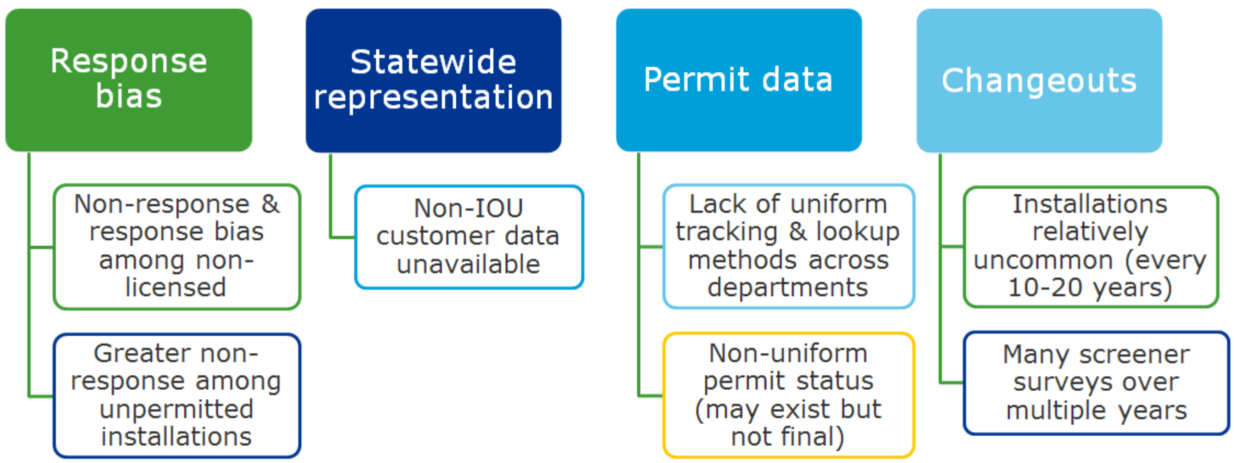
What are the implications of this finding? The analysis says more about what is happening than why it is happening. The initial idea behind the analysis was to disprove the possibility of strategic non-response. If we had found that the changeout rate from the top-down analysis were the same as the rate of changeouts from the MAPC survey, it would have ruled out strategic non-response. Since the MAPC survey resulted in a higher permitting rate, strategic non-response and strategic misreporting remain possibilities (but not certainties).

[40] Based on the weighted values from Table 7 (number of respondents with verified and eligible changeouts divided by number of completed MAPC screener survey respondents).

The fourth possibility, sample bias, seems unlikely to explain the low changeout rate, since the household characteristics skew toward more home ownership and higher education, which seem unlikely to result in lower changeouts.

In addition to response bias, other limitations to the study included the geographic area covered by the MAPC sample frame (IOU service territories only; not statewide) and the availability and consistency of tracking data across building departments. Figure 8 summarizes the limitations of the bottom-up analysis.

Figure 8. Limitation of the bottom-up approach



3.3 Conclusions

The permit rates estimated through the top-down and bottom-up approaches produced considerably different outcomes: 8% for the top-down analysis and 29% for the bottom-up. While the two do not align, recall that the intent of the dual approaches is because of high levels of uncertainty and potential bias with each approach. We believe that the true permit rate lies within the range represented by the two estimates; that is, that the top-down approach underestimates the permit rate, while the bottom-up approach overestimates it. While we cannot explain the gap with certainty, there are several hypotheses that may at least partly account for the discrepancy, and identifies sources of potential bias in each estimate.

First, the top-down and bottom-up estimates represent different timeframes, with top-down representing 2014 and bottom-up representing 2010-15. While this may only account for a small portion of the discrepancy, it is important to keep in mind that the two analyses do not attempt to estimate precisely the same permit rate.

The top-down estimate relied largely on HERS inspection data as a proxy for the number of permits. That approach may underestimate the number of permits, because building departments may fail to enforce (or under-enforce) HERS inspections. Evidence for under-enforcement includes:

- Some areas of the state have no HERS Raters.[41]
- The HERS data for the top-down analysis showed that 63 building departments had no HERS certificates for 2014, representing almost 12% of all building departments. Most of these are located in the less

[41] Based on a review of a list of more than 500 CalCERTS Raters.

densely-populated North Coast and North Inland climate regions. Inconsistent enforcement may also occur, but is more difficult to document.

- In researching permit status for MAPC respondents, DNV GL cross-checked building department permit status against the HERS Registry and found permits for 103 households. Of those, 85 should have required HERS inspections based on their climate zone and/or installation type, yet the registry contained some variation of a compliance form for only 74 of them (71%) and only 54 contained an actual CF-3R form.[42]

In light of the last point, we reanalyzed the top-down permit data assuming that the HERS certificate data represented only a portion of residential HVAC changeouts. Since we had previously prioritized the HERS data over the CIRB data because we believed it was more reliable, for this sensitivity analysis we reversed that and used CIRB data whenever it was available. Under these assumptions, the estimated number of permitted changeout units statewide grew by roughly half a percentage point, increasing the overall permit rate from 7.9% to 8.4%, but leaving our estimate at 8%.

There is also a great deal of uncertainty in the estimate of the denominator (total changeout units) for the top-down permit rate. The stock turnover approach relies on estimates of equipment stocks from RASS, and equipment lifetimes from DEER and other sources. Commenters to this report pointed to a number of alternative sources of shipment/changeout data suggesting that our estimate might be as much as 20% too high. We assessed many of those sources while developing the study approach, and each had its own sources of uncertainty and in some cases the potential for bias. While we believe that the stock turnover approach was the best choice for the study, it may nevertheless overstate changeouts (if the EUL estimates we used were too low). Assuming that total changeout units are 20% lower than estimated, the overall permit rate would be 25% higher than what we estimated, or 9.9% state wide. This accounts for only a small portion of the gap between the top-down and bottom-up estimates.

Combining our re-estimation of the number of permitted changeout units assuming that HERS certificates underestimate permits with the 20% lower estimate of total changeout units yields a statewide permit rate of 10.6%. This still does not fully address the gap between the top-down and bottom-up estimates. While the errors in the numerator and denominator may be greater than what we estimated for this back-of-the-envelope calculation, it is unlikely that resolving the uncertainties in the analysis would increase the top-down to the levels of the bottom-up rate of 29%.

An alternative explanation is the bottom-up permit rate may overestimate the true permit rate due to response bias. Concerns about response bias were a key reason we took the two-prong approach to estimating the permit rate (top-down and bottom-up).

There are other possible explanations for the difference between the top-down and bottom-up results. The RASS sample frame covered only 86% of the state. The remaining 14% of the state includes many of the least populous areas of the state. Small towns and rural areas may have fewer resources to devote to code enforcement. With a more dispersed population also comes fewer HERS Raters, potentially increasing inspection costs as travel times increase. This could be a disincentive for homeowners to obtain permits, and a disincentive for building departments to enforce them. Had the omitted portion of the state been included in the bottom-up analysis, it likely would have drawn the permit rate downward.

[42] See Chapter 6, Figure 15 for additional details and discussion on HERS documentation that was and was not available.

Given that California's population has shifted since we developed the RASS weights in 2008, we examined whether the weights we applied to the survey results were a factor in the high bottom-up permitting rate. Results of this investigation suggest that the weights are not a driving issue; the unweighted permit rate was almost as high as the weighted value, at 33%.

We also reviewed a number of previous permitting studies to put our findings in context. In 2014, DNV GL used a bottom-up approach to estimate permit rates for central cooling equipment on behalf of PG&E.[43] The study estimated that 38% of non-incentivized residential cooling equipment is permitted using an approach similar to our bottom-up study. That report cautions that the results were not extrapolated to the PG&E or state population and they were an indicator and not a precise estimate. The 2014 study's approach differed from the current study's approaches in terms of geography (PG&E's service territory vs. the RASS sample frame for the bottom-up and statewide for the top-down), equipment type (the current study includes ducted heating equipment as well as cooling), and its focus on non-incentivized equipment (both the top-down and bottom-up studies calculate an overall permit rate). Two earlier sources provide lower estimates of permit rates. According to the CEC's testimony in the "Underground Economy: Contractors Failure to Pull Permits for Residential HVAC Replacements," approximately 10% obtain permits and meet verification requirements.[44] Another study performed by Proctor Engineering Group for Assembly Bill (AB) 758 estimated less than 30% of units were permitted in the Sacramento region.[45]

The CPUC set goals in 2011 to increase the permit rate to 50% by 2015 and to 90% by 2020.[46] Despite the uncertainties associated with the current analyses, we are confident that the true permit rate lies between the two estimates. Even at 29%, the permit rate is low relative that goal. The results of the top-down analysis, as well as the inherent biases in the bottom-up analysis, suggest that the 29% is an overestimate of the permit rate. What is clear is that the state has a long way to go to meet a 50% permitting rate and a challenge to get to 90% by 2020.

While there remains a great deal of uncertainty in the true permit rate, we believe that it lies between the top-down and bottom-up permitting estimate. The results of the two analyses represent plausible lower and upper bounds for the true permit rate.

43 PG&E, 2014.

44 Pennington, G. W., 2014 and Institute of Heating and Air Conditioning Industries, Inc., 2013.

45 Proctor Engineering Group, 2012.

46 CPUC, 2011.

4 PERMIT RATE INFLUENCES

The study added additional efforts to explore the influences on the permit rate estimated by the bottom-up method. The tasks included interviews with the intent to develop case studies and statistical modeling using RASS and US Census data associated with respondents of the survey conducted for the bottom-up permit rate analysis.

4.1 Case studies

The initial approach to the case studies involved completing telephone interviews with 10 homeowners. We conducted in-depth interviews with a sub-group of on-site inspection participants with the intent of developing case studies to clarify why homeowners and their installation contractors do or do not pursue permits for HVAC changeout installations in existing homes. The original objectives of these case studies included obtaining the story of the permit path chosen for individual projects from the perspectives of the customer and the installation contractor and to review permit requirements of the associated building departments. The theory was that the chosen permit path would reflect numerous influences (e.g., information provided by the HVAC contractor and internal and external factors such as cost, scope, time, and customer preferences). Ultimately, however, we reduced the scope to focus on the customer experience via telephone interviews. These interviews are the only research effort in this study that elicit direct consumer feedback regarding permitting.

We also planned interviews with homeowner's installation contractors as well as additional follow-up with the relevant local building departments to learn about barriers to filing permits. However, after completing the homeowner interviews and initiating the contractor interviews, we reviewed preliminary results and decided not to pursue the task further. We provide more details on the results and rationale for this decision in Section 4.1.1. Below we summarize our approach to the interviews with homeowners and contractors.

4.1.1 Planned and completed sample

The starting population consisted of the 196 installations for which DNV GL staff conducted on-site inspections. We further reduced this population to the 46 installations that complied with the 2013 Standards (rather than the 2008 Standards) and included a split-system air conditioner replacement. These 46 installations served as the sample frame. We then distributed the sample into the following four categories (strata):

- Permit not found, did not meet the duct leakage test criteria (Non-permitted/Did not meet criteria)
- Permit not found, met the duct leakage test criteria (Non-permitted/Met criteria)
- Permit found, did not meet the duct leakage test criteria (Permitted/Did not meet criteria)
- Permit found, met the duct leakage test criteria (Permitted/Met criteria)

Instead of relying on customers to tell us the permitting status, we determined the status in advance of the interviews based upon permit records and phone responses from representatives at the respective building departments. The duct leakage test designations are based on on-site inspections we performed. We selected the duct leakage test as the qualifier because duct leakage testing is a mandatory requirement for all climate zones per the 2013 Standards.[47]

[47] We calculated the criteria of met/did not meet Standards by comparing the duct leakage rate found through our field test to the rate the installation should have meet according to the Standards (either 15% leakage for existing ducts or 6% leakage for new ducts).

Our initial goal was to complete two to three interviews in each stratum, but given the small sample sizes in some strata, we reallocated sample points to focus most heavily on the "Non-permitted/Did not meet criteria" stratum. Table 8 provides details regarding the sample frame and targeted number of completed interviews by stratum.

Table 8. Case studies sample frame and targets

Strata	Sample Size	Completed Interviews
Non-permitted/Did not meet criteria	18	5
Non-permitted/Met criteria	2	1
Permitted/Did not meet criteria	18	4
Permitted/Met criteria	8	1
Total	**46**	**11**

We achieved an overall response rate of 27% for the homeowner telephone interviews. We had a 10% refusal rate.[48] Prior to calling, we decided upon a limit of six calls per respondent, leaving up to three messages per respondent. Given that our goal was to complete 10 interviews, we did not reach the limit of six calls for any potential respondent. We placed at least one call to each potential respondent before completing 11 interviews (10 full interviews and one partial interview). Table 9 provides the disposition of the case studies sample.

The survey disposition suggests no greater or lesser likelihood of respondents completing interviews based on whether they represented a permit or no-permit installation. Once we reached a respondent, we had one out of four refusals from respondents from the no-permit installations compared to three out of four for permit installations. While the sample size was small, we did not find any correlation between customer age, income, education, or location and the decision whether to pursue a permit among the ten respondents who completed full interviews. We cannot conclude whether these correlations exist at the population level.[49]

Table 9. Case studies sample disposition

Strata	Sample Size	Total Calls	Number of Messages	Number of Refusals	Number of Completes
Non-permitted/Did not meet criteria	18	21	10	1	5
Non-permitted/Met criteria	2	4	3	0	1
Permitted/Did not meet criteria	18	21	15	3	4
Permitted/Met criteria	8	8	7	0	1
Total	**46**	**54**	**35**	**4**	**11**

* Includes one partially-completed interview.

During the homeowner interviews, DNV GL requested contact information for the installation contractor. Nine of the 10 homeowners were able to provide this information. We contacted each of the nine contractors

48 Response rate are based on AAPOR, response rate calculator 3: http://www.aapor.org/AAPOR_Main/media/MainSiteFiles/Response-Rate-Calculator-4-0-Clean-18-May-2016.xlsx

49 Based on the demographic information we obtained from the 11 homeowners who participated in the interviews, all live in single-family detached homes and all completed at least some college. Ten provided details regarding their employment and five were retired. English was the primary spoken language in each household, and of the six willing to disclose their income, five had incomes over $100,000.

twice and left voice messages for each one we did not reach. By the time we completed the 11 homeowner interviews, we completed one contractor interview. After reviewing the homeowner interview results, we decided not to pursue the contractor interviews further as described next in Section 4.1.2.

4.1.2 Homeowner interview results

After completing 11 homeowner interviews (in addition to one partial complete and one contractor interview), DNV GL staff reviewed the results. Based on these results, we decided not to pursue the case study task further because results from all interviews converged to a single permit path—one that is led by the contractor to include the permit as part of the installation agreement—as opposed a decision led by the customer, or a split decision between the customer and the installation contractor. Customers who did not have permits consistently said they didn't know they were supposed to have permits. The lack of variability in the permit paths led to our decision to cease the interviews.

Below we provide key takeaways from interviews with the 11 homeowners we interviewed. We also provide supplemental information from the one contractor we interviewed, who represented a large national HVAC equipment sale and installation company. Readers should take caution in extrapolating the results as they represent only the twelve respondents with whom we spoke, and the perspectives of these individuals do not necessarily represent the perspectives of the broader population of homeowners and/or HVAC installers. Key takeaways included:

- **Decision-making:** Interview results suggest that the installation contractor—not the customer—is the primary decision-maker regarding whether to pursue a permit. In all cases, homeowners indicated the installation contractor made the permit decision (e.g., contractor included permitting in the scope of work, mentioned permitting before the installation, or did not include permitting at all).
- **Awareness:** Findings from the homeowner and contractor interviews suggest that a lack of awareness of the permit requirement is the primary barrier to obtaining a permit. Of the homeowners who did not obtain a permit, none mentioned any other barriers (such as added cost, avoidance of inspection processes, or inconvenience). Homeowners who did not obtain permits stated that they learned of the requirement for the first time during our interviews. Among respondents with permitted installations, most respondents who could recall the details stated that they learned about the permit from the contractor.

  Of the 11 homeowners interviewed, six reported that they obtained permits for their installations and five reported that they did not. The homeowners' self-reported permit status was somewhat inconsistent with our permit record findings: of the 11 installation, homeowners' self-reported permit status agreed with our permit findings for seven installations but did not align for four installations.[50] Among the four that did not align, three respondents claimed the contractor completed the permit (or that they believed the contractor did so) and one respondent was unaware that a permit was filed on his behalf.

  Of the ten respondents who completed full interviews, none handled the permit process themselves. Additionally, none of the respondents said their contractor presented permitting as "optional"—either the contractor mentioned permits and obtained them or the contractor did not mention permits at all.

[50] For one of the 11 installations, the respondent had two units installed for which only one had a permit. We coded this respondent as having a permitted installation.

- **Installation Satisfaction**: All ten of the respondents who completed full interviews indicated they were satisfied with their new equipment. Results did not differ between respondents who did and did not have permits nor among homeowners whose installations had or had not met the appropriate duct test criteria established by the Standards.

4.1.3 No-permit respondents

Of the six respondents interviewed who did not have permits (according to DNV GL record requests), three believed that they did:

- Two respondents believed they had permits and indicated that they learned about the permits before the units were installed, but both said they were not home when the city inspector came to their properties. One of the two claimed to have a permit record while the other had no physical record. When asked about total inspections at their home, neither mentioned a HERS inspection.
- One respondent learned about the permit before the contractor installed the unit, but had no knowledge of a city inspection. Per his recollection, the only visits to his home for this purpose included DNV GL's inspection and another that was required for their financing.

The other three homeowners with non-permitted installations stated that they first learned about the permit process during the course of our telephone interviews.

There are several possible explanations as to why homeowners who did not have permits believed that they did. These reasons may include misunderstandings with contractors, inaccurate recall, the quality of building department record-keeping, the timing of the building department research (e.g., perhaps the building departments had not yet uploaded the permits to their systems), and/or other possible reasons. The limited nature of this research prevents us from drawing conclusions regarding which of these reasons (if any) may be most common.

4.1.4 Permit respondents

Of the five respondents interviewed who did have permits (according to DNV GL record requests), four were aware of the permit process and one was not.

- Four respondents believed they had permits and stated that they learned about the permits before their contractors installed the units. They stated that their contractors completed the permit process and the homeowners were either aware or present when the city inspectors came to their homes. In a few cases, the homeowner set up the appointment with the city inspector.
- One homeowner with a permitted installation was unaware his contractor completed the permit on his behalf. This respondent first learned of the permit process through our inquiry.

4.1.5 Case study conclusions

While we originally hoped to uncover unique causes for avoiding the permit process or for pursuing various permitting paths among homeowners, these 11 case studies all suggested that the contractor was the main driver for pursuing or not pursing a permit. Although the research was limited and results cannot be extrapolated to the entire population, the results of our effort suggested a relatively consistent homeowner perspective.

4.2 Statistical modeling of survey data

This surveys and on-site interviews used in this study were designed to answer basic research questions, but since the data were collected in a nested design, they also offer some statistical modeling potential for exploratory analysis. Ideally, the survey and analysis would be designed for robust logistic regression modeling (logit), but that was not the case for this study.

We used a simple logit analysis to predict what each population's variables should look like relative to its parent population, such as what permitted cases should look like relative to the overall known changeout population. Then we compared those variables to the actual population to assess the nature and extent of self-selection effects that might be biasing estimates of key outcomes (e.g., bottom-up permitting rate and the relative efficacy of permitted and unpermitted changeouts). Depending on the robustness of the model, we estimated an adjusted permit rate that aligns with the statewide independent variables from RASS.

We used respondents and non-respondent data and responses from the 2009 RASS survey and US Census data for neighborhood characteristics. The MAPC survey responses also provided insights into potential changes in occupancy, which may be drivers of self-selection just as stable household characteristics (e.g., household income, number of occupants, level of education) can be. We also examined Census information about the surrounding sample areas.

4.2.1 Modeling approach and variables of interest

This exploratory analysis aims to explain the variability in implementing HVAC changeouts and implementing permitted HVAC changeouts as a function of the potential explanatory variables listed below. The full list of 23 variables in the model was pared down to these nine predictor variables:

- Region (e.g., Coastal, Inland, etc.)
- Heating fuel type
- Education
- Household composition by age of residents
- Home ownership status
- Primary language in household
- Ethnicity
- Income
- Household size

The analysis approach had two steps: First, we explored the relationship between dependent and independent variables using simple statistics such as correlations and means to identify variables that more strongly predict the likelihood of obtaining permits and the likelihood of changeouts. Then we used the results to create multivariate logit models for implementing HVAC changeouts and then for implementing permitted versus unpermitted HVAC changeouts.

4.2.2 Modeling results and findings

The findings presented in this section are based on the 1,461 respondents who indicated that they had implemented HVAC changeouts and the 349 respondents that implemented permitted HVAC changeouts.

4.2.2.1 Correlations

Our correlation analysis showed that none of the predictor variables we considered had a strong impact on implementing HVAC changeouts or implementing permitted HVAC changeouts (correlations ranged from almost 0 to 0.13). Details of this analysis can be found in Appendix H, logit modeling detailed results. While these relationships may be characterized as weak overall, there are some predictors that are relatively stronger than others.

4.2.2.2 Average Permit and HVAC changeout rates

A comparison of the average changeout and permit rates by the variables that have relatively stronger correlations provides directional, but not necessarily statistically significant, evidence of trends. Households with over one-third of the residents aged 64 years or more are more likely to implement HVAC changeouts at 29% to 22%, and homes built in 1977 or earlier are more likely to implement HVAC changeouts at 28% to 21% (Table 10).

While none of the differences in average permit rates are statistically significant, there is some directional evidence to support further study into the following effects:

- Coastal – There is a higher incidence of permitted HVAC changeouts in coastal areas versus other areas (34% and 25%, respectively)
- Heating fuel type – There is a higher incidence of permitted HVAC changeouts amongst those with electric heating than without (50% vs. 26%)
- Education – Those with high school education or less have a lower incidence of permitted HVAC changeouts at 13% vs. 29% for those with greater education

Table 10. Average permit and HVAC changeout rates by select explanatory variables

Predictor Variable	Average Permit Rate[1]			Permit Status Correlation[2]	Average HVAC Changeout Rate			HVAC Changeout Correlation
	Var=Yes	Var=No	Signficant Difference	n=349	Var=Yes	Var=No	Signficant Difference	n=1,461
Region - Coastal	34%	25%	No	0.08	26%	23%	No	0.02
Heating fuel - Electric	50%	26%	No	0.11	35%	24%	No	0.05
Heating fuel – Natural gas	26%	40%	No	-0.1	24%	21%	No	0.02
Heating fuel - Other	30%	27%	No	0.02	16%	25%	No	-0.06
Education – High school or less	13%	29%	No	-0.11	24%	24%	No	0
Homes with over one-third of residents aged 64 years or more	30%	25%	No	0.05	**29%**	**22%**	**Yes**	**0.08**
Home ownership	28%	20%	No	0.04	25%	14%	No	0.08
Home age – built 1977 or before	25%	29%	No	-0.05	**28%**	**21%**	**Yes**	**0.07**
Asian ethnicity or language	17%	28%	No	-0.06	17%	24%	No	-0.05

[1] Dark Shaded cells denote no statistically significantly different averages.
[2] Un-shaded correlations are significantly different from zero. A less stringent criterion of p-value < 0.15 versus the more typical p-value < 0.05 is used to determine significance of correlations.

We note that the effects on HVAC changeout rates are not always concordant with the effects on permitted HVAC changeout rates. For example, while older homes built prior to 1977 have higher HVAC changeout rates, they do not have higher rates of implementing permitted HVAC changeouts. Income and household size had even less correlation with changeout and permitting status than originally suspected.

4.2.2.3 Multivariate Logit Model

The next phase of this exploratory analysis involved fitting multivariate logit models using the above explanatory variables and permitted HVAC changeout and HVAC changeout as dependent variables. The dependent variable in both cases is a binary outcome where 1 indicates that event occurred versus 0 that it did not. The probability modeled is for occurrence of the event—obtaining a permit and implementing an HVAC changeout.

Permitted HVAC changeouts

The logit model results corroborate the weak relationship observed in the above analysis. Model fit is poor[51] and none of the explanatory variables are significant. The odds ratio may be interpreted as follows: for a one unit change in the predictor variable, the odds ratio for a positive outcome is expected to change by the respective coefficient, given the other variables in the model are held constant. The confidence interval for the odds ratio estimates includes one, thus we fail to reject the null hypothesis that a particular regression coefficient equals zero and the odds ratio equals one, given the other predictors in the model (Table 11). Point estimates of odds ratios are above 1 for the following variables – Coastal region, home ownership, and homes with over one-third of residents aged 64 years or over. Further study into the potential impact of these on permitting rates is suggested.

Table 11. Logit model results – Permitted HVAC changeouts

Effect	Point Estimate	95% Wald Confidence Limits[52]	
Region - Coastal	1.47	0.84	2.58
Heating fuel - Electric	0.55	0.05	5.63
Heating fuel - Natural gas	0.23	0.03	1.93
Heating fuel - Other	0.29	0.03	2.95
Education level - High school or less	0.36	0.12	1.10
Home ownership	1.60	0.46	5.57
Homes built in 1977 or earlier	0.77	0.47	1.27
Homes with over one-third of residents aged 64 years or more	1.22	0.73	2.05

[51] Multiple statistics are examined to assess goodness-of-fit for the logit models and all of them agree on poorness of fit for the permit model. Akaike's Information Criterion and Schwartz Criterion for the Intercepts and Covariates model are higher than for the Intercepts Only model indicating that the predictors do not add any explanatory power in the permit model. Psuedo-R-square is low at 0.06. The Hosmer and Lemeshow Goodness-of-Fit test is not significant (p=0.36), leading to rejection of the null hypothesis that there is no difference between observed and predicted values of the response variable.

[52] Wald is a confidence interval calculation for binomial proportions that indicates a range of X.

Effect	Point Estimate	95% Wald Confidence Limits[52]	
Asian ethnicity or language	0.49	0.14	1.77

HVAC changeouts

The logit model results corroborate the weak but directionally insightful relationships observed in the correlations and means. Model fit is poor[53] and a few of the explanatory variables are significant. The confidence interval for the odds ratio estimates includes one for all but the following explanatory variables – home ownership, homes built in 1977 or earlier, and homes with over one-third of residents aged 64 or more (Table 12) We note the some of these same variables emerge as insignificant but relatively stronger in the permit model discussed above.

Table 12. Logit model results – HVAC changeout

Effect	Point Estimate	95% Wald Confidence Limits	
Coastal	1.08	0.80	1.45
Fuel type - Electric	1.38	0.37	5.16
Fuel type - Natural gas	0.86	0.27	2.78
Fuel type - Other	0.53	0.15	1.86
Education level - High school or less	1.03	0.67	1.59
Home ownership	1.96	1.19	3.21
Homes built in 1977 or earlier	1.28	1.00	1.64
Homes with over one-third of residents aged 64 years or more	1.32	1.01	1.71
Asian ethnicity or language	0.67	0.39	1.14

[53] Multiple statistics are examined to assess goodness-of-fit for the logit models and all of them agree on poorness of fit for the HVAC changeout model. Akaike's Information Criterion for the Intercepts and Covariates model is marginally lower than for the Intercepts Only model indicating that the predictors add some explanatory power in the HVAC changeout model. Psuedo-R-square is low at 0.03. The Hosmer and Lemeshow Goodness-of-Fit test is not significant (p=0.45), leading to rejection of the null hypothesis that there is no difference between observed and predicted values of the response variable.

5 ENERGY EFFICIENCY OF RESIDENTIAL HVAC CHANGEOUTS

This study is designed to test the assumption that permitted HVAC installations realize the full expected energy impacts and that—in the absence of oversight by building officials—non-permitted installations do not. To do so, we measured the level of compliance with Title 24, Part 6 Building Energy Standards (Standards) by conducting site visits at the sites of 196 residential HVAC changeouts. Then, we used these results to estimate the efficacy of each HVAC changeout to yield energy impacts. The goal was to determine whether there is a correlation between permitting status, compliance with the Standard, and energy efficiency efficacy.

During the site visits to the changeouts in the sample, we determined whether they were in compliance with each of 12 energy efficiency requirements of the Standards shown in Table 13, and for prescriptive requirements, to what degree. Since the changeouts included projects subject to the Standards in place during both the previous code cycle (adopted in 2008) and the current code cycle (adopted in 2013), one of two sets of compliance criteria were used, depending upon the vintage of the changeout. Of the 196 on-site visits conducted, 124 were subject to the 2008 Standards and 72 were subject to the 2013 Standards. Appendix I provides a more detailed version of Table 13. The study focused on single family homes within the IOU service territories with recent central heating or air conditioning replacements. The study initially focused on the 2008 Standards, but ultimately combined installations subject to the 2008 and 2013 Standards. The primary difference for residential HVAC installations is that the 2013 Standards made some previously prescriptive requirements mandatory requirements and the lists applicable climate zones for some requirements were expanded. Also, each site was compared to the requirements applicable based on the timing of the installation.

Table 13. Residential HVAC changeout compliance requirements

Requirement-level Compliance	M/P	2008 Standards Threshold	2013 Standards Threshold
Efficiency	M	≥SEER 13, AFUE 78, or HSPF 7.7	≥SEER 14, AFUE 78, HSPF 8.0 for packaged units, or HSPF 8.2 for split systems
Programmable thermostat	M	Required	Required
Load calculations	M	Required	Required
Duct insulation	M	≥R-4.2	≥R-4.2
Refrigerant line insulation	M	Required	Required
Refrigerant charge	P	Diagnostic testing in accordance with Reference Residential Appendix SA3.2 or have a Charge Indicator Display, for CZ 2 and CZs 8-15, as appropriate	Diagnostic testing in accordance with Reference Residential Appendix SA3.2 or have a Charge Indicator Display, for CZ 2 and CZs 8-15, as appropriate
Airflow	P	≥350 cfm/ton for CZs 10-15, as appropriate	≥350 cfm/ton for all CZs, as appropriate
Fan power index	P	≤0.58 W/cfm for CZs 10-15, as appropriate	≤0.58 W/cfm for CZs 10-15, as appropriate
Measurement access	M13	Required	Required
Static Pressure Probe/Hole	M13	n/a	Required
Additional duct insulation	M13	Required for some CZs	Required for some CZs
Duct leakage	P	≤6% total leakage (new ducts), ≤15% total leakage (existing), ≤10% leakage to outside, ≥60% improvement, or passing smoke test for CZ 2 and CZs 9-16, as appropriate.	≤6% total leakage (new ducts), 15% total leakage (existing), or ≤10% leakage to outside for all CZs, as appropriate.

M=mandatory requirement in 2008 and 2013; P=prescriptive requirement in 2008 and 2013; M13= prescriptive in 2008 and mandatory in 2013

At each of the sites in the sample, the following site-level metrics were used to assess the residential HVAC changeouts (defined in the Report Glossary).

- The requirement-level compliance is scored at by using a scale from zero to 100%. Some of the requirements in Table 13 are "pass/fail" and, hence, the requirement-level compliance receives a score of 100% or zero, respectively. The remainder of the requirement-level compliances each use a scale, from zero to 100%, to gage the extent to which the installation falls short of the threshold dictated by the Standards. Meeting the threshold for a given requirement yields a compliance rate of 100%; no bonus is given for conditions that exceed said threshold.[54]
- The HVAC installation efficacy (HIE) is a site-level ratio that aggregates the requirement-level compliance results for up to 12 requirements to the maximum possible compliance results for a given changeout. The maximum possible HIE is 100%—equivalent to meeting or exceeding compliance for all requirements triggered by the changeout. The maximum possible HIE for a given site depends upon the

[54] To establish appropriate ranges for these scales, lower limits were selected to be represented by a zero on the scale (e.g., 150 cfm/ton for airflow and 60% for total duct leakage). This was done to account for the fact that no installation could reasonably be expected to have conditions below those lower limits.

extent of the changeout, the climate zone, and the number of requirements that are triggered by the type of changeout. The weights for each requirement were established in proportion to their relative influence on the resulting energy impacts within each climate zone. More detail is provided in Section 5.1.

Then, using the preceding requirement-specific compliance values from the sites in the sample, we produced two overall metrics:

- The overall requirement-level compliance, which is an average of the requirement-level compliance results of the changeouts in the sample. This was determined for each energy efficiency requirement in Table 13 for each of the two building code cycles considered in the study. These results are provided in Section 5.4.
- The overall HIE, is the ratios of the total HIE across sites to the maximum possible total HIE. These were determined for both electric and natural gas energy efficiency and are provided in Section 5.5.

5.1 Weighting strategy to estimate site-level and aggregated compliance

The primary goal of the energy efficiency components of the Standards is to increase the energy efficiency of HVAC changeouts. However, a simple yes or no compliance does not provide enough information for the CPUC to understand the current market or to inform future policy and energy efficiency measure impacts estimates. It is, however, relatively straightforward to report compliance levels for each requirement across sampled projects. For example, we can report how many units complied with each requirement and determine which requirements are being met and which are not. This metric is intended to have primary value to the CEC and IOU codes and standards programs intended to promote specific requirements.

In addition to looking at each requirement independently, we can also look at each installation and assign it a score that estimates the efficiency of the installation from 0% (no requirements met) to 100% (all requirements met or exceeded). The CPUC sought a metric that could estimate the relative efficiency of permitted and non-permitted installations. Such a metric could serve as a baseline for pilot and proposed IOU programs that endeavor only to increase permitting rates. Prior to this study, there was no relative estimate of the efficiency increase associated with obtaining a permit—a leading indicator that energy impacts can be attributed to a permit. This research does not question the merits of obtaining permits, but tests the hypothesis that obtaining permits alone result in more efficient installations.

The approach of equally weighing all of the applicable requirements of the Standards was considered for this study, but would only indicate how many of the requirements are being met and in what proportions. The study would have missed an opportunity to consider the relative influence of each requirement on the resulting energy efficiency of permitted vs. non-permitted installations. To capture the variation in energy impacts yielded by the various requirements and to provide useful information to multiple stakeholders, we created the previously described metric termed HVAC installation efficacy (HIE).

HIE index scores were developed using estimates of how much annual electric energy is saved in the changeouts based on the energy code requirements with variation by climate zone. These estimates come from multiple sources and were chosen to show the relative energy impacts of different measures in different zones.[55] In addition, sites that replace full systems during the changeout (e.g., replace furnace, AC, and ducts) or that are in hotter climate zones have a higher potential score.

It is important to keep in mind these "energy scores" are effectively performance index ratings and do not represent quantified energy saving values. Each installation site has a maximum possible score based on the climate zone and project scope for the replacement type, and the maximum potential score for any site is 900. For example, a full system changeout in the hottest inland climate zone (15) has the maximum potential score of 900. Conversely, a component-only changeout in the cooler coastal climate zone (3) has the minimum potential score of 30.

This metric is estimated by taking the weighted average of the requirement-level compliance rate scores across requirements at each site. This metric includes different weights for each requirement based on potential energy impacts, which vary by requirement and by climate. If a requirement has potential energy impacts of zero it is not included in the analysis. This metric is estimated by taking the energy-weighted average of the requirement-level scores for a site. Some requirements are pass/fail with a score 100% or 0%, respectively. Requirements referencing a threshold value are scored based on deviation from the threshold, with the value capped at 100% so that exceeding code on one requirement cannot be traded off with another requirement. We evaluated lower limits as well, including 150 cfm/ton for airflow and 60% for total duct leakage. This acknowledges that we would not find a case where airflow is 1 cfm/ton or duct leakage is 90%, which helped set the appropriate range for scores.

When reporting compliance for permitted versus non-permitted changeouts, we reported the weighted average installation efficacy for each group. The study team compared installation efficacy by climate region (made up of two more climate zones). The weights were developed and are shown in Appendix J. They were taken directly neither from CASE reports nor from DEER, but rather draw from these sources where appropriate. The CASE reports provide impacts for the new-construction context and DEER provides impacts for individual measures are installed rather than for entirely new HVAC installations. We determined that these sources provided the best available estimates at the time we developed our methods and do not represent actual impacts. DNV GL provided a report in 2015 (Appendix J) that introduced the overall methodology and cites the data sources used for the compliance calculator.

5.2 Recruiting IOU residential customers for on-site inspections

At the onset of the study, researchers planned to restrict the compliance inspection sample to only those projects that were subject to the requirements of the 2008 Standards code cycle for the following reasons:

- Those projects subject to the 2005 Standards code cycle would likely show unit degradation and unreliable customer recall of HVAC replacement events.
- Those projects subject to the 2013 Standards cycle would likely be too few to achieve the desired sample target. The effective date of the 2013 Standards—July 1, 2014—was too near to the launch of the study in early 2015.

It was found, however, that restricting the sample to 2008 Standards cycle projects also resulted in too few sites due to both the small number of changeouts in that timeframe and the low rates of cooperation with on-site inspection requests. Hence, we made the decision to include changeouts that occurred in the 2013

[55] Estimates come from DEER and CASE reports with adjustments to normalize between the different software and assumptions used. The current values are the best available estimate and when the CPUC and CEC have better estimates in the future those estimates should replace those used in this analysis.

code cycle (July 2014-present). While the effect of this change does not affect the quality of this study, it does serve to complicate the reporting of the results because of the changes to the energy efficiency requirement. For instance, duct leakage must be assessed in all climate zones in the 2013 Standards whereas only those climate zones in the inland areas have such a requirement in the 2008 Standard.

Ultimately, the same RASS data that were previously used to produce the bottom-up estimate of the permit rate (described in Section 3) were used to generate the sample frame for this component of the study. Sites that completed surveys and indicated an eligible changeout were recruited for an on-site inspection.

Once the recruitment effort was successful for a given site, we performed a separate analysis of the permit status and HERS registry report. If a permit was identified, the permit data were then compared with the residential survey respondent’s self-reported information gathered during the screener survey. These included the year the changeout occurred (2010-15) and the type of equipment (heating, cooling, or both). Inconsistencies between the self-reported data and the permit data were prevalent regarding both the timing of the installation and the type of installation. In cases of inconsistencies, we deferred to the permit data. For instance, if a respondent reported that only the heating component had been replaced, but the permit indicated otherwise, we used the permit record data.

Further in the QC process, we removed sample points under the following conditions:

- The permit record showed the installation took place prior to 2010
- There were inconsistencies in the self-reporting of replacement date between the screener and recruitment surveys that made it likely that the installation occurred prior to 2010
- It became evident during the on-site inspection that the homeowner was confused about the timing of changeout and we found no evidence such as manufacture dates to support an installation date
- The equipment showed significant degradation that suggested it was installed prior to 2010 when nameplates were illegible

Since there were more than twice as many non-permitted changeouts as permitted ones, comparisons between the two samples were sometimes difficult. To complement the results and provide additional data points, we obtained additional permitted samples directly from the HERS registry. This added more cases of 2013 Standards changeouts and helped to balance the number of permitted and non-permitted samples for our comparative analysis.

There are several characteristics that we cannot ascertain about the evaluated sample. For instance, we cannot estimate how enforcement varied by region (e.g., whether every Standards requirement was enforced equally throughout the state). For the purposes of our analysis, we have assumed that the overall variation is higher than the variation for a specific mandatory or prescriptive requirement. The estimated coefficients of variation used for sampling are based on our experience and standard evaluation assumptions.

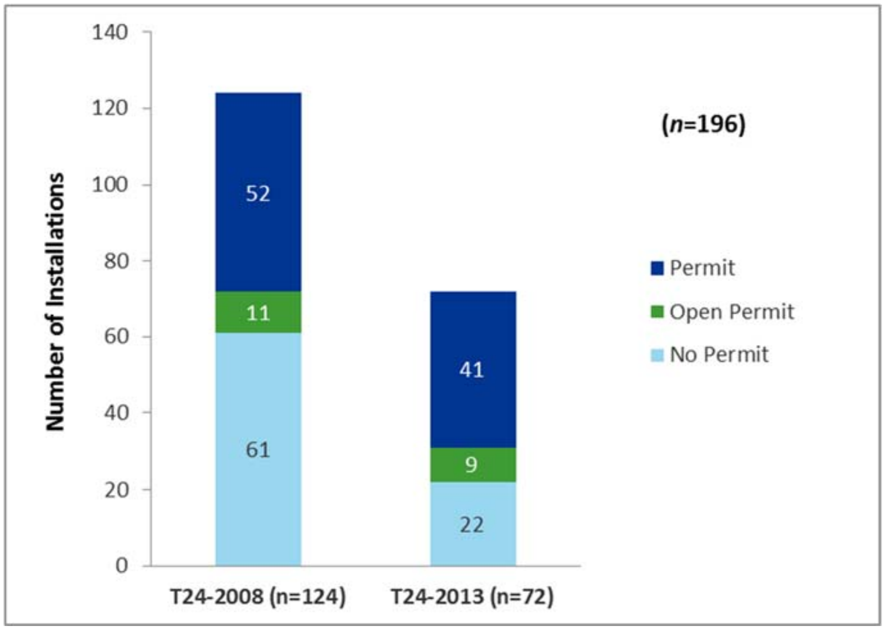
5.3 Characteristics of the on-site inspection sample

Upon review of the permitting records, it became necessary to distinguish between a final (closed) permit and a filed (open or expired) permit. Permits that were allowed to expire without final building department sign-off were not treated as equivalent to final permits and, hence, assigned to their own category of “open permit.” The total number of changeouts evaluated for the study was 196; this is slightly lower than the planned 200. In subsequent sections, when we provide compliance results by permit categories of “permit” and “no permit” we have excluded the cases of open permits because they are a distinct category.

5.3.1 Permit status by code cycle

Figure 9 compares the number of permits for the 2008 and 2013 code cycles. As previously indicated, of the 196 on-site visits conducted, 124 were subject to the 2008 Standards and 72 were subject to the 2013 Standards. The data suggest a lower permitting rate for projects subject to the 2008 Standards compared to those of the 2013 Standards. Closed permits represent 42% of the 2008 Standards sample, 57% of the 2013 Standards sample, and 47% overall. Open permits represent 9% of the 2008 Standards sample, 13% of the 2013 Standards sample, and 10% overall. Non-permitted sites represent 49% of the 2008 Standards sample, 31% of the 2013 Standards sample, and 42% overall. There were no statistically significant differences (at the 90% confidence level) between the compositions of the on-site samples subject to the 2008 Standards vs. the 2013 Standards.

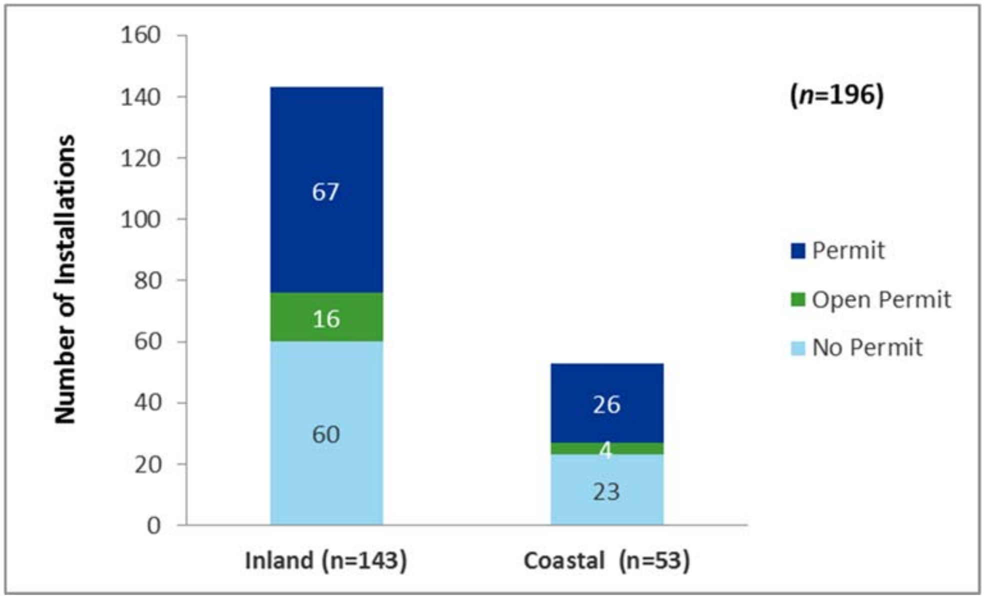
Figure 9. On-site permit status by Standards code cycle



5.3.2 On-site permit status by climate region

To assess the permit status of on-site inspections in this section and changeout types in the next (Section 5.3.3), we divided the evaluated sample into two climate regions: A Coastal region comprising climate zones 1, 3, 5, 6, and 7, and an Inland region comprising climate zones 2, 4, and 8-16. Figure 10 provides permitting status by climate region. This was done because the two climate regions are dramatically different and result in vastly different HVAC needs and, hence, different Standards requirements. The final sample contained 143 installations in the Inland region and 53 in the Coastal region. Inland regions have some additional compliance requirements that do not apply to coastal zones, particularly for the 2008 Standards.

Figure 10. Permit status by climate region



Coastal climate zones include 1, 3, and 5-7; Inland climate zones include 2, 4, and 8-16.

5.3.3 On-site HVAC system replacement types

Table 14 compares the sample HVAC system distribution by the Coastal and Inland climate regions. Inland regions have some additional compliance requirements that do not apply to coastal regions, particularly in the 2008 Standards. These additional requirements could be suspected to serve as further deterrents to permitting a project, but that suspicion was not supported by the data. The final sample contained 53 installations in the Coastal region and 143 in the Inland region.

Table 14. Distribution of HVAC system type by climate region

System Type	Coastal	Inland	Total	Proportion
Both heating and cooling components	19	109	128	**65%**
Cooling component only	3	8	11	**6%**
Heating component only	31	26	57	**29%**
Total	**53**	**143**	**196**	**100%**

Coastal climate zones include 1, 3, and 5-7; Inland climate zones include 2, 4, and 8-16.

5.4 Overall requirement-level compliance results

The requirement-level compliance results are summarized in Table 15 for each requirement. More detailed results are provided in Appendix I. Given some of the small sample sizes at the requirement level for permitted versus non-permitted, the uncertainty of the results can be high. We can draw a conclusion that the frequency of those requirements being triggered is low across a robust sample of 196 installations for the target population of single family HVAC replacements in IOU service territories. The frequency of applicable requirements increased from the 2008 to the 2013 Standards as anticipated. Overall, the tables show that the sample's mandatory requirements were met more often than the those for prescriptive measures (which vary by climate zone). The requirement-level compliance results are discussed below. Only those comparisons—between permitted (closed permits) and non-permitted sites (no permits)—that are specifically identified as statistically significant were found to be so at a 90% confidence level. Results include:

- **Minimum efficiency:** All units at the 196 installations visited met the minimum efficiency requirement regardless of permitting status.
- **Load calculations:** Since load calculations are a requirement for permitting, DNV GL made the assumption that they were performed in all cases where a permit was issued and that they were not performed in cases where no permit was issued. Although we did not attempt to collect load calculations for sites in the sample, DNV GL performed load calculation analyses on permitted projects in order to check relative sizing according to Manual J - but this cannot be used to determine compliance.
- **Programmable thermostats:** Almost all permitted installations (87% of 90) had programmable thermostats while less than three-quarters of the non-permitted installations (71% of 80) had programmable thermostats. This is a statistically significant difference. Field staff reported that it was common for homeowners in both samples to request non-programmable thermostats because of their simpler operation.
- **Duct insulation:** All sites met the minimum-duct-insulation mandatory measure (applies when ductwork is altered or added), regardless of permitting status.
- **Refrigerant line insulation:** Refrigerant line insulation was in place, at least where field staff could observe it, for nearly all sites. At permitted sites, 93% of the installations had the necessary insulation whereas, at non-permitted sites, 100% had it. This is a statistically significant difference.
- **Refrigerant charge:** Refrigerant charge was within the proper range (based on actual vs. target subcooling or superheat) for almost two-thirds (38 out of 61) of the systems we tested. Refrigerant charge was not measured for packaged systems because these systems are factory-charged and generally exempt from the refrigerant-charge measurement requirement. This limited our sample size, particularly in the San Joaquin Valley, where package systems prevail.
- **Airflow:** Overall, the minimum airflow requirement was met less than one-fifth of the time (19% of 70). Among permitted sites, 26% met or exceeded the minimum requirement; among non-permitted sites, only 14% did so; and among open permit sites, none did so. The extent to which the open permit sites differed from both the permitted and non-permitted sites is statistically significant. Some homeowners remarked to field staff that they had asked the contractor to reduce fan speed to minimize noise or drafts from the system. These data suggest the possibility that—at those sites with open permits—a decision was made not to close the permit when it became evident that the site would not be in compliance.
- **Fan power index**: The maximum fan power index requirement was met by about two-thirds of both the permitted and non-permitted installations.
- **Measurement access:** Measurement access existed at 86% of both permitted and non-permitted sites.
- **Static pressure hole or probe:** This requirement only came about in the 2013 Standards cycle. It was found to have been implemented at nearly two-thirds (63% of 60) of the relevant sites.
- **Additional duct insulation:** All of the 151 sites affected by this prescriptive requirement met it—that varies by climate zone—whenever ductwork was altered or added.
- **Duct leakage:** A little more than half (56% of 68) of permitted sites in the sample passed our duct leakage tests as did slightly fewer than half (47% of 64) of non-permitted sites. If a site fails to meet

duct leakage requirements through testing, contractors are allowed to meet requirements by performing "smoke tests" accompanied by sealing of all accessible leak, but verification through smoke testing was beyond the scope of this study. As a result, the actual rate of compliance may be higher than reported.

Table 15. Summary of requirement-level compliance results of on-site inspections

Requirement-Level Compliance Rate, percent (n)	2008 Standards Cycle				2013 Standards Cycle				Both Standards Cycles			
	No Permit	Open Permit	Closed Permit	Overall	No Permit	Open Permit	Closed Permit	Overall	No Permit	Open Permit	Closed Permit	Overall
Minimum Efficiency (M)	100% (61)	100% (11)	100% (52)	**100%** (124)	100% (22)	100% (9)	100% (41)	**100%** (72)	100% (83)	100% (20)	100% (93)	**100%** (196)
Programmable Thermostat (M)	64% (61)	86% (7)	80% (51)	**72%** (119)	95% (19)	100% (9)	95% (39)	**96%** (67)	71% (80)	94% (16)	87% (90)	**81%** (186)
Load Calculations (M)	0% (61)	100% (11)	100% (52)	**51%** (124)	0% (22)	100% (9)	100% (41)	**69%** (72)	0% (83)	100% (20)	100% (93)	**58%** (196)
Duct insulation (M)	100% (41)	100% (7)	100% (44)	**100%** (92)	100% (16)	100% (8)	100% (35)	**100%** (59)	100% (57)	100% (15)	100% (79)	**100%** (151)
Refrigerant Line Insulation (M)	100% (27)	100% (5)	100% (32)	**100%** (64)	100% (9)	83% (6)	84% (25)	**88%** (40)	100% (36)	91% (11)	93% (57)	**95%** (104)
Refrigerant Charge (P)	62% (13)	100% (2)	64% (22)	**65%** (37)	83% (6)	20% (5)	62% (13)	**58%** (24)	68% (19)	43% (7)	63% (35)	**62%** (61)
Airflow (P)	25% (8)	0% (4)	27% (11)	**22%** (23)	7% (14)	0% (5)	25% (28)	**17%** (47)	14% (22)	0% (9)	26% (39)	**19%** (70)
Fan Power Index (P)	78% (9)	50% (4)	71% (14)	**70%** (27)	50% (12)	50% (4)	67% (24)	**60%** (40)	62% (21)	50% (8)	68% (38)	**64%** (67)
Measurement Access	82% (57)	91% (11)	76% (50)	**81%** (118)	95% (19)	88% (8)	97% (38)	**95%** (65)	86% (76)	89% (19)	85% (88)	**86%** (183)
Static Pressure Probe or Hole	n/a	n/a	n/a	n/a	67% (18)	63% (8)	62% (34)	**63%** (60)	67% (18)	63% (8)	62% (34)	**63%** (60)
Additional Duct insulation	100% (42)	100% (7)	100% (43)	**100%** (92)	100% (16)	100% (8)	100% (35)	**100%** (59)	100% (58)	100% (15)	100% (78)	**100%** (151)
Duct Leakage	47% (45)	75% (8)	51% (37)	**51%** (90)	47% (19)	63% (8)	61% (31)	**57%** (58)	47% (64)	69% (16)	56% (68)	**53%** (148)

5.5 Energy efficiency efficacy of residential HVAC changeouts

As discussed earlier, there are uncertainties in the results since the surveys and site visits have the potential for self-selection bias, or study avoidance in the case of non-permitted replacements. We acknowledge these uncertainties and conducted case studies and additional modeling (Section 4). We did not find a strong correlation indicating strong self-selection biases, however we cannot say for certain there is no bias. The case studies showed that there is little incentive for customers who didn't pull a permit to avoid the study at disproportionate rates, and the logit analysis showed that if there are strong self-selection effects going on, they have remarkably few demonstrable demographic correlations. The research plan outlined many of these issues and the plans to develop analysis metrics and apply them to the dataset.

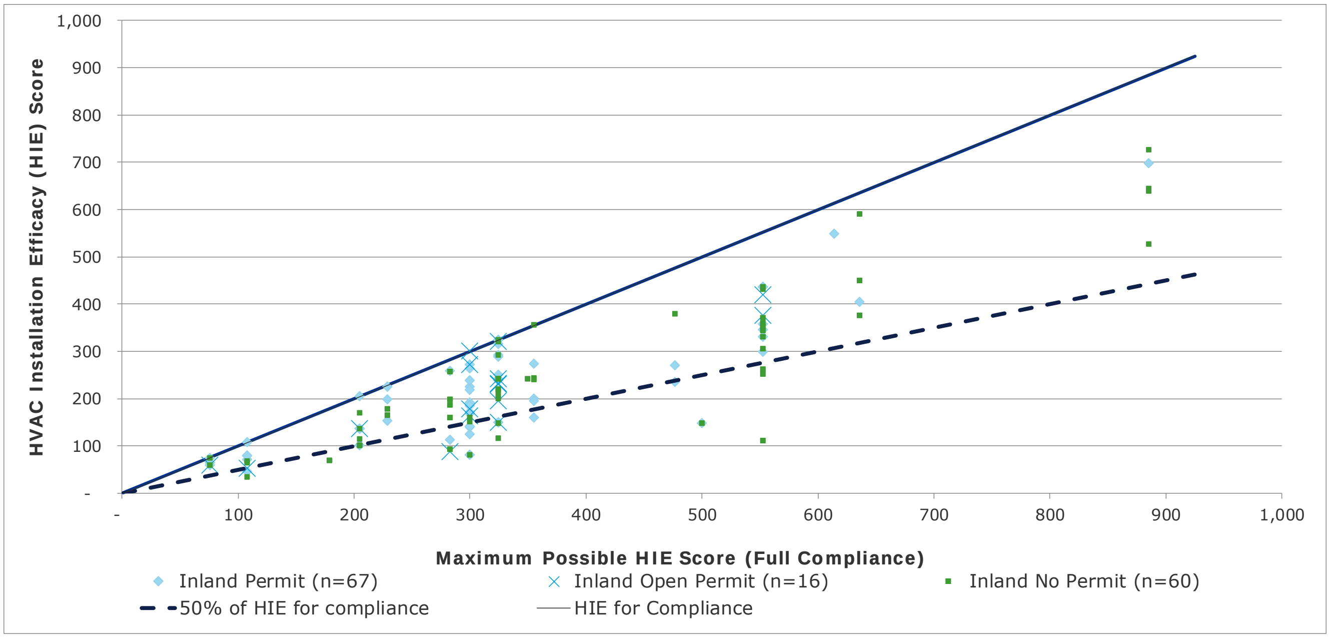
Given the wide variance of the total compliance scores by region, we present the HIE index results for Inland and Coastal regions in separate figures, Figure 11 and Figure 12, respectively. The figures display one data point per changeout, with different colors and symbols distinguishing permitted from non-permitted changeouts. These figures also show open permits—treated as a unique category—as they initiated permits, but may not have completed HERS verification testing; hence, compliance rates may differ from those of completed permits. The methodology report in Appendix J provides further discussion about how these underlying scores were developed and their limitations.

The x-axis in both figures represents the maximum possible HIE score a site can achieve; the y-axis represents the actual scores received. If a given changeout meets or exceeds all of the requirements triggered by the changeout, that sample point would fall directly on the "Total Compliance" line (the solid blue line in the figures that follow). If a site partially meets a given requirement, then they receive a score below a perfect score for that requirement and the resulting HIE falls below the "Total Compliance" line. This method provides an estimate of the level of compliance and, therefore, a relative estimate of how much impacts are being lost (or energy wasted) by failing to meet code requirements. The figures also include a second line that indicates 50% compliance (depicted by the broken blue line), for reference. The data points appear to occur in vertical clusters only because the maximum allowable HIE scores increase incrementally for each additional requirement that is triggered by the installation components and climate zone.

5.5.1 Electric HVAC installation efficacy

For the Inland region, most sites measured between 50% and 100% compliance (72%), a few at 100% (5%), and some equal to or below 50% (22%), as shown in Figure 11. There is no distinct pattern based on permit status; the permitted changeouts appear to score higher than the non-permitted changeouts in some cases, but not others.

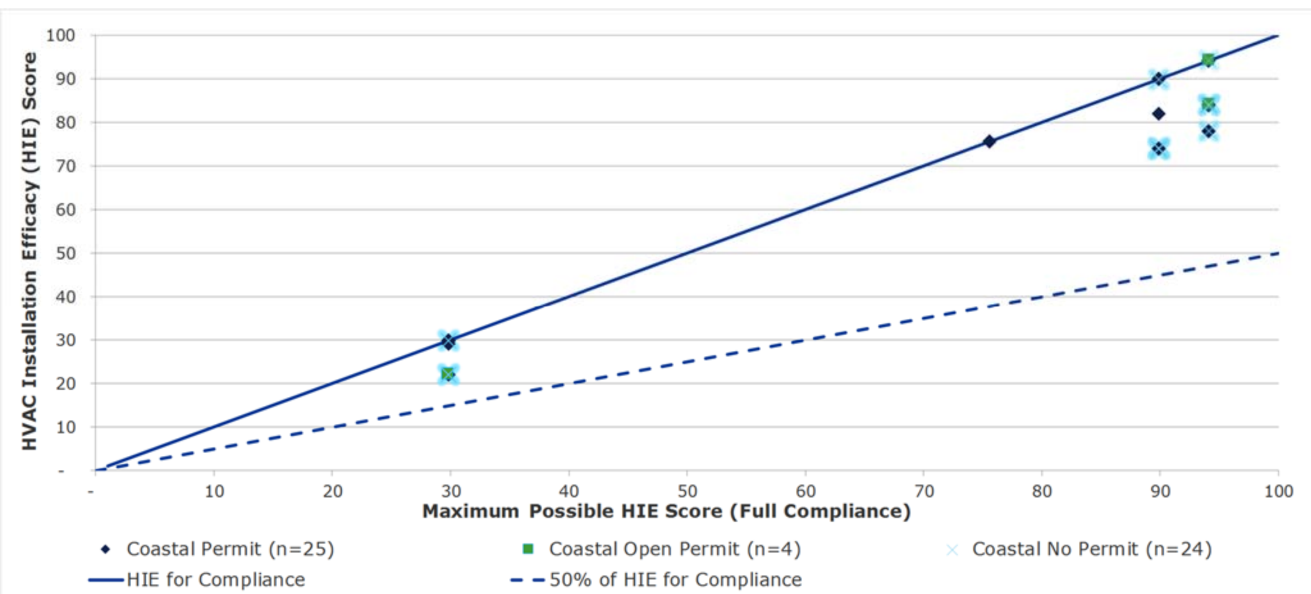
Figure 11. Electric HVAC installation efficacy (HIE) scores for the Inland changeout sample



Coastal region includes climate zones 1, 3, and 5-7; Inland region includes climate zones 2, 4, and 8-16.

All of the Coastal sites are well above 50% compliance and most are near the 100% line and more than one-third are thoroughly compliant (42%) as shown in Figure 12. Again, there is not a strong pattern between permitted and non-permitted groups. Many of the 53 HIE scores measured coincide and, hence, only nine distinct outcomes are discernable.

Figure 12. Electric HVAC installation efficacy (HIE) scores for the Coastal changeout sample



Coastal region includes climate zones 1, 3, and 5-7; Inland region includes climate zones 2, 4, and 8-16.

The error bounds were calculated based on the variability in the HIE score.

Table 16 provides a summary of the electric energy compliance results with the weighted averages of the HIE scores, the associated error bounds, and a test of statistical significance between permitted and non-permitted installation efficacy. The trend is for a higher electric HIE in the Coastal climate region—the region with fewer compliance requirements *and* far lower energy impacts potential—than the Inland region.

While the overall HIE is lower for Inland region, there are smaller differences among the permit statuses for Inland installations than for Coastal. However, for the Inland region (and statewide), the lower bound for permitted estimate overlaps the upper bound for the non-permitted estimate and therefore there is not a statistically significant difference. The error bounds were calculated based on the variability in the HIE score.

Table 16. Electric HVAC installation efficacy (HIE) rates and significance testing

Region	Group	Sample Size	Weighted Average Electric Energy Compliance	Error Bound (90% CI)	Significant Difference
Inland	Permit	67	69%	±10%	**No**
	No permit	60	65%	±12%	
Coastal	Permit	25	94%	±20%	**No**
	No permit	24	87%	±17%	
Total	**Permit**	**92**	**70%**	**±12%**	**No**
	No permit	**84**	**66%**	**±13%**	

Coastal region includes climate zones 1, 3, and 5-7; Inland region includes climate zones 2, 4, and 8-16.

Table 17 and Table 18 provides similar analysis by Standards cycle to investigate any potential trends from 2008 to 2013 Standards. We did not find any statically significant differences by permit status for either set of Standards. The No permit group had stable averages across cycles and for the Permit group there was some variation, but no statistically significant trends.

Table 17. Electric HIE rates and significance testing by Standards Cycle – 2008 Standards

Region	Group	Sample Size	Weighted Average Electric Energy Compliance	Error Bound (90% CI)	Significant Difference
Inland	Permit	41	72%	±15%	**No**
	No permit	42	65%	±14%	
Coastal	Permit	11	88%	±30%	**No**
	No permit	19	88%	±21%	
Total	**Permit**	52	72%	±17%	**No**
	No permit	61	67%	±16%	

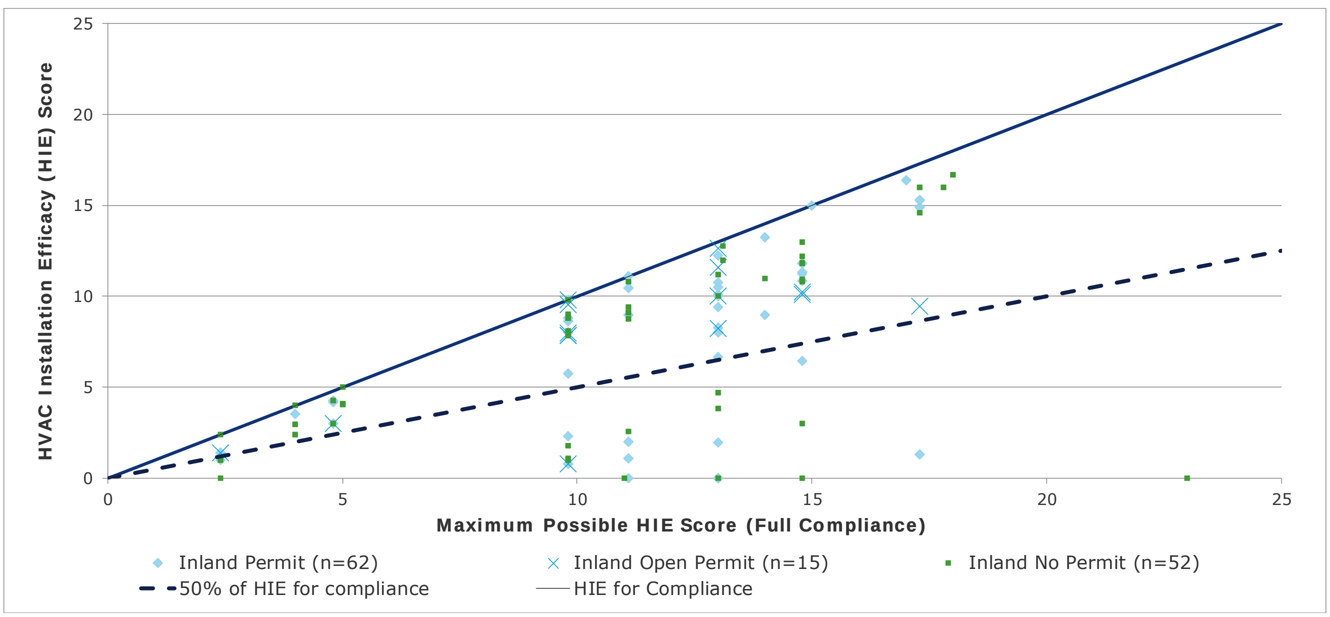
Table 18. Electric HIE rates and significance testing by Standards Cycle – 2013 Standards

Region	Group	Sample Size	Weighted Average Electric Energy Compliance	Error Bound (90% CI)	Significant Difference
Inland	Permit	26	64%	±13%	**No**
	No permit	18	65%	±21%	
Coastal	Permit	14	98%	±29%	**No**
	No permit	5	86%	±43%	
Total	**Permit**	40	67%	±17%	**No**
	No permit	23	66%	±24%	

5.5.2 Natural gas HVAC installation efficacy

For natural gas-consuming changeouts in the Inland region, 69% of the sites measured between 50% and 100% efficacy, 8% measured at 100% efficacy, and 24% measured equal to or below 50%. The distribution of efficacy scores—by permitting status—is shown in Figure 13.

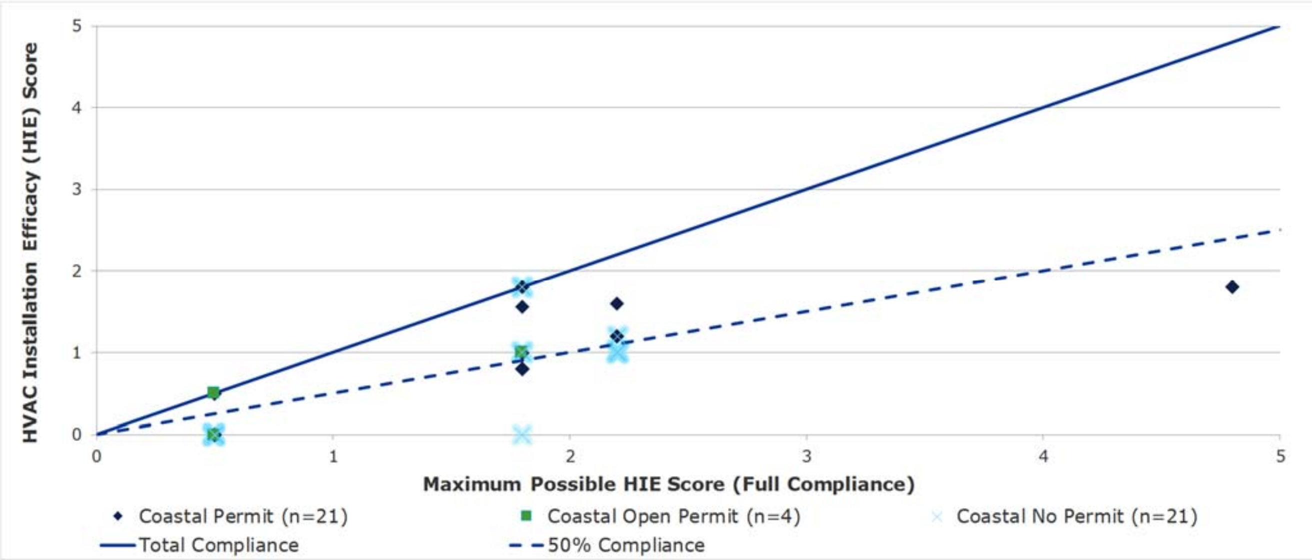
Figure 13. Natural gas HVAC installation efficacy (HIE) scores for the Inland changeout sample



Coastal region includes climate zones 1, 3, and 5-7; Inland region includes climate zones 2, 4, and 8-16.

For natural gas-consuming changeouts in the Coastal region, 54% of the sites measured between 0% and 50% efficacy (54%), 20% at 100% efficacy, and 26% equal to or below 50%. The distribution of efficacy scores—by permitting status—is shown in Figure 14.

Figure 14. Natural gas HVAC installation efficacy (HIE) scores for the Coastal changeout sample



Coastal region includes climate zones 1, 3, and 5-7; Inland region includes climate zones 2, 4, and 8-16.

Table 19 provides a summary of the gas installation efficacy results with the weighted averages of the HIE scores, the associated error bounds, and the results of a test of statistical significance between permitted and non-permitted changeouts. The error bounds are significantly wider for gas compliance because fewer sites require gas compliance, so there is a more polarized distribution with more close to 0% and to 100% than clustered around the average. The relatively large error bounds make it difficult to compare the results for permitted and non-permitted changeouts. In the Coastal region, there were more extreme cases of high and low installation efficacy thus contributing to wider error bounds than measured in the Inland region. The error bounds were calculated based on the variability in the HIE score.

Table 19. Natural gas HVAC installation efficacy (HIE) rates and significance testing

Region	Group	Sample Size	Weighted Average Gas Energy Compliance	Error Bound (90% CI)	Significant Difference
Inland	Permit	62	65%	±11%	**No**
	No permit	52	66%	±12%	
Coastal	Permit	21	52%	±19%	**No**
	No permit	21	50%	±19%	
Total	**Permit**	**83**	**65%**	**±13%**	**No**
	No permit	**73**	**65%**	**±15%**	

Coastal region includes climate zones 1, 3, and 5-7; Inland region includes climate zones 2, 4, and 8-16.

Table 20 and Table 21 provides similar analysis by Standards cycle to investigate any potential trends from 2008 to 2013 Standards. We did not find any statically significant differences by permit status for either set of Standards. While there are no statistically significant trends between Standards cycles, this analysis revealed some of drivers of the variability in the overall results.

Table 20. Natural gas HIE rates and significance testing by Standards Cycle – 2008 Code

Region	Group	Sample Size	Weighted Average Gas Energy Compliance	Error Bound (90% CI)	Significant Difference
Inland	Permit	39	63%	±14%	**No**
	No permit	35	69%	±15%	
Coastal	Permit	7	65%	±43%	**No**
	No permit	17	56%	±23%	
Total	**Permit**	46	63%	±16%	**No**
	No permit	52	68%	±19%	

Table 21. Natural gas HIE rates and significance testing by Standards Cycle – 2013 Code

Region	Group	Sample Size	Weighted Average Gas Energy Compliance	Error Bound (90% CI)	Significant Difference
Inland	Permit	23	70%	±18%	**No**
	No Permit	17	58%	±23%	
Coastal	Permit	14	47%	±22%	**No**
	No Permit	4	30%	±44%	
Total	**Permit**	37	68%	±23%	**No**
	No Permit	21	57%	±25%	

5.6 Conclusions

In summary, we concluded that the permitted and non-permitted installations in this study had similar rates of compliance with requirements related to their electric and gas energy efficiency. Furthermore, both the requirement level and efficiency scale results were relatively higher than generally expected for non-permitted installations. Since the potential bias identified for the bottom-up permit rate analysis also applies to the on-site findings at non-permitted installations, both results have greater inherent uncertainty than those for the permitted installations. There was no evident reason for people with permitted projects to avoid our study. Our additional case studies and modeling also supported the onsite sample as not being significantly biased.

We found somewhat different results for electric installations versus gas installations:

- For electric measures, regardless of where they were located in the state, most met at least half of the energy efficiency requirements but only a handful met all of them. There was no clear pattern based on permit status, but the results for both permitted and non-permitted cases suggest that the potential impacts from improved compliance may not be large for many areas of the state.
- For gas measures, there was also no clear pattern of meeting requirements based on permit status. While the relative average scores were lower than electric for both permitted and non-permitted cases, there are fewer requirements with gas impacts. The relative scores were lower, but the potential impacts from improved compliance may not be large for many areas of the state.

Because our assessments suggest that the potential energy impacts from improved compliance in installations may not be substantial (although results for gas measures are somewhat less clear than for electric), the value of achieving the state's permitting rate goals under current market and enforcement conditions is unclear from an energy efficiency perspective. There may be value in pursuing intervention strategies designed to improve installation practices for the entire residential HVAC market (without regard to permitting as the sole driver for energy efficiency improvement) or in pursuing interventions designed both to improve the efficacy of permitting and the permitting rate together. The results from this study suggest that market interventions that focus solely on the permitting rate may not be successful in increasing the energy efficiency of residential HVAC change-outs in California. Additionally, the barriers we documented with regard to further improving installation practices suggest that achieving energy impacts by improving compliance may pose substantial challenges.

6 REVIEW OF HERS DOCUMENTATION AND TEST RESULTS

6.1 Introduction

DNV GL conducted an assessment of HERS Compliance Forms (CFs) for a sample of permitted installations or replacements of central HVAC system components in California residences and evaluated the field test findings among those installations. The purpose of these analyses was to assess the prevalence and completeness of CFs and diagnostic tests to determine whether HERS inspections of residential HVAC installations produce the intended result of HERS-compliant residences.

In this chapter, we provide:

- A brief description of HERS CFs and requirements (Section 6.2)
- An overview of our objectives and approach, including key research questions (Section 6.3)
- Results of our review of CFs and field tests (Section 6.4)

Section 6.5 presents a summary of findings as they relate to each research question. APPENDIX M (Comparison of results for HERS and DNV GL field tests) provides site-by-site results of the field diagnostic tests conducted by HERS Raters and DNV GL. APPENDIX N (HERS Rater compliance form [CF3R] templates) provides the compliance form templates referenced in our analyses. APPENDIX O (HERS testing requirements) provides an overview of installation characteristics that trigger HERS tests as well as the Residential "Trigger Sheet" that assists HVAC contractors in determining the HERS tests required in a range of residential HVAC changeout scenarios. APPENDIX P (Limitations of HERS data acquisition) provides an overview of the limitations we encountered with regard to HERS data acquisition.

6.2 HERS compliance forms and requirements

California requires pre-installation permits for HVAC replacements in existing homes. The homeowner or the HVAC contractor may apply for the permit. Most replacements also require that the units be inspected by an independent third party, specifically a HERS Rater.[56] The role of a HERS Rater is to perform field verification and diagnostic testing (FV/DT) to demonstrate compliance with Title 24, Part 6 Building Energy Standards (Standards). The local building department enforcement division is ultimately responsible for verifying that the unit was installed according to the Standards. The installation contractor must hold a C-20 license and both the contractor and HERS Rater have a shared responsibility to submit CFs to the selected HERS Provider at separate stages during the project.

The CEC approves HERS Providers and is responsible for oversight of the Providers' Registries and HERS certification program. The Providers' responsibilities include creating a Registry (database) to store compliance forms, training and certifying Raters to perform inspections, and creating a quality assurance (QA) program and conducting QA tests to verify the quality of HERS Raters' work. There are currently two HERS Providers that own and manage HERS Registries: CalCERTS, Inc. and more recently, ConSol Home Energy Efficiency Rating Services, Inc. (CHEERS).[57] A third Provider—the US Energy Raters Association

[56] For more information regarding HERS Providers & Raters, please refer to the CEC website at http://www.energy.ca.gov/HERS/providers.html.

[57] For more information regarding each of these HERS Providers, please refer to https://www.calcerts.com/ for CALCERTS, Inc. and http://www.cheers.org/ for CHEERS.

(USERA)—suspended operations October, 2016 in response to the CEC's request that USERA undergo recertification as a HERS Provider.[58]

Different HVAC configurations and system conditions trigger different CFs and testing. Requirements may differ somewhat depending upon local building department practices, customer preferences, and/or contractors' or HERS Raters' diligence, but (per the 2013 Standards) typically involve three primary forms as part of the compliance process:

- CF1R "Certificate of Compliance." This form, which describes the project's scope and addresses several of the requirements in the Standards (e.g., efficiency levels), is required for all HVAC installations and replacements. The contractor typically completes this form and uploads it to the HERS Registry. Local building departments may require this form as part of their standard permit filing processes.
- CF2R "Certificate of Installation." The contractor typically prepares this form during system installation and submits it to the building department and to the HERS Registry (where the local building department can also reference it). There are multiple CF2R forms for different measures. The CF2R-MCH-01 form determines which additional CF2R and CF3R forms the contractor and/or Rater must prepare for the project.
- CF3R "Certificate of HERS Field Verification." The CF3R forms address duct leakage; airflow and fan power index; and refrigerant charge tests. The HERS Rater completes these forms during the HERS inspection (after the contractor installs the unit). As stated above, there are a suite of additional CF3R forms relevant to the type and scope of the installation (see Table 22). The HERS Rater is responsible for submitting these compliance form to the selected HERS Registry. The local building department typically reviews these forms. Note that the 2013 Standards refer to these as the CF3R forms, while the 2008 Standards refer to them as the CF4R forms.

For HVAC changeouts, the contractor typically submits the CF1R and CF2R forms to the Registry and to the building department, and also manages the permit process.[59] HERS Raters perform inspections and may interact on-site with the contractor, homeowner, and less frequently, with the enforcement department during the inspection, but their primary role is to perform a set of tests triggered by the installation type and climate zone. Raters submit the CF3R pass or fail testing results to the HERS Registry. If the installation fails the first inspection, Raters will re-test after the contractor corrects the installation. Table 22 presents the set of compliance forms included in our HERS documentation review.

Table 22. CF3R and CF4R sub-form types and numbers

Sub-form Type	Form Number
Duct leakage diagnostic test for new or replaced ducts	2013-CF3R-MEC-20, 2008-CF4R-MEC-20
Duct leakage diagnostic test for existing ducts	2013-CF3R-MEC-20 2008-CF4R-MEC-21
Airflow and fan-watt draw	2013 CF3R-MCH-22, 2008 CF3R-MCH-22
Refrigerant charge verification	2013 CF3R-MCH-25, 2008 CF4R-MCH-25

Refer to APPENDIX N, HERS Rater compliance form (CF3R) templates, for the compliance form templates used in our review of HERS documentation.

[58] For more information regarding USERA, please refer to https://useraraters.com/.
[59] CEC, 2012.

6.3 Approach

As described above, DNV GL reviewed the HERS CFs for a sample of permitted installations and evaluated the field test results among those installations. The purpose of these analyses was to assess the prevalence and completeness of CFs and diagnostic tests to determine whether HERS inspections of residential HVAC installations produce the intended result of HERS-compliant residences. Below we describe the key research questions and review our approach to reviewing and assessing the CFs and diagnostic test results.

6.3.1 Research questions

Table 23 provides the specific research theories and the questions we addressed in this assessment. In this section, we identify the prevalence of compliance forms and then compare DNV GL's test results to those of HERS Raters. DNV GL's test methods adhered to the Standards, and our test results serve as the benchmark to determine if installations were Standards-compliant.

Table 23. Research theories and related research questions

Theory	Research Question
Inconsistent permit enforcement may result in either incomplete CFs or no CFs. As a result; these projects may not meet the mandatory and prescriptive requirements.	1. What is the prevalence of the required HERS CFs among the sample of open and closed permitted installations?
There may be fluctuations in HERS Rater services due to outside influence from contractors, customers, and building departments—not to mention price pressure from competing Raters and/or lack of training on the proper forms to use. As a result, some projects may not meet the mandatory and prescriptive requirements.	*Using DNV GL inspections as the benchmark and adhering to the Standards:* 2. What percent of installations indicate Raters perform only a subset of the required verification activities?
	3. What percent of installations indicate the system does not pass or is out of compliance with the Standards requirements?

To probe why HERS Raters may not perform the work correctly or as thoroughly as necessary, we conducted exploratory surveys with Raters across different California climate zones. We provide these survey results in Section 7.4 of the report.

6.3.2 Documentation review and testing procedures

Our approach to the HERS CF documentation review and testing included five steps performed in the following order:

1. **Perform on-site inspections:** DNV GL performed diagnostic tests and verified compliance with the Standards for each of the 196 installations. We based the scope of the installation ("what was installed") upon survey respondents' self-reports and our on-site inspections. During the on-site inspection, we assessed each unit to validate respondent claims and probe further on project scope. Engineers then systematically performed a comprehensive set of tests, which in some cases included additional tests not stipulated by Standards.[60] We also considered possible issues related to the time elapsed between the installation and HERS testing and our testing (roughly one to three years). However, HERS testing

[60] We included the following tests where applicable: duct blaster test, airflow, fan watt-draw, and refrigerant charge. If the duct blaster test failed, we also conducted blower door tests.

covers elements of the installation that should be persistent over time (such as duct leakage and refrigerant charge[61]), suggesting that the elapsed time is unlikely to account for differences in test results.

2. **Identify permit status:** DNV GL analysts independently contacted building departments and placed public record requests or (where available) obtained permit data from online websites. When necessary, we placed telephone calls to building departments for permit records. We then assigned each site in our sample to one of three permit description bins: 1) no-permit, 2) closed permit (completed) or 3) open permit (incomplete).
3. **Collect HERS compliance forms:** DNV GL requested CFs from the HERS Registry Provider CalCERTS on behalf of the CPUC. We screened addresses to identify if compliance forms existed, and if so, we requested these forms. Due to contract limitations and cost, Providers screened only 80% of the sample for compliance forms. We estimate the Registry contains CFs for at least six installations in addition to what we requested, but CalCERTS did not make these available to the study. DNV GL's evaluation focused on the CF3R CFs completed by HERS Raters due to the lack of available data for the other forms. APPENDIX P (Limitations of HERS data acquisition) provides additional details regarding limitations to HERS data acquisition).
4. **Screen for HERS test exemptions**: DNV GL evaluated which installations required one or more of the three tests (duct leakage, airflow and fan power index, and/or refrigerant charge) as recorded on the CF3R and CF4R forms. We conducted these evaluations regardless of the permit status.
5. **Compare HERS test results:** Among the samples of inspected units with CFs available, DNV GL compared our field test values to HERS values for all tests available.

We evaluated results for the three diagnostic tests (duct leakage, airflow and fan power index, and refrigerant charge) and took into account exceptions from the Standards where applicable. For a given installation, the approach for assessing testing results was as follows:

- For duct leakage:

  Did the HERS Rater perform a duct leakage test for a given installation?
  Did the Rater use the correct form? Did the scope of the changeout align with our findings? Based on customer self-reports and DNV GL inspection of duct lines, we sought to identify if the ducts were newly installed, if greater than 40 feet of ducting was replaced, or if the ductwork was existing (noting any obvious repairs). Based on the data from the on-site inspections and customer self-reports, we determined whether Raters used the "correct" HERS forms.
  Did the HERS duct leakage test results align with our findings? If not, how disparate were the results?

- For airflow and fan power index:

  Did the HERS Rater complete an airflow and fan power index test for a given installation?
  Did the HERS airflow and fan power index test results align with our findings? If not, how disparate were the results?

- For refrigerant charge:

  Did the HERS Rater conduct a refrigerant charge test for a given installation?

[61] The CPUC Database for Energy Efficient Resources (DEER) has measure lives of 10 years for refrigerant charge, 18 years for duct sealing, and 15 to 20 years for new equipment.

Did the HERS refrigerant charge test results align with our findings? If not, how disparate were the results?

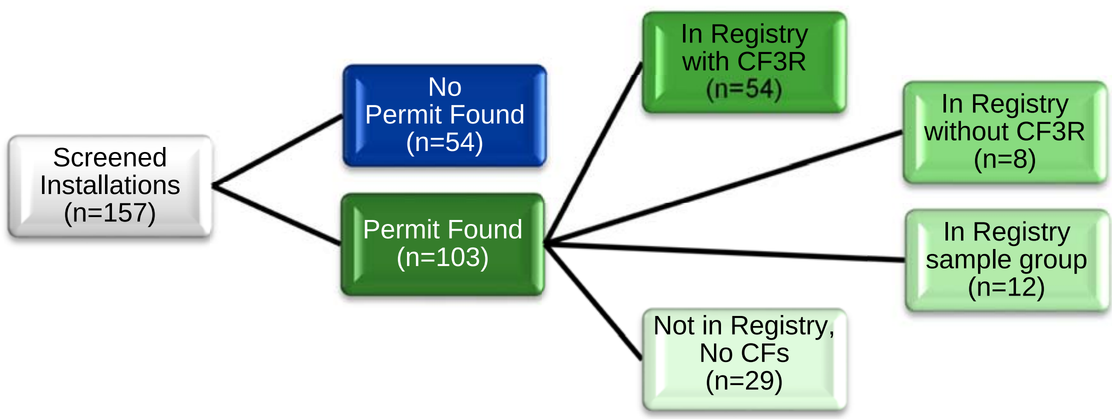
6.4 Results

Below we present results regarding the prevalence of HERS CFs and the accuracy of diagnostic testing. We divide the latter into three subsections (one for each test): duct leakage, airflow and fan power index, and refrigerant charge.

6.4.1 Prevalence of HERS Compliance Forms

As described above, DNV GL conducted a total of 196 site inspections. The HERS Providers screened 157 of these installations for the presence of CF (81% of total sites we inspected) but were unable to screen the remainder due to contract limitations. Figure 15 illustrates the prevalence of compliance forms among the sample of 157 screened installations. Of these, 103 contained a complete or incomplete (open) permit and 54 had no permit on file (66% and 34% of screened installations, respectively).

Figure 15. Prevalence of HERS CF



As shown in the figure, the HERS CF3R or CF4R was present in the Registry for a subset of the 103 permitted installations. The disposition of permitted installations was as follows:

- **In Registry with CF3R (n=54):** These installations included one or more of the CF3R or CF4R, although not necessarily the complete set of forms for a given installation. We present results regarding these forms in Section 6.4.2 below.
- **In Registry without CF3R (n=8):** These installations included no CF3R or CF4R but did include an indication that the CF1R and CF2R were in the registry. However, the Providers did not supply CF1R and CF2R data for the evaluation. It is unclear whether permit enforcement departments may have enforced only a subset of the required forms (CF1R and/or CF2R). Some forms were absent in both the 2008 and 2013 code cycles.

- **In Registry sample group (n=12):** The HERS requirements allow some installations to be part of a pre-determined sample group.[62] HERS Raters only have to test one in seven new homes or alterations (changeouts) from a given contractor if that contractor has a good record of HERS testing. The Registry lists these samples as part of a one-in-seven group, so there is no test data for the given installations.
- **Not in Registry, no CFs (n=29):** The Registry had no record of these installations and no compliance forms, which may in part be due to the "open or incomplete" permit status for a few of the installations. We also evaluated whether the scope of the installation would have triggered any one of the three tests or if the installation would have been exempt based on the project scope. All of these installations should have had at least a CF1R form, which is required for all installations. We estimated that 18 of the 29 installations did not require any of the CF3R or CF4R, and 11 did require one or more of the CF3R or CF4R tests.

This process identified a relatively high prevalence of HERS CFs, with forms present for more than three-fourths of projects in the permitted sample, although it is important to note that not all forms submitted contained the full set of tests as triggered by the Standards. The remaining one-fourth of installations had no CFs at all in the Registry.

6.4.2 Accuracy of diagnostic testing

While the previous section focused on whether forms were present regardless of their content, this section focuses on whether the forms were complete and accurate.

For each of the 54 installations for which we acquired CF3R forms, we reviewed the CFs available for three diagnostic tests (as applicable)—duct leakage, airflow and fan power index, and refrigerant charge. We then performed our own diagnostic tests in accordance with HERS procedures and compared our testing results to those of the HERS Raters. We present the results of each of these analyses below.

6.4.2.1 Duct leakage

Changes or alterations trigger a duct leakage test (DLT) in all climate zones under the 2013 Standards (when 75% or more of the ducts are replaced) and only a subset of the climate zones under the 2008 Standards. The project scope dictates which of the DLT compliance forms should be used as these forms vary slightly depending on the version of the energy code, and there are three exceptions for which the DLT requirements do not apply. For example, installations that contain duct systems with less than 40 linear feet in an unconditioned space are excepted.[63]

CF review

Changes or alterations to the HVAC system triggered a DLT for 53 of the 54 installations we reviewed, and the remaining installation did not trigger a DLT because it was a ductless system. Of the 53 installations for which changes or alterations to the system triggered a DLT, 46 had DLT forms available (87%). All of these showed that the installations passed the HERS Raters' DLT, including seven that passed using smoke tests. Smoke testing is an approved method when all accessible leaks are repaired. When HERS Raters use smoke tests, they do not need to meet the 15% leakage threshold. As such, comparing the HERS Raters' test results to our results is not relevant to compliance for these installations.

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[62] For more information regarding HERS Procedures – Group Sample Field Verification and Diagnostic Testing, please refer to APPENDIX O: Residential Alterations HERS Sample Group – 2013 Code Reference

[63] Exceptions to 2013 Standards 150.2(b)1E whereby DLT does not apply: https://energycodeace.com/site/custom/public/reference-ace-2013/index.html#!Documents/section1502energyefficiencystandardsforadditionsandalterationsin.htm

Of the 46 installations that had DLT forms available, five Raters used the incorrect forms and thus performed incorrect tests. Of these five:

- One Rater used a form that was more stringent than necessary given the scope of the installation (existing ducts). The Rater used the form for completely new ducting that allows a maximum 6% leakage to pass as opposed to existing ducts that allow a maximum 15% leakage to pass.
- The four other Raters who used incorrect forms made the opposite mistake, using existing DLT forms (allowing 15% leakage) when they should have tested at the new duct leakage rate (6% leakage).

DLT results

We performed tests on 44 installations of the 46 installations for which HERS DLT results were available (the other two were inaccessible with the required safety standards). Figure 16 shows the results of our DLT versus the HERS Raters' tests for these 44 installations. Data points on the diagonal line demonstrate that DNV GL's test results matched the HERS Raters' results. Points below the line suggest higher leakage rates in the HERS Raters' tests than in our tests, and points above the line suggest lower leakage rates in the HERS Raters' tests than in our tests.

As mentioned, the criteria for DLT are 6% total leakage for new ducts or 15% total leakage when modifying existing ducts. As shown, our results suggest that 34 of the 44 installations met the DLT criteria and ten exceeded the criteria. We placed the installations that passed HERS DLT using the smoke test into a separate category.[64]

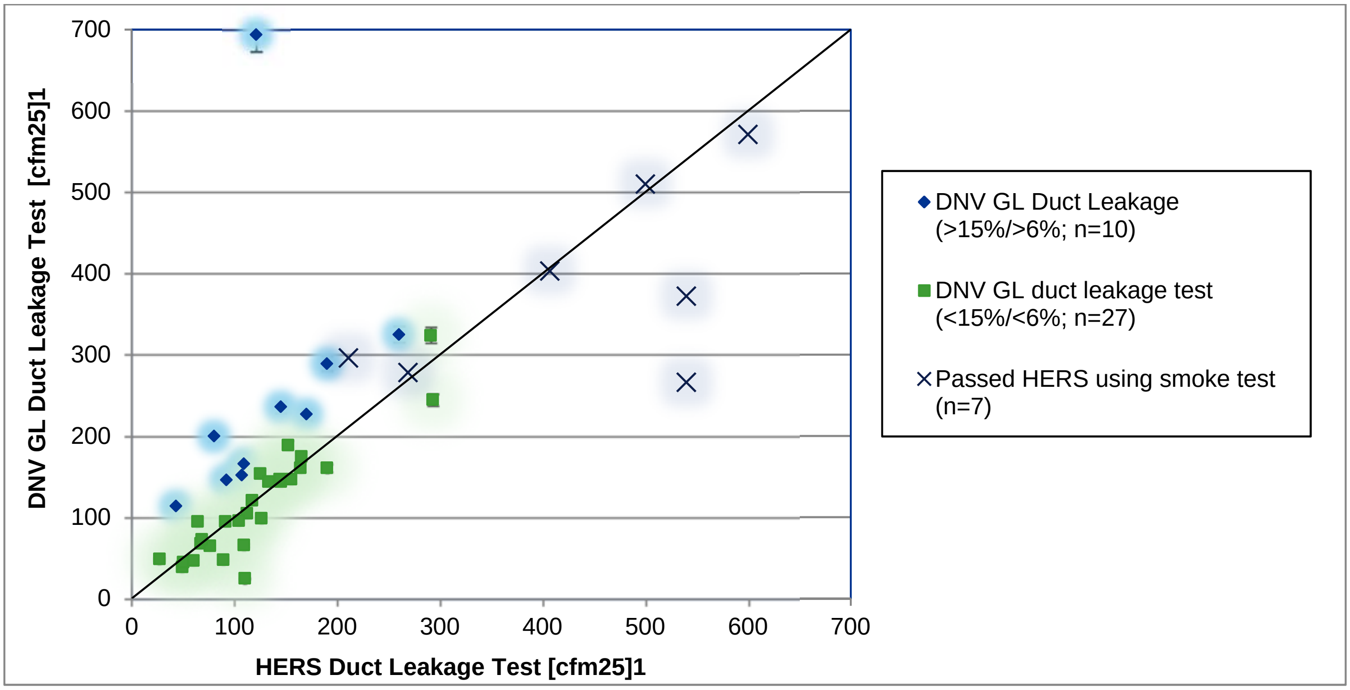
What is most noteworthy in Figure 16 is the tests that met the DLT criteria (and smoke tests) are clustered around the line. This means that on average, our test results agreed with the HERS Raters' tests. Of the ten sites where our DLT results did not meet the criteria, differences were substantial: HERS Raters' results suggest that the installations had leakage of less than 20 cfm_{25} or more under the allowable leakage limit while our results suggest that all of the installations had leakage of at 25 to 514 cfm_{25} over the allowable limits. When our DLT results did not meet the criteria, there are several possible explanations that may vary for each installation. These include:

- Raters may conduct HERS duct tests multiple times and record only the final passing test. In comparison, DNV GL used a two-point test approach (repeating the test a second time) and focused on the criteria established by the test equipment manufacturer to determine a valid and repeatable test. This means DNV GL would not go back to reconfigure the test setup until the test met the 6% or 15% DLT criteria while a HERS Rater may do this. In some of these cases, the HERS DLT may be more accurate. In others, someone on-site may have sealed a leak temporarily during testing which would result in underreported leakage.
- Although less likely than testing differences, degradation of the duct sealing measure (failure over time) may be a plausible explanation as to why DLT tests of Raters do not match ours. However, this is unlikely because, if degradation over time were a factor, this would be present in all systems, not just those that had a HERS test.

APPENDIX M (Comparison of results for HERS and DNV GL field tests) provides further detail regarding DNV GL's and the HERS Raters' DLT results.

[64] One of the HERS tests reported 1600 cfm_{25} for one of the passing smoke tests. We assumed this was a typo and corrected the result to 600 cfm_{25}.

Figure 16. DNV GL comparison to HERS DLT results (n=44)



Note: Line x = y shows where DNV GL DLT = HERS DLT.
1 The unit cfm_{25} is a standard unit of duct leakage measurement indicating the number of cubic feet per minute leaking from the duct system at 25 Pascals of pressure.

6.4.2.2 Airflow and fan power index

CF review

HERS Raters must test airflow and fan power index on air conditioning systems when the ducts are new and when the existing portion of the ducts can be accessed for sealing.[65] Among the 54 installations for which DNV GL acquired a 2013 CF3R or the equivalent 2008 CF4R compliance forms, 18 required airflow and fan power index tests. We found a significant discrepancy in the Registry for these tests: HERS Raters prepared the required 13-T33-CF3R-MCH-22 form (or the equivalent 2008 form) for only one of these installations.

Airflow and fan power index test results

For the single installation for which the Registry included the airflow test form, Table 24 shows results of the airflow tests performed by both the HERS Rater and DNV GL. The uncertainty of the True Flow measurement equipment used by DNV GL is 7%, or 50 cfm. There was no measurable difference between the airflow measured by the HERS Rater and by the DNV GL team. We were unable to measure the fan power index, so no comparison of fan power index was possible.[66]

[65] Under the 2008 Standards, the percent of new ducting is not a factor in the test requirement, however under the 2013 Standards at least 75% of the ducts must be replaced to trigger the test. Additionally, the system must have an air conditioner – heating only systems do not require airflow and fan watt-draw.

[66] We were not able to measure the fan watt-draw because the tight cabinet space did not permit our bulky electrical safety equipment.

Table 24. Comparison of HERS and DNV GL airflow and fan power index tests

Test	HERS Test Results	DNV GL Test Results
Airflow	720 cfm	714 ±50 cfm
Fan Power Index	355 W	Missing

6.4.2.3 Refrigerant charge

CF review

HERS Raters must verify refrigerant charge in climate zone 2 and 8 through 15 when the installation involves replacement or addition of a component that contains refrigerant (except in the case of package units, which are exempt from this requirement).[67] As part of the charge verification procedure, HERS Raters must also check the airflow of the unit because refrigerant charge diagnostic tests are incorrect when performed on systems with low airflow. Of the 54 installations for which DNV GL acquired HERS verification forms CF3R or CF4R, 28 had the required forms available. Of these, only 22 required refrigerant charge tests. (08-T36-CF4R-MCH-25 or 13-T36-CF3R-MCH-25) while six did not. Five of the six installations did not require testing because they involved package units and the other case was in a climate zone that did not require testing.

Refrigerant charge test results

Of the 22 changeouts for which Raters filed refrigerant charge testing forms, two of the forms contained null values for all refrigerant and airflow tests.[68] The result of our testing for these two changeouts showed that both of them met the criteria of the refrigerant charge portion of the test,[69] and one met the criteria of the airflow portion of the test.[70] The one that did not meet the airflow criteria had extremely low airflow at 129 cfm per ton making the refrigerant charge test invalid. Notably, airflow this low brings risk of damaging the compressor should liquid refrigerant enter it.

Of the remaining 20 changeouts for which Raters filed refrigerant charge testing forms containing data, 17 showed airflow as “complies” or “pass” and three showed ”fail”. DNV GL tested airflow on 14 of these units,[71] and eight met the minimum airflow requirement while six did not. Figure 17 presents the DNV GL airflow test results for the 14 changeouts measured using the Energy Conservatory True Flow testing equipment with uncertainty of 7% (error bars included in the figure). The HERS forms did not report the airflow test results. Five of the 14 installations are from 2008 and used the temperature split method to determine airflow. Given the uncertainty regarding the precision of this method, the 2013 HERS Rater

[67] The 2013 Standards state clearly that package units are exempt from the testing requirement; however, the 2013 HERS Residential Alterations Manual states on page 2 of Chapter 8 (Refrigerant Charge Protocols) that the RCA field verification requirement includes ducted package systems.

[68] HERS requires airflow tests in two different circumstances: first, when the installation involves duct replacement (as we discuss in section 6.4.2.2); and second, whenever HERS requires refrigerant tests, as discussed in this section. In the former circumstance, HERS Raters record airflow tests on the MCH-22 forms and in the latter, on the MCH-25 forms.

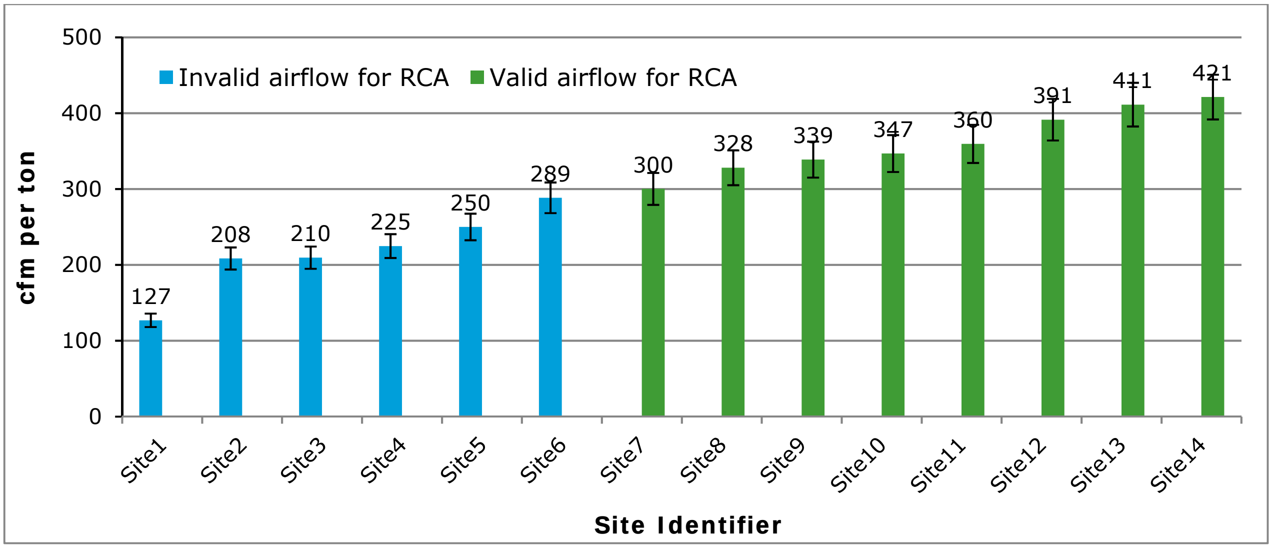
[69] Both of these units had thermostatic expansion metering valves requiring actual subcooling within ± 6°F of target subcooling.

[70] Passing airflow is 300 cfm per rated ton of cooling for a valid refrigerant charge test.

[71] Of the three that we did not test, one was a ductless mini-split, one had a filter slot too brittle to install testing equipment, and third had multiple tests but could not reach a repeatable test value.

guidelines have replaced it with higher certainty methods: pressure matching, True Flow, and flow capture hood.[72]

Figure 17. DNV GL airflow test results with error bounds



Adding back in the changeouts that failed the airflow tests, there are 20 installations where the forms showed refrigerant charge tests as passing. HERS Raters used the subcooling (SC) test, appropriate for systems with a thermostatic expansion valve metering device, in all 20 cases.[73] Of the 16 we tested, eight of the systems passed the subcooling (SC) test and eight failed.[74]

The SC test requires the technician to measure the discharge pressure—the pressure of the refrigerant leaving the compressor—and determine the saturation temperature of the refrigerant at that pressure. Technicians measure the temperature of the refrigerant leaving the condenser coil, and subtract that from the saturation temperature previously determined. The SC refers to the number of degrees the liquid refrigerant is cooled below saturation temperature. The measured SC is then compared to the target SC (published by the manufacturer), and if it falls within 6°F of the target, the unit passes the refrigerant test.

The HERS Rater protocol states that the HVAC unit's nameplate or manufacturer's literature should list the target SC. If the Rater cannot find it in one of these two places, the protocol advises calling the manufacturer. In our experience, both the superheat[75] and SC tests are prone to error because many different factors can affect their outcomes. These factors may include indoor and outdoor temperature, airflow rate, and non-condensable elements in the refrigerant.

6.5 Summary of findings

Below we present the summary of findings specific to each research question in Section 6.3.1 above.

[72] See, for example, Metoyer, J. and E. Swan, 2009.

[73] Other metering devices require a superheat test.

[74] We could not test 4 because one was a ductless mini-split, 2 had non-operational AC units, and one had site dangerous conditions that precluded testing (crawlspace access and recent rain storm).

[75] The superheat test is the appropriate refrigerant test for systems with non-TXV metering devices.

1. What is the prevalence of the required HERS CFs among the sample of open and closed permitted installations?

Findings among our sample of 103 installations identified a fairly high prevalence of the required HERS CFs with one or more forms present for more than three-fourths of the installations. The Registry included incomplete sets of forms for many installations, however; for example, the Registry included only the CF1R or CF2R for some installations even though the scope of work should have triggered verification tests (CF3R or 4R). Among the remaining installations absent from the Registry (approximately one-quarter of our sample), some were missing, while others may have been exempt from HERS verification tests (CF3R or 4R) or could have been represented in the other HERS Registry that was active at the time the Raters performed the tests. It is important to note we draw these conclusions based on limited access to the full set of HERS forms: had the Providers made all of the relevant data available the study, findings may have differed.

2. What percent of installations indicate Raters perform only a subset of the required verification activities?

The prevalence of required verification activities varied substantially by test type. Among the sample of sites for which we obtained CFs, we found that 13% of installations did not include a duct test where required (n=53), 94% did not include the airflow and fan power index tests where required (n=18), and 21% did not include the refrigerant charge test where required (n=20).

- **Duct leakage.** DNV GL reviewed 53 installations for which changes or alterations to the system triggered a DLT, and 46 of these had DLT forms available (87%). Raters used the incorrect forms for five of these installations, in one case testing to 6% leakage instead of the 15% required for that installation, and in four cases testing to only 15% leakage when 6% was required.
- **Airflow and fan power index.** Of the installations we reviewed, 18 required airflow and fan power index tests. HERS Raters prepared the required form for only one of these installations.
- **Refrigerant charge.** Twenty-eight of the installations we reviewed required refrigerant charge tests. HERS Raters performed the tests for 22 of these and did not perform the tests for six of them. In addition to these, DNV GL found six forms that HERS Raters filed in cases where the installations did not require refrigerant charge tests.

We discuss the various reasons that Raters may not conduct the required tests in detail under the summary of Finding 3 below.

3. What percent of installations indicate the system does not pass or is out of compliance with the Standard requirements?

As stated above, study results suggest that passing of the tests varied by testing type:

- **Duct leakage.** We performed DLT on 44 of the installations for which HERS Raters also conducted tests. While the Raters' tests suggested that all installations passed, our results suggest that ten of these (23%) did not meet the appropriate DLT criteria.
- **Airflow and fan power index.** For the single installation for which the Registry included the airflow test form, there was no measurable difference between the airflow measured by the HERS Rater and by the DNV GL team (and we were unable to measure the fan power index).
- **Refrigerant charge.** Of the 22 installations for which Raters filed refrigerant charge testing forms, two of the forms contained null values for refrigerant tests, but both of these met the appropriate criteria in our refrigerant charge test (although one did not meet the airflow test criteria of 300 cfm per ton, which would make that refrigerant charge test invalid). Of the other 20 changeouts, all showed passing

refrigerant charge tests, though only 17 showed HERS Rater tests of sufficient airflow for an accurate charge test (the other three showed insufficient airflows). We were able to test refrigerant charge and airflow on 14 of these 20 units,[76] and 8 met the airflow criteria of 300 cfm per ton, 6 of which also met the criteria of the refrigerant charge test.

6.6 Review of HIE Analysis by HERS Status

We reviewed the HVAC installation efficacy (HIE) scores developed in Chapter 5 in conjunction with this chapter's results of permitted installations and HERS documentation. Table 25 and Table 26 summarize our findings. The number of installations without HERS documentation was not proportional by climate region so a higher percentage of permitted coastal installations lacked HERS documentation. This led to the non-intuitive result that the gap between the HIE for HERS-documented and non-HERS-documented installations is narrower at the state level than it is for either the Coastal or Inland Regions alone. Note that all sampled HERS documented coastal installations had 100% HIE scores.

In general, we believe the permitted score including cases with no HERS reflects the current state of the market and enforcement conditions in IOU service territories. However, we do believe further research should be done to further investigate this question.

Table 25. Electric HVAC installation efficacy (HIE) rates and significance testing by HERS Status

Region	Group - HERS Status	Sample Size	Average Electric HIE	Error Bound (90% CI)	Significant Difference
Inland	Yes	53	70%	±11%	**No**
	No	14	63%	±26%	
Coastal	Yes	10	100%	±39%	**No**
	No	15	90%	±24%	
Total	**Yes**	**63**	**71%**	**±13%**	**No**
	No	**29**	**69%**	**±27%**	

76 Of the three that we did not test, one was a ductless mini-split, one had a filter slot too brittle to install testing equipment, and third had multiple tests but could not reach a repeatable test value.

Table 26. Gas HVAC installation efficacy (HIE) rates and significance testing by HERS Status

Region	Group - HERS Status	Sample Size	Average Gas HIE	Error Bound (90% CI)	Significant Difference
Inland	Yes	49	68%	±12%	**No**
	No	13	53%	±27%	
Coastal	Yes	10	46%	±25%	**No**
	No	11	60%	±31%	
Total	**Yes**	**59**	**66%**	**±14%**	**No**
	No	**24**	**53%**	**±30%**	

6.7 Conclusions

Our review of HERS documentation and test results point to specific deviations that help explain our findings from Chapter 5, specifically that several permitted installations do not comply with one or more compliance requirements, and that the overall HIE for inland permitted installations was lower than expected. The documentation review shows that many of these installations were not identified as deficient by the HERS process. We also found that documentation did not exist in cases where it should.

The lack of convergence of the HERS and DNV GL data may be explained by one or more of the following factors; however, we cannot rate one factor as more or less likely than another:

- **Building department confusion for required test.** Building department staff may be indifferent, confused, or unaware which HERS tests are necessary for different systems, particularly when new code cycles are adopted. This may cause a trickle-down effect in which contractors refuse to pay Raters to perform tests that the building departments do not request or require.
- **Degradation in system condition over time.** For approximately one-quarter of the installations, DNV GL staff performed field tests on units up to six years after the HERS Raters initially tested them. As a result, system degradation over time could contribute to poor performance of these units. In general, unit degradation could be a contributing factor in test performance discrepancies (for all units—not just those that were part of the HERS verification).
- **Inability to verify that HERS Raters performed the required tests.** Inherent in our assessment is the concept that HERS Raters actually performed all of the tests associated with the CFs they submitted. However, it is at least theoretically possible that some Raters simply fill out and submit the required CFs without actually performing the required tests. In these cases, we would expect wildly divergent results between the HERS Raters' test results and ours. The duct leakage testing results shown in Figure 16 are consistent with the possibility (but do not prove) that some Raters misreported test results. The figure showed a high degree of agreement between our tests and the HERS Raters' test when duct leakage met the criteria, but poor agreement (often differences of 50% or more) when it did not. While unfortunately we cannot reject the possibility of misreported test results, the other factors in this list could also explain the results.

- **Incorrect characterization of the installation**. DNV GL and/or HERS Raters may have had incorrect information regarding the scope of the installation, which could have led to incorrect conclusions regarding the scope of the tests required.
- **No indication of failed tests in CFs.** HERS Raters can only submit CFs to the Registry once a changeout has passed the HERS tests. As such, the HERS process retains no indication of whether the changeout initially passed or if the installation required the contractor to perform subsequent adjustments and the HERS Rater to re-test the unit. It is possible that HERS Raters recorded the test as passed when in fact it may have never passed.
- **Misplaced documentation.** HERS Raters may have failed to retain testing data, or may have failed to submit test results to the Registry. The HERS Registry may have lost the data somehow. In addition to the data we obtained for the study, there was one other HERS Registry active at the time of testing; it is possible that this other Registry held the missing testing data. Any or all of these factors could be reasons for the absence of HERS documents.
- **Testing errors.** DNV GL and/or HERS Raters may have performed tests incorrectly. The approved testing methods for airflow and refrigerant charge tests are particularly prone to error—especially under the 2008 Standards—and can vary with testing conditions.

The results of our tests suggest that even with HERS inspections, there are significant deficits in duct leakage, airflow, and refrigerant charge only a few years after installation. Of the units we tested, only 77% passed the duct leakage test, 57% passed the airflow test, and 43% passed the refrigerant charge test. However, because these deficits could be due to any combination of explanations from the above list, it is not obvious how to remedy the situation. More stringent enforcement of requirements? Better training of HERS inspectors? Or do homeowners simply need to take better care not to damage their systems? Taking all these possibilities into account, we make recommendations on process improvements, which are presented in Chapter 8.

7 EFFECTIVENESS OF HERS RATERS

7.1 Objectives

This section of the report assesses HERS Rater effectiveness based on telephone and online surveys with HERS Raters. The objectives are to:

- Identify knowledge gaps where training may help HERS Raters, contractors, and inspectors to improve compliance with Standards HVAC requirements
- Examine HERS Rater awareness and understanding of Standards code requirements and inspection processes
- Assess the HERS Rater efficacy in terms of whether inspected changeouts actually meet Standards requirements

DNV GL tested eight research theories relevant to these objectives. We show these theories and the related research questions in Table 27.

Table 27. HERS Rater research theories and related research questions

Theory	High-Level Research Question
1. Training is expensive, not readily available, not effective (e.g., includes no or limited field training), and/or training material is inconsistent among training HERS Providers.	What are the key barriers associated with training for HERS Raters?
2. Inconsistent knowledge among HERS Raters leads to inconsistent/erroneous assessments in customers' homes.	What is the level of competency among HERS Raters in completing accurate inspections?
3. There may be barriers to Standards compliance among HERS Raters including the expense and time associated with HERS testing.	What are the key barriers to Standards compliance among HERS Raters?
4. There may be barriers to Standards compliance among contractors including the expense and time associated with HERS testing.	What are the key barriers to Standards compliance among contractors?
5. Contractors may find it difficult to keep up with changes to Standards, which may contribute to poor-quality installations.	To what extent are contractors aware of the current requirements for HERS tests and inspections in Standards?
6. Enforcement of HVAC compliance requirements by building officials is inconsistent between building departments.	How consistently do local building departments enforce Standards requirements throughout the state?
7. Enforcement of HVAC compliance requirements by building officials is inconsistent within building departments.	How consistently are Title24 requirements enforced by different officials within a local building department?
8. Additional regulation will improve the HERS Rater services and lead to better quality installations.	Is there adequate regulation for HERS Raters and Providers?

We have organized the remainder of this chapter into the following sections:

- Section 7.2 (Background) provides further detail regarding the HERS program, installation and inspection processes, and the key players involved
- Section 7.3 (Approach) provides a high-level overview of our approach to the HERS Rater surveys (a screener survey conducted via telephone, and a full-length survey conducted online)
- Section 7.4 (Results) summarizes the results from the HERS Rater surveys and related analyses

In addition to these summaries, six appendices support this chapter:

- Appendix Q provides a detailed discussion of survey methods
- Appendix R provides a more detailed discussion of the telephone screener survey results
- Appendix S provides a more detailed discussion of the full-length online survey results
- Appendix T provides full-length survey participants' verbatim responses to open-ended questions in the survey
- Appendix U provides data tables that highlight statistically significant differences in HERS Raters' responses to rating scale questions in the full-length survey
- Appendix W provides the HERS Rater data collection instruments (telephone and online surveys)

7.2 Background

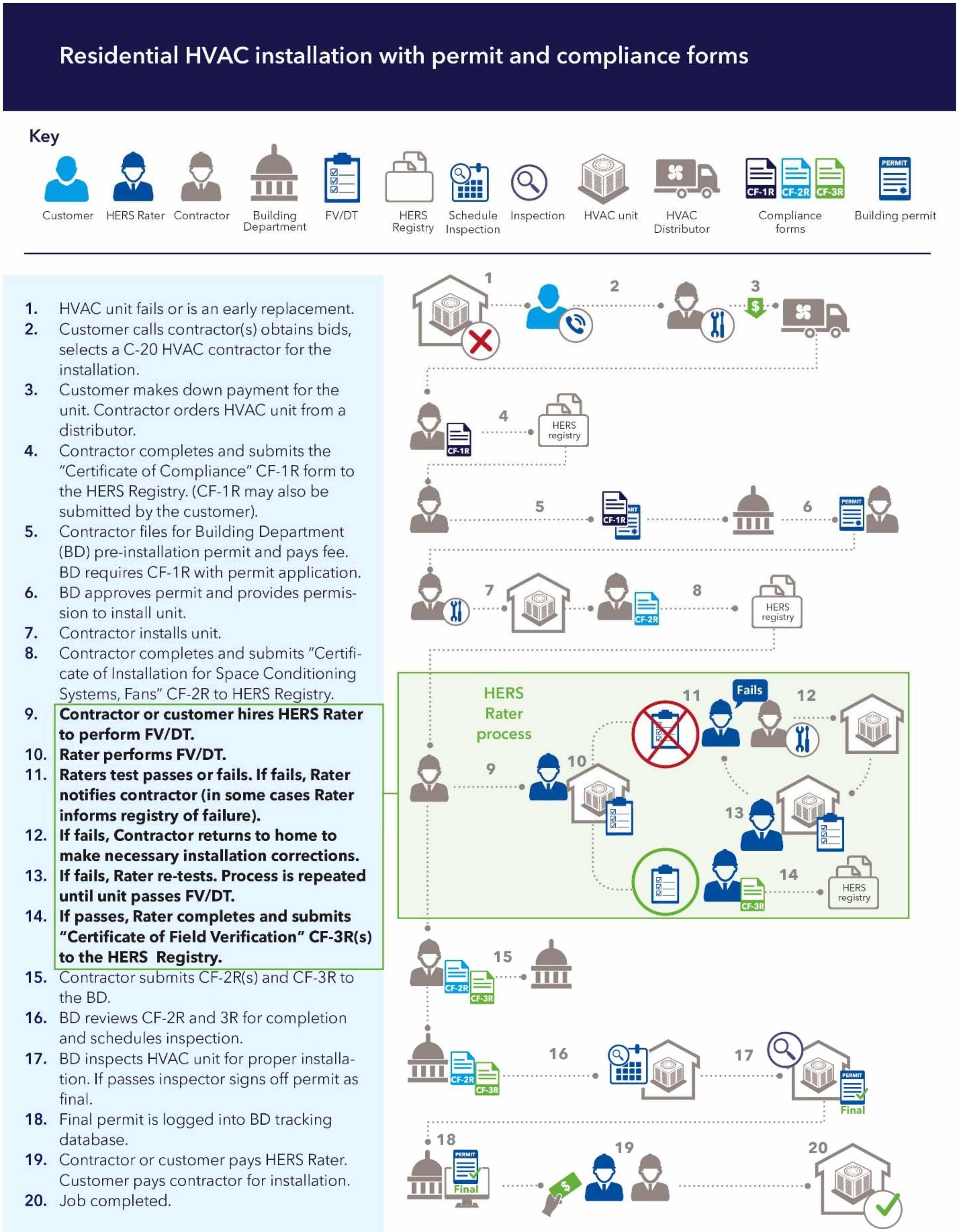
As described in Chapter 6, California requires HVAC installers to obtain permits when installing HVAC units and requires a HERS Rater to inspect the unit after installation. A Rater's role is to perform field verification and diagnostic testing (FV/DT) to demonstrate that the installation complies with Title 24, Part 6 Building Energy Standards (Standards). The CEC implemented the HERS program to address construction defects and equipment installations that contractors had historically not performed correctly. Because Raters are part of the HVAC changeout compliance process, we assessed the prevalence of systematic issues, knowledge gaps, and barriers to HERS inspections on HVAC installations.

Local building inspectors are ultimately responsible for verifying that contractors install HVAC systems according to the Standards. Both the installation contractor and HERS Rater are responsible for submitting compliance forms (CF) at different stages of each project.

The process for submitting the forms may vary based on local building department requirements. Generally, the HVAC contractor or HERS Rater submits the compliance forms to a HERS Registry. The local building department is then responsible for reviewing these forms and for permit enforcement at the installation site.

Figure 18 presents a flow diagram illustrating the ideal residential HVAC installation processes with a complete set of permits and compliance forms. The figure shows the role of the customer, contractor, HERS Rater, building official, the related paperwork (permit and compliance forms CF-1R, -2R and -3R) and the inspection processes (HERS Raters and building official) that are necessary to complete a permitted and compliant HVAC installation. The figure presents an idealized depiction of the steps, but in reality, the actual occurrence of events may not follow the same path or produce the same outcomes; for example, building departments' compliance review protocols may differ, and some building departments may not enforce all of the compliance forms but still finalize the permit. The HERS Rater's role begins at step 9 and ends at step 14 (of 20 total steps).

Figure 18. Flow diagram depicting the permit and compliance process



7.3 Approach

To address the objectives outlined above, DNV GL conducted surveys with HERS Raters. To first identify Raters who had recent experience performing HVAC inspections, we conducted a screener survey to identify Raters who completed at least one HVAC inspection in a residential dwelling in California within the 12 months prior to the survey. We conducted the screener survey via telephone, and invited eligible Raters to participate in a full-length survey. We conducted the full-length survey online.

We obtained HERS Rater contact information from the CalCERTS online Rater directory in November 2015. After removing duplicate entries and further cleaning the contact file, the sample frame for the screener survey included 648 Raters who worked for 508 different companies including sole proprietorships, which represented the majority of Raters. Based on this information, we targeted 57 completes for the full-length surveys to achieve a coefficient variation of 0.5 and 90% confidence interval with precision at 10%. To further ensure representativeness of the HERS Rater survey results, we attempted to complete interviews with only one HERS Rater per company.

We ultimately completed 122 screener surveys and 57 full-length surveys. In one instance, we completed online surveys with two Raters from the same company, so the final online survey results included respondents from 56 companies. We calculated and applied sample expansion weights based on self-reported estimates of responding companies' number of annual inspections to extrapolate the results to the population of Raters in the CalCERTS directory.[77] We report full-length survey results in terms of the share of HVAC changeout inspections (projects) for which respondents' companies are responsible in a typical year (e.g., "Raters accounting for X% of projects").

7.4 Results

This section summarizes results from the HERS Rater surveys. Section 7.4.1 summarizes HERS Rater characteristics based on screener survey results to provide context for the other results. Sections 7.4.2 through 7.4.9 summarize online survey results for each of the eight research questions we describe above in Section 7.1.

Appendix S in Volume II provides a more detailed discussion of the screener survey results. For the full-length online survey, please refer to Appendix W for a more detailed discussion of results, Appendix U for participants' verbatim responses to open-ended questions in the survey, and Appendix V for tables that highlight statistically-significant differences in HERS Rater responses to rating scale questions.

7.4.1 HERS Rater characteristics

During the screener surveys, we asked respondents to describe the scope of their activities and characteristics of their companies. Below we present results from the screener survey for the 57 HERS Raters who also participated in the full-length surveys. These results are unweighted, and percentages in this section thus reflect the share of HERS Raters rather than the share of projects represented by the HERS Raters who participated in the surveys. Key findings include:

- Almost three-fourths of Raters own their own companies (73%), and the majority of companies are sole-proprietorships (72%).

[77] Ideally, we would have calculated the weights based on data included in the HERS Registry versus self-reports from Raters, but the former is not publicly available, and we were unsuccessful in obtaining this information from the HERS Providers.

- All of the Raters performed residential alterations (a requirement for participation in the online survey), and roughly two-thirds also performed inspections on new construction (68%). The majority also performed non-residential alterations, and slightly more than one-quarter said they performed whole-house inspections (56% and 28%, respectively).
- More than half of respondents' companies completed 100 or more inspections of all types in California during 2015 (residential or otherwise; 54%), while 40% completed 100 or more residential HVAC alteration inspections. On average, respondents' companies completed inspections of 226 installations of all types and inspections of 159 HVAC alterations during 2015. One-third of respondents said they personally completed inspections of more than 150 such installations (34%).
- Most respondents said they work in multiple regions, with Northern California being slightly more common (56% of Raters) than Southern or Central California (42% and 26%, respectively).
- All but one of the 57 respondents were registered with CalCERTS, Inc. (which was unsurprising given that CalCERTS provided our sample frame). Eighteen percent of respondents reported that they were registered with CHEERS and another 12% with USERA. Approximately 72% were registered only with CalCERTS and no other Providers, and just one respondent was registered with all three Providers.
- Approximately 58% of respondents said they had less than 5 years of experience as a HERS Rater and 51% said they had backgrounds as HVAC contractors or technicians.

7.4.2 Barriers to HERS Rater training

The first research question we investigated relates to shortfalls in the HERS Registry certification or re-certification training courses. The theory states that HERS Registry training is expensive, not readily available, not effective (e.g., includes no or limited field training), and that the training materials are inconsistent among HERS Providers. These shortfalls, if present, could lead to poor quality FV/DT.

Survey findings confirm some elements of the research theory but contradict other elements:

- Results suggest that the key barriers associated with training for HERS Raters relate to a lack of hands-on elements in the training for certain diagnostic tests, inadequate training regarding how to complete the CF-3R form(s), and inadequate training on the using Registry websites to submit testing results.
- Although training participants were less than satisfied with the cost of training, there was no evidence of widespread dissatisfaction with the location or frequency of the training opportunities.
- Additionally, while a couple of respondents mentioned inconsistencies among HERS Provider training, this was a relatively minor issue compared to other, much more prevalent issues brought up by respondents (such as challenges with completing the required CF-3R and uploading them to the Registry).

7.4.3 HERS Rater competency

The second research question investigates whether there is inconsistent knowledge among HERS Raters that may result in inconsistent and erroneous assessments of HVAC installations.

Survey results confirm inconsistent knowledge among HERS Raters regarding which tests they are required to perform for specific installations. The full-length survey provided a mock changeout scenario to Raters, and survey responses suggest inconsistency in FV/DT procedures. Results suggest that Raters typically collect data in the climate zones where they are required to do so with the exception of duct testing: Raters accounting for only 71% of projects stated they would have performed this test even though the test should be performed for 100% of projects. Results also suggest that some Raters may collect or verify information that is not required.

7.4.4 Barriers to Standards compliance among HERS Raters

The third research theory we investigated was whether there are barriers to Standards compliance among HERS Raters. We specifically investigated the potential barriers of the time and the expense involved with proper HERS testing. Survey findings suggest that barriers to Standards compliance exist for HERS Raters, but that expense and time are not chief among them.

- When we asked Raters to rate their level of agreement with potential reasons that some Raters may not fully comply with the Standards requirements, their level of agreement was strongest with regard to a lack of technical experience. On a scale of 1 to 10 where 1 means "strongly disagree" and 10 means "strongly agree," Raters representing 75% of projects strongly agreed with the statement that "Raters may not have enough technical experience to perform a quality inspection" (ratings of 8 through 10).
- Additionally, when we asked for open-ended feedback from survey respondents, respondents most frequently cited a lack of experience and training.
- HERS Raters representing more than half of projects in California for 2014 also strongly agreed that a lack of enforcement by building departments and a lack of the proper equipment to perform the required tests were barriers to Standards compliance among HERS Raters.
- Interestingly, respondents did not indicate that time constraints were a barrier to performing quality inspections and complying with code. Raters representing less than a third of projects found this to be a barrier.

7.4.5 Barriers to Standards compliance among contractors

Similar to the previous theory about HERS Raters, we also investigated whether Raters believe there are barriers to compliance with Standards requirements for HVAC contractors. Overall, survey results suggest that HERS Raters do not believe contractors are knowledgeable regarding the Standards: using a 10-point scale in which 10 indicated "very knowledgeable" and 1 indicated "not at all knowledgeable," Raters accounting for half of projects suggest that contractors are not very knowledgeable (ratings of 1, 2, or 3) and Raters accounting for less than 10% of projects suggest that contractors are very knowledgeable (ratings of 8, 9, or 10).

Survey findings suggest several barriers to Standards compliance among contractors (from the HERS Raters' perspectives):

- Some barriers are systemic, such as contractors not obtaining permits if they think their installations will not comply, or focusing their work in local jurisdictions that do not consistently enforce some testing and verification requirements. Addressing these barriers would require modifying some aspects of enforcement or expending more resources on enforcement.
- HERS Raters cited additional barriers including contractors' lack of understanding of Standards requirements and knowledge regarding how to repair installations that fail HERS tests.
- Respondents also suggested that HVAC contractors did not believe that HERS Raters are necessary to make sure installations are correct.
- Nearly 60% of project Raters cited a lack of training as the key reason for contractors' lack of knowledge regarding the Standards.

7.4.6 Contractor awareness of HERS requirements

The fifth theory we investigated was HERS Rater perspectives on whether HVAC contractors find it difficult to keep up with changes to the Standards. If so, they may not be aware of the current requirements for HERS tests and inspections, which could lead to poor quality inspections.

Our HERS Rater survey results corroborated this theory. We found that overall, respondents were pessimistic about contractors' knowledge both of the 2013 code requirements for HVAC changeouts generally and with several different aspects of the Standards requirements. Raters suggested that contractors had several knowledge gaps and agreed that many poor-quality installations result from contractors having never been taught about Standards requirements. Among the open-ended survey comments on this topic, the most prevalent among HERS Raters was that contractors need more training and education.

7.4.7 Consistency of Standards enforcement across building departments

While the Standards apply across every jurisdiction in California, local building departments may enforce compliance requirements inconsistently throughout the state. This could be due in part to the fact that the requirements vary by climate zone and the lack of uniformity may result in misinterpretation of the code. In theory, this could cause confusion among contractors that operate within multiple building department jurisdictions and/or lead to contractors only adhering to the aspects of the code that are enforced most strongly across the majority of building departments.

We investigated HERS Raters' perceptions of the consistency with which local building departments enforce Standards requirements throughout the state and respondents generally agreed that building departments differ in their enforcement. Among HERS Raters who work with multiple building departments, Raters representing only 2% of projects said there was no difference among those departments in terms of how they enforce Standards requirements. Raters accounting for 70% of projects said that the different building departments either "somewhat" or "significantly" differ in their enforcement. More specifically, respondents were least confident in the ability of building inspectors in different jurisdictions to know what the requirements are and to do all of the required inspections.

7.4.8 Consistency of Standards enforcement within building departments

While there may be inconsistency across building departments, different officials within a single local building department may also enforce the HVAC compliance requirements inconsistently. This could also cause confusion among contractors and lead them to adhere only to the aspects of the code that particular building officials enforce most strongly. We thus explored the consistency with which different officials within a local building department enforce the Standards.

As with our results across building departments, we mostly found agreement among HERS Raters that different code officials within building departments differ in their enforcement of Standards requirements. Among the 23 HERS Raters who worked with multiple officials at the building department with which they most often do business, the majority reported they had observed differences. From the Raters' perspectives, the least uniform elements among building officials within the same department included treating all contractors equally and following up on open permits.

7.4.9 Adequacy of regulation for HERS Raters and Providers

The eighth and final theory we investigated was whether additional targeted regulation would improve the HERS Rater services and lead to better quality installations. As such, we explored HERS Raters' perspectives regarding whether there is adequate regulation for HERS Raters and Providers.

The full-length HERS Rater survey asked questions regarding three categories of regulations:

- Regulations for HERS Rater training and testing (including specific topics on which training should focus)
- Regulations for contractors
- Regulations as they relate to QA programs

Results suggest that HERS Raters perceive opportunities to improve regulations regarding field training requirements, and the survey's open-ended comments in particular cite deficiencies with the support provided by the HERS Registries in this regard. HERS Raters representing the majority of projects agreed that "most HVAC jobs are installed without a permit and there is little a HERS Rater can do to change that." Respondents also agreed that a contractor rating system would be a possible solution to improve contractor installations and improve transparency. HERS Raters suggested that the QA process may be an effective way to hold HERS Raters accountable and ensure they are performing all the required tests.

7.5 Conclusions

HERS Rater interviews generally confirmed the existence of the expected barriers to permitting and compliance that by homeowners, contractors, and Raters experience. The study found gaps and some discrepancies in the documentation for some of the permitted sites visited. Some contractors have a lack of knowledge or awareness about documentation requirements as well as which tests are required for which jobs. Varying levels of enforcement from building departments (both among and within departments) also contributed to inconsistent compliance.

8 CONCLUSIONS AND RECOMMENDATIONS

This study had three broad objectives regarding replacements of existing HVAC components or systems and installations of new central systems at existing residential dwellings (rather than new construction) in California:

- Estimate the percentage of HVAC installations that are permitted versus non-permitted
- Estimate the energy efficiency of residential HVAC installations of all permit statuses
- Assess the effectiveness of the HERS verification process

DNV GL pursued these objectives through a variety of study methods. The primary findings and conclusions include:

- As anticipated, the permitting rate was quite low and ranges from 8% to 29%. While the results of the top-down and bottom-up analysis did not converge, they both support the conclusion that the permitting rate remains a persistent challenge in California.
- A significant difference between the efficiency of permitted and non-permitted installations was anticipated, but the results revealed very few statistically significant differences. We expected the permitted installations to meet or exceed all requirements, but that was not the case, especially for the Inland region (climate zones 2, 4, and 8-16) where the HIE was about 70% for electric and gas. Non-permitted cases had a wider range of performance, but still the average HIE was greater than 60%. Many stakeholders anticipated a lower average HIE among non-permitted installations and have suggested that the result indicates a bias in the study methodology. We performed additional analysis to measure bias and found no evidence of what could be driving the bias but we cannot claim with certainty that some bias does not exist.
- Since the study anticipated that barriers to permitting and compliance would be well understood by HERS Raters, we interviewed a sample of Raters. The study generally confirmed the existence of barriers, including lack of knowledge on the part of contractors and homeowners, and inconsistent enforcement by building officials and departments. The study also found gaps and some discrepancies in the documentation for some of the permitted sites we visited.

8.1 Proportion of projects that obtain necessary building permits

The first objective of this study was to estimate the proportion of projects that complete the required building permitting process and comply with building energy efficiency standards. The permit rates estimated through the top-down and bottom-up approaches produced considerably different outcomes: 8% for the top-down analysis and 29% for the bottom-up. While the two do not align, this was not unexpected; two approaches were used because of the high levels of uncertainty and potential bias inherent to each approach. We believe that the true permit rate lies within the range represented by the two estimates; in other words, the top-down approach underestimates the permit rate whereas the bottom-up approach overestimates it.

To put our findings in context, we reviewed a number of previous permitting studies. In 2014, DNV GL used a bottom-up approach to estimate permit rates for central cooling equipment on behalf of PG&E.[78] The study estimated that 38% of non-incentivized residential cooling equipment was permitted using an approach

[78] PG&E, 2014.

similar to our bottom-up study. That report cautions that the results could not reliably be extrapolated to PG&E customers or state populations and that they should be treated as an indicator rather than a precise estimate. The 2014 study's approach differed from the current study's approaches in a couple of ways:

- **Geography.** The 2014 study covered PG&E's service territory whereas the bottom-up approach used the RASS sample frame and the top-down approach used statewide data.
- **Equipment type.** The 2014 study addressed cooling equipment only, whereas the current study also includes ducted heating equipment.

Two earlier sources provide lower estimates of permit rates. According to the CEC's testimony in the "Underground Economy: Contractors Failure to Pull Permits for Residential HVAC Replacements," approximately 10% obtain permits and meet verification requirements.[79] Another study performed by Proctor Engineering Group for Assembly Bill (AB) 758 estimated less than 30% of units were permitted in the Sacramento region.[80]

The CPUC set goals in 2011 to increase the permit rate to 50% by 2015 and to 90% by 2020.[81] Despite the uncertainties associated with the current analyses, we are confident that the true permit rate lies between our 8% and 29% estimates. Even at 29%, the permit rate is far below the 2015 goal. The results of the top-down analysis, combined with the inherent biases in the bottom-up analysis, suggest that the 29% is an overestimate of the permit rate. What is clear is that the state has a long way to go to meet a 50% permitting rate and will be challenged to reach 90% by 2020.

These goals were established based on the assumption that permitting leads to more efficient installations that would be more likely to comply with the Standards. These assumptions were tested through this study by conducting site visits for recent installations. In light of the findings of this study, our recommendations focus on improving energy efficiency of HVAC changeouts, and we do not recommend major efforts to solely increase permit rates.

8.2 Correlation between permitting and code compliance

The second objective of this study was to determine the energy efficiency of residential HVAC installations and determine the correlation between permitting and efficiency. The requirement-level results, detailed by each requirement, are summarized in Table 15 and provided in greater detail in Appendix I. Briefly, we found that:

- **Complete / full compliance:** Regardless of permitting status, there was 100% compliance with the requirements of the Standards that include minimum efficiency, duct insulation, and additional duct insulation requirements.
- **Programmable thermostats:** 87% of permitted installations had programmable thermostats while only 71% of non-permitted installations had them. This is a statistically significant difference. Field staff reported that it was common for homeowners in both samples to request non-programmable thermostats because of their simpler operation.

79 Pennington, G. W., 2014 and Institute of Heating and Air Conditioning Industries, Inc., 2013.

80 Proctor Engineering Group, 2012.

81 CPUC, 2011.

- **Refrigerant line insulation:** Refrigerant line insulation was in place, at least where field staff could observe it, for nearly all sites. At permitted sites, 93% of the installations had the necessary insulation whereas, at non-permitted sites, 100% had it. This is a statistically significant difference.
- **Refrigerant charge:** Refrigerant charge was within the proper range for almost two-thirds of the systems we tested. Refrigerant charge was not measured for packaged systems, however.
- **Airflow:** Overall, the minimum airflow requirement was met less than 20% of the time. Among permitted sites, 26% met or exceeded the minimum requirement; among non-permitted sites, only 14% did so; and among open permit sites, none did so. The extent to which the open permit sites differed from both the permitted and non-permitted sites is statistically significant. Some homeowners remarked to field staff that they had asked the contractor to reduce fan speed to minimize noise or drafts from the system. These data suggest the possibility that—at those sites with open permits—a decision was made not to close the permit when it became evident that the site would not be in compliance.
- **Fan power index**: The maximum fan power index requirement was met by about two-thirds of both the permitted and non-permitted installations.
- **Duct leakage:** A little more than half of permitted sites in the sample passed the duct leakage tests as did slightly fewer than half of non-permitted sites. The actual rate of compliance may be higher, however, if any contractors opted to use the smoke testing compliance path at installations visited.

We reported individual results for duct leakage, airflow, and fan power index but these results, along with the installed system's static pressure, are interrelated. We present these results so that stakeholders can consider these interrelationships and the resulting design constraints in future program design and code development.

For the electric HVAC installation efficacy (HIE) assessment, all of the Coastal sites are well above 50% HIE and most are near 100% HIE, but only a few are fully compliant (with a 100% HIE). No strong pattern exists between permitted and non-permitted groups. In the Inland region, there are many sites between 50% and 100% HIE with a few at 100% and a few below 50%. Again, there is no distinct pattern based on permit status. While the trend is for greater efficacy in the Coastal climate region, this region has fewer compliance requirements than the Inland region. In the Inland region, the weighted average efficacy is lower and there is less variability between the sites in the sample. For both the Inland region and statewide, the weighted average efficacy for permitted installations does not significantly differ from that at non-permitted installations.

For gas efficacy, the results differ somewhat from those for electric, but these differences are not significant. Some sites had relatively low gas efficacy when no changes had been made to heating components. This was due to changes to cooling components that led indirectly to small gas impacts. Greater gas efficacy tended to occur at sites with changes to heating components. These polarized gas efficacy results led to slightly larger error bounds and showed no significant difference between permitted and non-permitted changeouts. A larger sample may be needed to determine the average gas efficacy of residential HVAC changeouts. A larger sample might also make it possible to distinguish between the gas efficacy at sites with furnace changeouts and those without.

In summary, we concluded that the permitted and non-permitted installations had similar requirement-level compliance rates and energy efficiency. Furthermore, these metrics were both lower than expected for permitted installations and higher than expected for non-permitted installations. Since the potential bias identified for the bottom-up permit rate analysis also applies to the on-site findings at non-permitted installations, these results have greater inherent uncertainty than those for permitted installations. The compliance and efficacy results for the permitted installations are more likely to be representative of the population.

A standing hypothesis is that the training and information provided by the CEC, IOUs, CPUC, and others—both within and outside of the permitting process—have improved contractor practices that lead to improved energy efficiency and installation quality. If true, it may partially explain the trend of increasing installation quality despite stagnant permitting rates in the decade since the Standards were put into place. Furthermore, the narrow gap between permitted and non-permitted installations may pose an additional barrier to achieving the state permitting goals as these results become more widely known.

While it may be a challenge to maintain the goal of achieving 90% permitting by 2020, it will also be important to improve the energy efficiency of permitted installations. Hence, many of our recommendations focus on what improvements are needed for permitted residential changeouts. Our recommendations support statewide legislation including AB802 and AB758 that emphasize improving all possible system deficiencies directly.

For the CPUC and utility programs, it may not make sense to continue targeting increased rates of permitting without also increasing efforts to improve system efficiency. This means that incentives to offset the cost of permits to drive higher permitting may not produce expected energy efficiency benefits. Most importantly, to improve compliance in existing programs the IOUs should continue to support training as it appears to have contributed to higher than expected efficiency for the overall installation market. Community Choice Aggregators (CCAs) and Regional Energy Networks (RENs) as well as other jurisdictional entities should work to improve the overall permitting and enforcement market. Given that statute already dictate permits for IOU program participants, programs that incentivize system efficiency improvements would still likely raise permitting rates to some degree.

In summary, achieving the state's goal of 90% permit rate by 2020 should likely not be a primary energy efficiency strategic goal. Equal or greater effort should be focused on improving the permitting and enforcement market.

Our recommendations for improving energy efficiency efficacy include:

1. The CEC should develop energy modeling software for existing residential buildings to inform estimates of the energy saving potential for changeouts in existing residential buildings. While DNV GL created metrics to measure compliance and made use of current information from workpapers and DEER, the absence of a functioning model prevents stakeholders from making realistic predictions about the impacts associated with the set of compliance measures required. We recommend the model include features such as a cost calculator to factor average costs estimates for permit and compliance requirements including HERS certification.
2. Streamline and simplify statewide codes for the mandatory and prescriptive HVAC requirements across climate zones. Contractors and building departments may not have the resources or interest to understand or enforce the nuances of the code and how they differ by climate zone. This would build on the Energy Code Ace[82] efforts, which provides free online energy code training, tools, and resources for understanding and meeting Standards requirements.

[82] https://energycodeace.com/content/about/

3. Reevaluate necessity of codes that, effectively, provide no energy impacts. Consider new cost calculations that explicitly show non-energy cost savings or extended equipment life to improve the value proposition.
4. Design forms that reduce the paperwork required for code compliance.
5. Sponsor legislation to support improvement in permitting and enforcement practices.
6. Consider the requirement that only licensed contractors could operate in the HVAC installation market with periodical re-certification.

8.3 Efficacy of HERS Raters and if inspected jobs meet Standards requirements

The third research objective was to assess the effectiveness of the HERS verification process. This involved interviews with HERS Raters to test eight categories of theoretical barriers. The barriers and the associated findings are summarized below. Since the findings regarding the first three barriers are mixed, they are divided into two groups: validating findings and countervailing findings. Then, where appropriate, we provide recommendations to address identified barriers. Overall many of the theories were validated in the interviews, identifying a number of barriers for all of the involved market actors.

Theory 1: Training is expensive, not readily available, not effective (e.g., includes no or limited field training), and/or training material is inconsistent among training HERS Providers.

✓ Validating: Results suggest that the key barriers associated with training for HERS Raters relate to a lack of hands-on elements in the training for certain diagnostic tests, inadequate training regarding how to complete the CF-3R form(s), and inadequate training on the using Registry websites to submit testing results. Training participants were less than satisfied with the cost of training.

o Countervailing: There was no evidence of widespread dissatisfaction with the location or frequency of the training opportunities. Additionally, while a couple of respondents mentioned inconsistencies among HERS Provider training, this was a relatively minor issue compared to other, much more prevalent issues brought up by respondents (such as the challenges faced in completing the required CF-3R compliance forms and uploading them to the Registry).

➢ Recommendation: Evaluate HERS Rater training for field-testing procedures intended to assess prescriptive measures. Also, consider developing mentoring programs for new Raters.

Theory 2: Inconsistent knowledge among HERS Raters of the Standards leads to inconsistent/erroneous assessments in customers' homes.

✓ Validating: Survey findings confirm there is inconsistent knowledge among HERS Raters for which tests the Standards require. For the mock changeout scenario (as described in Appendix T, research question two) presented to Raters in the online survey, they showed inconsistent field verification/diagnostic testing (FV/DT) procedural knowledge. Assuming these Raters would perform the same activities when applied to real world applications, results indicate inconsistent FV/DT testing and/or verification procedures. For some requirements, we found Raters are collecting or verifying requirements that are not their responsibility or not performing all the tests they should. Our results corroborated the notion that there are barriers to conveying failed test results to contractors and that additional tools would be beneficial.

- o Countervailing: In climate zones where Raters are responsible for collecting diagnostic testing data, results show that Raters accounting for the majority of projects (90%) are appropriately collecting all of the necessary data. There is one exception, however: Raters accounting for 29% of projects indicate that they would not have performed this duct leakage testing when required.
- ➢ Recommendation: Find creative ways to reiterate diagnostic testing requirements periodically.

Theory 3: There may be barriers to Standards compliance among HERS Raters including the expense and time associated with HERS testing.

- ✓ Validating: Raters believe there are barriers to compliance with Standards requirements. Chief among these was a lack of technical experience and training to perform the required inspections. When we asked Raters to rate their level of agreement with potential reasons for not fully complying with the Standards requirements, the level of agreement was strongest with regard to lack of technical training. Raters also reported challenges with completing the required CF-3R and uploading it to the Registry, which could reflect both a lack of training and technical barriers to using the Registry. HERS Raters reported a lack of enforcement by building departments as a serious barrier.
- o Countervailing: Interestingly, respondents did not feel that time constraints were a barrier to performing quality inspections and complying with code.
- ➢ Recommendations: Improve the process for submitting forms and provide technical training on new methods. Explore ways to provide information in mobile-based or web-based forms so that data enters a database directly, allowing specific forms to be populated electronically. An additional potential benefit would be to allow homeowner access to information about their HVAC system performance.

Theory 4: There may be barriers to Standards compliance among contractors including the expense and time associated with HERS testing.

- ✓ Validating: From HERS Raters' perspectives, there are several barriers to HVAC contractors complying with the Standards requirements. Some of these were systematic barriers, like not obtaining permits when they think their installations will not comply, or working in local jurisdictions that do not enforce all of the testing and verification requirements. Another barrier cited was a lack of understanding of Standards requirements among contractors, as well as how to repair installations that fail HERS testing. Finally, it is thought that HVAC contractors are not convinced that HERS Raters are necessary to verify correct installation.
- o Countervailing: None.
- ➢ Recommendation: Improve the marketing and branding of the HERS compliance process. Improve customer awareness of permit and compliance requirements for HVAC changeouts. Presently, there are very few relatively recent articles online to promote the program.
- ➢ Recommendation: We recommend the CEC and IOUs improve engagement with California's Contractors State Licensing Board (CSLB) to establish additional requirements for C-20 contractors. Specifically, encourage them to adopt requirements for continued education training courses and leverage IOU resources such as "Energy Code Ace." In order to get all parties in the value chain on the same path, we recommend establishing requirements for building inspectors to participate in continued education training courses.

Theory 5: Contractors may find it difficult to keep up with changes to Standards, which may contribute to poor-quality installations.

- ✓ Validating: Overall, respondents were pessimistic about contractors' knowledge, both of the 2013 code requirements for HVAC changeouts generally, and with several different aspects of the Standards requirements. Raters suggested that contractors had several knowledge gaps regarding the Standards that contributed to poor-quality installations.
- o Countervailing: None.
- ➢ Recommendation: Develop a statewide, online permit database that allows customers and contractors to file permit requests remotely and access permit status and compliance documents.
- ➢ Recommendation: We recommend the CEC and IOUs engage with California's Contractors State Licensing Board (CSLB) to encourage them to adopt requirements for continued education training related to Standards and changes to Standards.

Theory 6: Enforcement of HVAC compliance requirements by building officials is inconsistent *between* building departments.

- ✓ Validating: There was general agreement that building departments differed in their enforcement of the Standards requirements. Among Raters who work with multiple building departments, those representing only 2% of projects reported no difference among those departments; those accounting for 70% of projects reported that jurisdictions either "somewhat" or "significantly" differ in their enforcement. More specifically, Raters have little confidence in the building inspectors' knowledge of Standards requirements and inspections required. In particular, verbatim responses to open-ended questions pointed to the prevalence of building departments requiring duct testing, but not requiring other tests and verification measures.
- o Countervailing: None.
- ➢ Recommendation: The CEC could work with building departments to have HERS Raters perform all HVAC inspection points with marginally increased fees and then offload building department staff from doing HVAC replacement inspections. This would allow homeowners to only pay for a single inspection instead of one from the building department and another from a HERS rater.
- ➢ Recommendation: Create a compliance complaint line to be used by contractors, HERS Raters, and homeowners who believe building departments are not providing adequate enforcement.

Theory 7: Enforcement of HVAC compliance requirements by building officials is inconsistent *within* building departments.

- ✓ Validating: As with our results across building departments, we mostly found agreement that different code officials *within* building departments differ in their enforcement of Standards requirements. Among the 23 HERS Raters who worked with multiple officials at the building department with which they most often do business, Raters accounting for approximately three-fourths of projects reported having observed differences. From the Raters' perspectives, the least uniform characteristics among building officials within the same department included equal treatment of contractors and following up on open permits.
- o Countervailing: None.

Theory 8: Additional regulation will improve the HERS Rater services and lead to better-quality installations.

- ✓ Validating: The HERS Rater online survey asked questions regarding three categories of regulations: regulations for HERS Rater training and testing (including specific topics on which training should focus), regulations for contractors, and regulations as they relate to quality assurance (QA). HERS Raters perceive opportunities to improve regulations regarding field training requirements and, in particular, cite deficiencies with support provided by the Registry. The HERS Raters accounting for the majority of projects agreed that "most HVAC jobs are installed without a permit and there is little a HERS Rater can do to change that." This suggests that, even with additional regulation, compliance gaps will persist due to low levels of enforcement. Respondents agreed that a contractor rating system might improve contractor installations and improve transparency. Last, HERS Raters suggested that the QA process may be an effective way to hold HERS Raters accountable for performing all required tests.

- o Countervailing: None.

- ➢ Recommendation: Improve the marketing and branding of the HERS compliance process. Improve customer awareness of permit and compliance requirements for HVAC changeouts. Presently, there are very few relatively recent articles online to promote the program.
- ➢ Recommendation: Consider enforcement paths other than penalty fees (e.g., HERS requirements, inspections at the time of sale).

8.4 Recommendations for IOUs

Given the findings and conclusions, we offer the following recommendations for IOU program planners and staff:

- Evaluate current residential pilot programs that aim to increase permit rates in light of this study's findings and current regulations aimed at addressing permitting within energy efficiency programs (e.g., SB1414). In particular, we recommend that such programs:
- Inform homeowners that the permitting responsibility is theirs and that they must hold contractors accountable.
- Have program contractors emphasize other potential benefits of permitted installations for customers, and consider literature for homeowners that does the same. Given that the Standards already dictate permits for IOU program participants, programs that incentivize system efficiency improvements (such as Home Upgrade or Quality Installation) should raise permitting rates to some degree.
- Leverage local government partnerships and non-IOU program administrators where feasible. Community Choice Aggregators (CCAs) and Regional Energy Networks (RENs) can administer energy efficiency programs under the same guidelines and funding mechanisms as the IOUs. However, these local program administrators could work directly with the building departments in their regions to improve their enforcement processes over multiple years. Because of the large number of building departments in each IOU's service territory, it may be less feasible for the IOUs to work directly with the building departments.
- Based on findings from the HERS interviews, we recommend the IOUs continue to support workforce education and training (WET). Studies from the early 2000s identified a number of issues related to HVAC changeouts. The 2005 update to the Standards addressed these issues. We also know the IOUs have supported WET during the same timeframe. As an example, the Standards require temperature measurement access, and we found this at over 80% of non-permitted installations. This would indicate

installer knowledge of some aspects of the Standards. We believe that in the current market these IOU and CEC trainings affect contractors that perform both permitted and non-permitted installations. Future studies on permit rates and compliance should account for any changes in WET efforts as they may affect installation quality regardless of permit status.

- Leverage this study's performance test results to support workpaper inputs for measures addressed in the Home Upgrade and Quality Installation programs. This includes information regarding cases in which code requirements are not triggered, such as equipment-only replacements or system airflow in certain climate zones. The appendices of this report (Volume II) include summaries of data collected at sites that go beyond the analysis of compliance and energy efficiency associated with compliance. There are specific opportunities where code is not triggered based on installation scope and some limited opportunities for improvement above code where code is triggered. While we did not find statistically significant differences based on permit status, current practice (permitted or not) on average does not meet full compliance.

8.5 Recommendations for key stakeholders

Continued collaboration between the California Energy Commission (CEC) and CPUC is essential to continue improving the energy efficiency of HVAC installations in California. This could take the form of simultaneous improvement in permitting and enforcement processes, improvement in efficacy of the inspections process, or through other means. We also recommend the following:

- The CEC and CPUC should consider developing energy modeling software or approaches for existing residential buildings to estimate the energy saving potential for changeouts in all low-rise residential dwellings. The California Technical Forum may be a venue for this collaboration since it includes the IOUs and the largest publicly-owned utilities in California. The absence of a functioning model prevents stakeholders from making realistic predictions about the impacts associated with the required set of compliance measures. The absence of such a model also necessitated the creation of metrics by this study using secondary information. We recommend the model include features such as a cost calculator to factor average costs estimates for permit and compliance requirements including HERS certification.
- Assuming the HERS process will continue to be used in compliance enforcement, the following recommendations could improve the State's oversight of the HERS Registries and improve the efficacy of the HERS verification processes:
  - If stakeholders pursue further research regarding HVAC permitting and compliance, the CEC and HERS Registries should take action to ensure access to information to support future research efforts. For instance, terms for sharing compliance data collected with researchers, including results of HERS tests could be added as conditional for certification of registries in the future Title 24 updates.
  - Additionally, the CEC and HERS Registries should take action to ensure public access to information collected by HERS Raters for the benefit of homeowners. The documentation required in the HERS process includes measurements of home performance, but these documents are not required to be provided to the homeowner or to the building department for later access. Streamlined access could be achieved by mandating building departments retain the compliance forms or by the CEC retaining the forms or by Registries responding to requests for information. Information regarding a current or prospective home's performance characteristics could be valuable to homeowners.

- The CPUC and IOUs should inform stakeholders of energy efficiency requirements currently being met for permitted installations, including the results of this study and general research in HVAC performance.

- The CEC should take action to streamline and simplify statewide codes for mandatory and prescriptive HVAC requirements throughout California. Contractors and building departments may not have the resources to understand or enforce the nuances of the code or the interest in doing so. The CEC should also consider designing forms that reduce the paperwork required for code compliance.
- The CEC should take action to reevaluate, from an energy efficiency perspective, codes that effectively provide no energy impacts or verification benefits. This includes requiring calculations for sizing without a corresponding requirement to reduce size whenever possible. The CEC should consider new cost calculations that explicitly show non-energy cost savings or extended equipment life to improve the value proposition.
- To increase the incidence of HVAC inspections, building departments should consider requiring duct testing and performance measurement for air conditioners at the time of sale for existing homes. Homes should be required to be "to code" when sold. Such a requirement would be easier to enforce than permitting at time of replacement and would be difficult to ignore, as several other inspections are ordered at time of sale. The City of Davis has already adopted this model for existing home sales. Another option would be to provide homebuyers with a path to order a HERS rating just as they can order other inspections during sale negotiations.
- Building departments should eliminate inconsistent enforcement of the Standards among employees through more routine training and internal auditing.
- Building departments and HERS Registries should improve coordination to eliminate open permits.
- The Contractors State License Board should consider requiring workforce education and training credits for C-20 contractors to verify knowledge of the Standards and HERS process.
- Training for contractors and HERS verification Raters should emphasize the interrelationships among static pressure and the duct leakage, airflow, and fan power index requirements. This training should also emphasize the importance of proper duct system installation and its effect on a system's ability to meet these requirements.

8.6 Future research needs and priorities

Additional research on residential HVAC compliance can provide additional insights and also provide indications of changes in market and enforcement conditions. Specific research topics and approaches could include the following:

- Study whether spillover savings may exist for the CEC's and IOUs' workforce education and training efforts. The relatively high rates of compliance and energy efficiency at non-permitted installations among non-participants in energy efficiency programs may be indirectly attributable to these efforts. This study did not pursue evidence suggesting this connection, but such a connection is plausible. It may be important to acknowledge that these trainings are being taken by contractors who are not pulling permits. This implies the education and training to improve compliance affects the broader HVAC replacement market and not just permitted installations.
- Perform a "secret shopper" study where researchers pose as homeowners in need of HVAC replacements in regions of California with high uncertainty of permitting and compliance. Consider working with Contractors State License Board and specific building departments to identify the worst installation cases that may avoid scrutiny. The actual volume of the extreme cases is a particular research question to answer.

- Continue analyzing performance data; If data access is improved as recommended in the previous section, compliance data collected by HERS Raters can be mined and analyzed to help target insufficient installation practices. Reviewing detailed data can help to track progress toward improving compliance of HVAC replacements. In general, we encourage future study designs that measure performance to consider modeling and measurement and analysis options.

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APPENDIX A. PUBLIC COMMENTS AND RESPONSES

Page or Section	Para-graph	Comment	Source	DNV GL Response	Change to Report	Location of Change in Report
N/A	N/A	The report repeatedly makes the point that all dwellings in the study were single-family homes. What then is the relevance of the reference to multifamily homes in note #35?	Nehemiah Stone	We included the reference to multifamily homes to provide an example of why, statewide, the ratio of units to permits might be greater than 1.	N	
5	2	On page 5, 2nd paragraph, the report notes that homeowners asked contractors to reduce the air-flow due to noise concerns. This suggests that the CEC (re: Standards) and the utilities (re: programs) should require quieter (lower some) fans. ...to 1.0 or less.	Nehemiah Stone	We debated recommending that the CEC and CPUC consider low-noise, high-efficiency fans but decided that the evidence is anecdotal and not sufficient to justify such a recommendation.	N	
1.3.3	2	Based on the 2nd paragraph in 1.3.3, it appears that another study is in order, to determine if the problem is non-compliance or performance degradation over time, since there will be	Nehemiah Stone	Per the report, even with HERS inspections there are significant deficits in duct leakage, airflow, and refrigerant charge only a few years after installation. But we are not suggesting that our results were influenced by system degradation over time; it	N	

		different solutions.		was mentioned only to acknowledge the passage of time as one of many possible causes. It's not clear that any viable study could answer the question without long-term monitoring starting soon after installation.		
1.4		Section 1.4 is misnamed since there are no recommendations in this section.	Nehemiah Stone	Correction made to report	Y	Section 1.4 rename d
1.6		In Section 1.6, the 2nd sub-bullet under the 2nd bullet, DNV makes the suggestion that building departments retain compliance forms in order to facilitate later research/analysis. BDs regularly purge documents related to finalized permits and un-finalized permits past a certain age. Some do this with archive boxes stored off-site and others simply toss the old docs. Expecting them to hang on to energy code compliance forms is not a real solution, since it won't often happen.	Nehemiah Stone	As BDs become more digitalized and move to online forms submission, this could allow indefinite archival storage and reduce the effort needed to file, store, and purge records. Compliance forms are stored with other types of permits - since BDs are provide them for verification they could retain the documentation and store them in the files.	N	
1.6		In 1.6, 7th (high-level) bullet, DNV suggests BDs require HERS testing at time of sale. This is a great idea, except for the resistance	Nehemiah Stone	The approach has been successfully deployed in the city of Davis. We recommend exploring the option of requiring HERS verification testing to	Y	

		it will receive from CAR.		ensure that HVAC systems are "to-code" at time of sale, recognizing that there will be challenges at the state and jurisdiction level.		
1.6		In 1.6, 8th bullet, DNV suggests HERS Raters doing all the inspections for replacement HVAC equipment, reliving BDs from the task and reducing the number of inspections homeowners need to pay for. This would take careful consideration since there are things the BD has to inspect for that HERS Raters aren't trained on. e.g., gas line pressure testing, electrical code, etc.	Nehemiah Stone	We recommend exploring the option and recognize there may be challenges at the state and jurisdiction level.	N	
8.5		In Section 8.5, 1st bullet, DNV suggests creating new software for modeling all elements of an HVAC change-out in single-family homes. I'd like to suggest that the software should also be designed to work for MF too.	Nehemiah Stone	The study can generally recommend this effort be considered for all low-rise residential buildings.	Y	Page 95, Section 8.5, first bullet point

N/A	N/A	It is SCE's experience that residential HVAC systems have a longer lifetime than 15 years as assumed in the report. This would imply that permit compliance rates are much higher than calculated in this report. Are there any studies to confirm that the assumed "15-year" lifetime is accurate? From anecdotal evidence of everyone that I know that have replaced residential HVAC systems, lifetime is 25 years or more. If there is not support from studies that actual lifetime is 15 years, then a range should be given such as 15 to 30 years.	SCE	The life of an individual unit could be greater than 15 years, but the effective useful life estimates half of the installed population will fail by year 15. Some individual units may last up to 30 years per the Weibull distribution. The 15-year EUL is based on our review of recent retention studies, utility workpapers, and related literature. Our estimate is adjusted by usage such that units with lower usage could have greater than 15 year lives in milder climates.	N	
N/A	N/A	Not all central HVAC units are replaced with like systems due to homeowner financial issues. Some simply cannot afford to replace the existing system. In many cases, central HVAC units are replaced with window air conditioners that provide cooling only where needed.	SCE	We took care to use like-with-like replacements for this study by screening out dissimilar equipment replacement (e.g. replacing a split system with a PTAC.)	N	

N/A	N/A	SCE supports the conclusion of this study that the code compliance and energy performance of permitted residential HVAC replacement systems is similar to that of non-permitted systems. Feedback from the building inspector community (from the thousands building inspectors that participate in utility training programs over the years) supports this study conclusion.	SCE	N/A	N	
N/A	N/A	The study uses 2003 and 2009 RASS saturation data for regression analysis. They extrapolate the data for following years. Although the executive summary doesn't explain this method, the report does discuss the limitations of using this data in the study's analysis. Because of the limitations, the study's conclusion should be viewed with some skepticism. Even if more recent data was used (if available), the CPUC's goals of 50% permit rate for 2015 and 90% permit rate by 2020 (90%) may not be achievable. The study	SDG&E	N/A	N	

		provides a good discussion about the "underground economy" that exists among HVAC system installers. Unless an effort to curb this activity through stricter enforcement in the contractor community, non-permitted installations will continue to undermine the permit process and compliance efforts.				
N/A	N/A	The study also didn't provide enough discussion about whether the sample size they used was enough to make statistically significant inferences about the population of installations. Are the sample sizes sufficient so that the conclusions are reliable?	SDG&E	In Section 5.4 and 5.5 we do provide sampling errors for key outcome variables. Overall, we believe the samples to be reliable. The samples cannot support cross-tabulation or precision at more granular levels. The onsite sample size was a budget trade off with the other samples and efforts in the study. During the development of the research plan we requested comments where we detailed the sampling strategy and no alternatives were suggested. Given the lack of previous studies, an outcome of the study is that an estimate can now be made of required sample size to achieve greater precision.	N	
N/A	N/A	It would have been nice if the study did an AMI analysis when they are	SDG&E	This can be considered as a follow up analysis in future EM&V roadmaps.	N	

		discussing the energy efficiency of HVAC permitting. Could that be possible for some selected customers?				
N/A	N/A	The study suggests that contractors drive the decisions about permitting in most cases. However, most of their recommendations include more educative and informative prescriptions. Would it be possible to have a randomized study (pilot) using varying information or incentive intervention to determine which type of interventions are effective using behavioral factors?	SDG&E	This could be considered. This study did not specifically develop information on what may be most effective for customers or possible study designs. Pilots can be developed through the exisitng ideation process.	N	
N/A	N/A	Also, on the consumer side, information about HVAC installation quality, equipment efficiency and durability, etc., could be too complex for most customers to understand. Information provided at the time of purchase (especially at equipment failure) might have little or no effect on the decision. As a result, customers may choose the simplest solution in order to get their system operational	SDG&E	Our recommendations are made in the context that permits are required already, but customers are unaware or indifferent under current market conditions. The Standards are meant to apply to every installation so even the cheapest one is done well. Customers may not understand the details but well-tailored messaging that clearly presents the risks and benefits could engage customers. Programs may be able to play a role in creating	N	

		as soon and as cheaply as possible. In this regard, it is felt that the recommendations lacked a thorough understanding of the consumer's buying decision process. Forcing mandatory measures and other regulatory restrictions could further exacerbate the "underground economy" that currently exists in this market.		materials for this messaging.		
N/A	N/A	IHACI regards as critical the performance by licensed contractors of work under permit, in counterpoint to the prevalence of work in the present environment, as the Assessment indicates, substantially outside either requirement.	IHACI	N/A	N	
		The changing emphasis on energy compliance in installation is a work in progress from both a regulatory and market needs perspective. Some approaches such as consumer rebates and incentives have affected the consumer mindset, but in so far as they are not tied to regulatory verification for permit issuance and could not, as practical	IHACI	N/A	N	

		matter be so linked, are primarily educational in impact.				
		It is neither clear nor verifiable that a compliance mandate is part of the mindset of enough of the construction community, the issuers of permits, or of the workers doing the installations.	IHACI	N/A	N	
		The report concludes that there is no difference in efficiency between a permitted system and an unpermitted system. While the permit itself may not lead to higher efficiency, the requirements of the energy code which is triggered by the permit DO make a system more efficient. The inference of this report that a, "permit doesn't affect efficiency", is misleading and dangerous to increasing efficiency of HVAC systems in California. A permit is the necessary entry point to ensure that systems are installed	IHACI	Our conclusion should not be taken out of context. We do not dispute that the permit process may have other benefits. Given the current enforcement practices and other market conditions, the permits are not achieving the expected energy efficiency benefits. Enforcement and broader market practices and dynamics must be improved for permits to achieve the expected results. Commenters should review "Table 15. Summary of requirement-level compliance results of onsite inspections" and the related chapter to learn about the findings concerning this topic. We provide and welcome recommendations	N	

		correctly. Without a permit, these installations are outside the energy code and the State has no way to monitor or verify that systems are being installed properly.		to improve energy efficiency of HVAC installations regardless of the permit status.		
		IHACI questions if the data sample from the RASS study is a representative sample of installed jobs. The most obviously glaring problem is that the study shows that 100% of the permitted jobs evaluated had a load calculation done. Our experience is that very rarely does a building department ask for a load calculation on a residential change-out. New construction, yes, change-out, no. A 100% correlation should cause serious concern over the quality of the sample.	IHACI	DNV GL would like to clarify this point. Since load calculations are a permitting requirement, DNV GL assumed that they were performed in all cases where a permit was issued and that they were not performed in cases where no permit was issued. DNV GL did not request or receive any load calculations for any project we evaluated.	Y	Page 55, "Load calculations" bullet. Reviewed ES and CH8, found no changes necessary there.

		IHACI rejects any suggestions that the scope of HERS raters be increased. Permitted jobs are subject to HERS inspection. Unpermitted jobs are not. The fact that there is no statistical difference between permitted and unpermitted jobs should cause all parties to pause and question the HERS model for verifying compliance. This certainly requires further investigation, and alternative pathways to compliance with title 24 should be explored.	IHACI	The study report mentions that if the current processes continue we offer certain recommendations. We are not able to make broader policy recommendations which must consider many sources of information including this study. Recommendations on other policy changes are encouraged to be put forth in Title 24 rule-making.	N	
Table 15	Airflo w	This report shows that 81% of the systems measured did not pass Airflow requirements. Airflow repairs are one of the most expensive and unknown factors in a system change-out. Unless airflow is checked in advance, there is no way to predict if the new equipment will deliver the required airflow. This again becomes a major training problem. Contractors as well as HERS raters struggle to properly measure airflow. Homeowners are very reluctant to pay for duct system upgrades that are often required	IHACI	We agree with the recommendation for training. In general we would consider duct design and fan settings to drive the results more than the condition of the filters. The Appendix has additional the field testing procedures and data on measured operating pressures with existing filters and any unusual conditions our field staff encountered.	N	

		for proper airflow. IHACI strongly recommends additional training for contractors, HERS raters as well as homeowners on this issue. Appropriate follow up questions include: (1) What was the condition of the system when the follow-up test was performed? (2) Had they been maintained? (3) Were the filters clean? (4) Could this have been a cause for low airflow rates?				
Table 15	Fan Power Index	The Fan Power Index is directly related to the static pressure of the installed system. This goes back to proper airflow and duct leakage. If the duct system is not installed properly, the proper Fan Power Index will not be met. Contractors and HERS raters both need proper training to properly implement this requirement.	IHACI	The recommendations have been edited to articulate this point. The duct leakage, airflow, and fan power index are all interrelated and design constraints exist. The study reports what we found for these metrics so that stakeholders can consider this further in program design and code development.	Y	Page 89, Section 8.2; added the first paragraph following the bullet points (conclusion). Page 95, Section 8.5; added final bullet point (recommendation).

Table 15	Measurement Access	It is worth noting that although the reports indicates that 86% of non-permit, 89% of open permit and 85% closed permit have them, field experience would likely show otherwise.	IHACI	Trained DNV GL field staff recorded the presence or absence of measurement access holes, so we respectfully disagree that field experience would likely show otherwise; field experience forms the basis of our finding.	N	
Table 15	Static Pressure Probe or Hole	On this point the analysis reports 67% of jobs with no permit, 63% open and 62% closed. Field experience suggests that it is unlikely that a higher percentage of non-permitted jobs have static pressure probe holes.	IHACI	These values are derived from direct observation by DNV GL field staff.	N	
Table 15	Duct Leakage	44% of closed permitted systems fail the duct leakage requirements. This clearly shows that HERS raters are marginally effective at monitoring contractor installations. 47% of the jobs passed with no permit or HERS inspection. If HERS raters are to be part of the compliance verification process moving forward, they must be able to show that their rated jobs are more efficient than an unpermitted, unrated job. It is also worth studying that duct line	IHACI	Our study was to assess compliance aspects and the current process and was not meant to imply that HERS verification processes measure efficiency. We also did not attempt to make a system performance measurement over time due to project constraints, but we are confident that our measurements provide a valid measure of efficiency and that they support our conclusions. We encourage future study designs that measure performance independent of permit status. We have modified the recommendation to include	Y	Page 97, final bullet point. Added final sentence.

		set and minimum equipment efficiency are already controlled at the supply house. Furthermore, the comment that: "there is no difference in efficiency between a permitted system and an unpermitted system", taken in context, conflicts with the actual measurement of efficiency. In this sense, HERS cannot not measure efficiency. The analysis seems to assume that meeting all the HERS check points equals efficiency. Efficiency is measured with tools over a period of time. To determine true efficiency you must measure it, it cannot effectively be modeled.		considering modeling and measurement and analysis options in the future.		
N/A	N/A	Education of workers and contractors through IOU and other training programs, including union and other apprenticeship programs should be a controlling priority. This is both a qualitative and quantitative factor because pride of workmanship, in an individual trained worker, is itself an incentive towards compliance. Training is	IHACI	The recommendation in the report is for ongoing training for all involved parties; this recommendation is supported by the findings.	N	

		also quantitatively important, especially in the context of the shortages of trained workers in the context of growing new California skilled and trained workforce requirements. Workers shortages, in effect, incentivize noncompliance, as unlicensed contractors turn to unidentified labor pools to staff their projects training them “on the job”. Finally, training is perhaps the most accessible and reliable of all tools to producing measurable change. Accordingly, a metric for assessment that identifies who has been trained in the tools of compliance, can be an independent analytical tool in an overall compliance assessment going forward.				

		CalCERTS, Inc. acknowledges the importance of objective assessments to gauge the effectiveness of the Energy Efficiency Standards and guide future policy decisions. Designing a comprehensive study to accurately reflect the diverse nature of California's building stock, climate zones and economic demographics is an extremely challenging task that should be critically examined to avoid arriving at inaccurate conclusions. CalCERTS would like to take this opportunity to express our reservations about the methodology and findings offered in DNV-GL's report and suggest that this report is inconclusive and should not be used to guide policy decisions. Overall, too many variables were introduced into this study without adequate controls to account for the inclusion of projects subject to both 2008 and 2013 Standards.	CalCERTS, Inc.	We agree that a comprehensive sample is of great importance, which is why the sample frame we used (RASS, 2009) was sourced from a statistically representative sample of households in CA. The variables included in the study are requirements as triggered by the Standards for HVAC changeouts in CA for existing buildings. Each 3-year code cycle change includes modest increases in requirements. We included samples from both cycles and evaluated differences in permitting by code cycle and also given the similarity in the codes, we also pool cases for a more robust sample. The CPUC directed this study and solicited input from the CEC and stakeholders. While we acknowledged there are areas of uncertainty, the data gathered and analysis are robust and they substantiate the results and recommendations. As such, it is appropriate for the CPUC to use the study to help guide program administrators' program and policy directives as needed.	N	

		It is important to note that the 2013 Standards introduced significant new requirements, duct leakage and airflow/fan-efficacy, into several CZ's (climate zones) which had not previously been subject to HERS verifications. Installers and building inspectors in those CZ's were assimilating new requirements into their workflow during the timeframe of this study.	CalCERTS, Inc.	We recognize that the code changes every three years and each time it changes there are new requirements for Raters, Contractors and Code Officials to modify or adopt. The study evaluated difference in requirements for each code cycle and for both codes collectively. The context for any future large scale studies will also likely look at two code cycle since as one is ending, there's another starting. Studies launched as code cycles start have few cases of new code to investigate and studies at end of cycles may provide information too late to influence the next code.	N	
		Additionally, the study was based on a limited number of sample sites dispersed over a very wide range of CZ's. Based on the study's top-down estimate of just over 1M HVAC change-outs in 2014, the 200 site visits represent only 0.02% of those projects. It may have been more effective to focus exclusively on CZ's 10-15; jurisdictions previously familiar with HERS verification requirements and in which all 4 measures	CalCERTS, Inc.	We also note the uncertainty in the variability of the population going into the study. We were not able to focus only on climate zones with the most requirements as there are many more installations in the other climate zones where there are very large populations of residences. We disagree that the sample was too small; we achieved acceptable precision at the overall sample level and the development of the sample is consistent with accepted sampling theory. During the development of the	N	

		were required for both 2008 and 2013 code cycles (duct testing, refrigerant charge and airflow/fan-efficacy).		research plan we requested comments where we detailed the sampling strategy and no alternatives were suggested. Comments like this are best offered at the RP stage, when adequate changes can be made. We encourage future study that is targeted to build more sample where there is more potential improvement and where installation volumes may be growing with population growth.		
		The report focused on 12 requirements most of which were ill suited to demonstrate whether there was a correlation between permitting and efficiency. Two of the requirements, Static Pressure Probe and Measurement Access, were intended to support diagnostic tests and have no direct impact on efficiency. Refrigerant Line Insulation is another measure with little impact on efficiency. Four requirements were reported as 100% compliant: Minimum Efficiency, Duct Insulation, Additional Duct Insulation, and Load Calculations.	CalCERTS, Inc.	The twelve requirements must be met for a change-out to be permitted. DNV GL recorded the presence or absence of required equipment as part of an overall attempt to determine if permitting requirements were met. Separately we only looked at requirements that provided direct energy benefits in our HIE metric. Many of the HERS testing measures have direct impacts and other requirements do not, but they are relevant to compliance and permitting.	N	

		· Minimum Efficiency of HVAC equipment is enforced at the point of sale per Federal regulations and would not be affected by permit compliance.	CalCERTS, Inc.	The study was agnostic to this market effect and focused on what was installed and whether Standards as written were met. This comment provides additional context about the market, confirming the study findings.	N	
		· Supply houses and installers have always been quick to recognize and adopt minimum duct insulation requirements and as such would not normally be affected by permit compliance.	CalCERTS, Inc.	The study was agnostic to this market effect and focused on what was installed and whether Standards as written were met. We appreciate the context for why these findings confirm these market assumptions.	N	
		· 100% Compliance for Load Calculations was met with due skepticism, notably by Bob Wiseman (IHACI) during the August 18, 2017 presentation. CalCERTS believes this finding was a misinterpretation of registry data by the researchers.	CalCERTS, Inc.	This point should be clarified. Since load calculations are a permitting requirement, DNV GL assumed that they were performed in all cases where a permit was issued and that they were not performed in cases where no permit was issued. DNV GL did not request or receive any load calculations for any project we evaluated.	Y	Page 55, "Load calculations" bullet. Reviewed ES and CH8, found no changes necessary there.

		A certain degree of improvement is intrinsic to the replacement of any HVAC equipment regardless of whether a permit is issued due to the increased equipment efficiency (AFUE, SEER/EER). The marginal efficiency gains of permitted jobs would be primarily affected by the distribution system. Under current market conditions, when performing an equipment change-out, most installers fail to consider performance of the duct system unless forced to do so by HERS verifications triggered by a permit. But the HIE (HVAC installation efficacy) metric is constructed in a manner which may discount these benefits by capping the credited performance at the prescriptive targets for Duct Leakage and Airflow.	CalCERTS, Inc.	We considered options during the research plan and methods memo phases for the HIE metric. Overwhelmingly, stakeholders preferred a compliance cap rather than a trade-off analysis allowing some factors to go better than minimum compliance that would mask other deficiencies. During the development of the research plan we requested comments where we detailed the sampling strategy and no alternatives were suggested. Comments like this are best offered at the RP stage, when adequate changes can be made. We encourage future study that improves on the metrics developed. To the first point, we agree that - all things being equal - newer equipment should be more efficient than old equipment, but this study is not concerned with improvements in equipment efficiency over time.	N	

		The study suggests that there are "relatively high rates of compliance and energy efficiency at nonpermitted installation." But in reviewing the data presented, it is difficult to see a strong correlation to support that assertion. As noted by members of the WHPA Committee during the HVAC6 Memo Results Overview on May 12, 2016, the findings presented are not consistent with the experience of building inspectors and other 3rd party quality control programs, including HERS raters. In their conclusions, the authors assert that "permitting does not result in increased energy efficiency of HVAC change-outs," but can provide no 'statistically significant' data to support the claim. Importantly, the summary table of requirements appears to demonstrate a general trend that counters this conclusion. Focusing specifically on diagnostically tested measures (airflow/fan-efficacy and duct	CalCERTS, Inc.	It is important to correct the statement in the comment. The study concludes that **under current enforcement and market conditions,** permitting does not result in increased efficiency. This is due to permitted sites not fully achieving the intended result. This is reflection of the process of implementing and enforcing the code, not the presence or not of a permit. We urge that the conclusions of this study are not taken out of context. The results presented in Chapter 5 support the assertion that there are relatively high rates of compliance at non-permitted installations by requirement-level. The compliance tests performed at each inspection were consistent from site to site regardless of the permit status (which was not known at the time of the inspection). The study performed tests on over roughly 100 non-permitted and 100 permitted units. The finding of no statistically significant differences means that our estimates are too close to each other to suggest there is a major difference for the individual requirements or for the HIE metric overall.	N	

		leakage), when comparing No-Permit vs. Closed-Permit columns the permitted projects appear to score consistently better.		For permit samples, airflow/fan-efficacy and duct leakage did score better on these tests, but the difference was not significant (<10% better for 2 of the 3 measures). DNV GL applied significance testing to all of the results in Chapter 5.		

		During the presentation on August 18, 2017, conclusions on permit rate analysis included the claim there were "No correlations between demographics and households characteristics on whether a permit is pulled or not." But previously, in the same presentation, two contradictory statements were made about the statistical modeling results: · In a coastal region – higher incident of permitted change-outs vs. other areas. · Education, those with high school education or less, lower incident of permitting change-outs vs. those with higher education. Based on anecdotal evidence from industry stakeholders and supported by the experience of our Quality Assurance Raters in the field, enforcement and installation quality correlate strongly with home values. This might suggest, in contrast to the study's findings, that stricter permitting compliance could have a positive impact on HVAC-QI (quality	CalCERTS, Inc.	While home values may be a driving factor in permit adoption, this information was not available in the residential saturation dataset. Household income tend to correlate with home values and was included in the analysis. For future research exploring permit drivers, more effort to collect actual data on home values should be considered. The study added statistical modeling of survey responses for permit respondents and residential household data (RASS - 2009) to explore if there was a relationship between household characterizes and permitted changeout frequency. Our correlation analysis showed that none of the predictor variables we considered had a strong impact on implementing HVAC changeouts or implementing permitted HVAC changeouts. While none of the differences in average permit rates are statistically significant, there is some directional evidence to support further study into the following effects: Coastal, Heating fuel type and Education	N	

		installation). But this would not be revealed by the study which was spread over a very disperse selection of sites.				
		Furthermore, the study does nothing to address intangibles that affect the longevity of efficiency gains and important health and safety issues associated with HVAC equipment which protect the consumer.	CalCERTS, Inc.	Longevity of efficiency gains and important health and safety issues were not within the scope of the study. Additionally, this topic has come up and study authors welcome citations to studies that have demonstrated these assumed benefits for permitted HVAC changeouts. Our recommendation encourage IOUs to cite these benefits in programs.	N	

		The report did accurately reflect limitations in HERS Rater training and workforce education which CalCERTS had identified concurrent with the timeframe of this study. Since that time, CalCERTS has continuously implemented improvements to increase hands-on training of its raters. Recently, CalCERTS has implemented an outreach program for Building Departments; offering free training focused on requirements of the Efficiency Standards, the compliance process and use of the Registry to fulfill the	CalCERTS, Inc.	Study authors recommend CalCERTS review the Appendices for additional areas for improvement. (Appendix R through U)	N	
		Building Department's responsibilities. CalCERTS has long supported a robust Field Support Program accessible to all stakeholders via phone or e-mail. This Field Support Team has become a valuable resource for all stakeholders, providing answers to technical questions on code requirements well beyond the scope of	CalCERTS, Inc.	Study authors recommend CalCERTS review the Appendices for additional areas for improvement. (Appendix R through U)	N	

		HERS verifications. As the Efficiency Standards have evolved, HERS Raters have become the experts (advocates) on compliance; educating California's designers, builders, contractors, installers and building officials on changes in the Efficiency Standards and compliance requirements.				
		One of the report's recommendations was to "require BD's [building departments] keep compliance forms on record." It should be noted that the Efficiency Standards already include language on the document retention requirements for building departments. By design, building officials have access to any project in the HERS registries within their jurisdiction. The Project Status Report, implemented in the CalCERTS Registry since the time of this study, simplifies the task of verifying that all compliance forms have been completed for permit closure and makes the completed compliance forms available to building	CalCERTS, Inc.	We encourage developing reports across jurisdictions for CEC, CPUC and other regional and state stakeholders so information statewide and major differences in certain jurisdictions can be identified. We intend to keep our recommendation that the Project Status and other reports continue to be developed and disseminated.	N	

		officials which may meet their document retention requirements.				
		Increasing the permitting rate for HVAC change-outs has been an acknowledged issue for several years. CalCERTS does agree with other recommendations to simplify the compliance process, permitting and forms, for HVAC change-outs. However, it is problematic to target 'customer awareness' of code requirements, permitting and the HERS program when those customers will typically only encounter an HVAC change-out once every 15 years. In our opinion, targeting stakeholders for the purpose of improving compliance should focus on those who are involved on a day-to-day basis;	CalCERTS, Inc.	Our recommendations are made in the context that permits are required already, but customers are unaware or indifferent under current market conditions. The Standards are meant to apply to every installation so even the cheapest one is done well. Customers may not understand the details but well-tailored messaging that clearly presents the risks and benefits could engage customers. Programs may be able to play a role in creating materials for this messaging.	N	

		Installers, HVAC suppliers, Inspectors and Raters.				
		The CPUC Energy Division's Evaluation, Measurement, and Verification work is very important to California's energy goals, consumers and the energy efficiency industry. It is imperative that the information gathered to inform future program and policy decisions be correct and complete. CalCERTS believes that the findings in this report that suggest a lack of correlation between permit rates and efficiency improvements are unsupported and should be discounted in any related decisions.	CalCERTS, Inc.	The study goal was to conduct market research to assist CPUC and IOU policy development and it provides a first robust look into the research questions posed about permitting, compliance, and the HERS process. The study followed sampling theory, used available tools, and was specific about which results and recommendations can or cannot be extrapolated. The study was designed and executed to inform policy and should be considered a more reliable source of information than anecdotal evidence. We also urge stakeholders to cite and interpret the findings accurately - under current enforcement and market conditions.	N	

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.