Putting Codes Into Action: How Newly Updated Building Codes Translate Into Practice

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Abstract

Estimating energy savings from codes and standards programs is a complex undertaking. In addition to the quantification of expected savings resulting from an increase in code stringency, the approach must also account for the effect of pre-existing utility incentive programs, naturally occurring market trends, and non-compliance rates. This paper describes the methods employed and empirical findings from one study aimed at quantifying non-compliance rates for a sample of newly codified (and newly code-updated) building measures in California.

We looked at seven building measures in both the residential and nonresidential sectors to learn how closely actual building practices adhere to newly adopted codes. Data were collected by reviewing permits and conducting verification site visits for a sample of building projects throughout the state. Key findings from this study include quantitative estimates of noncompliance rates for the seven measures, as well as qualitative information about some unexpected complexities associated with data collection efforts around building practices, both at building departments (during permit review) and at building sites (during inspection).

This study found a range of noncompliance rates, from 28% (± 3%) for residential hardwired lighting to 100% (± 1%) for the duct testing requirement for new nonresidential buildings. Qualitatively, the study yielded lessons on the research process; for example, building permit data were often found to be incomplete, and compliance criteria were often partially – but not fully – met, raising important questions about the appropriateness of awarding "partial credit," and if so, the appropriate level.

This paper is targeted at providing participants with the following: For utilities and designers of codes and standards programs, insight into realistic ex ante savings estimates with respect to noncompliance rates; for evaluators, important process lessons including how to effectively work with building departments and streamline data collection efforts.

Introduction

For over thirty years, the California Energy Commission has worked to advance energy efficiency through promulgation of energy codes and standards for buildings and appliances known as Title 20 (appliances) and Title 24 (buildings). These standards are updated periodically to reflect the emergence of new energy-efficiency technologies and methods.

The California Statewide Codes and Standards Program (C&S Program, or Program) is implemented by the state's investor-owned utilities and seeks to improve energy efficiency by influencing the periodic updates to the Title 20 and Title 24 standards. A consortium of representatives from each of the investor-owned utilities, called the Stakeholder Review Committee (SRC), works to propose the updates and monitor changes in energy use and market trends as a result of the codes. The most recent round of updates to the Title 24 building standards went into effect in late 2005.

Past studies have worked to estimate the energy savings attributable to the Program, but due to a lack of empirical data, have typically assigned rough place-holder values for key influencing factors such as building non-compliance rates. A 2005 study assigned a uniform 30% noncompliance value to all building measures included in the 2005 Title 24 standards in its estimations of savings attributable to the C&S Program.[1] A central goal of this study was to investigate actual rates of noncompliance to "true up" the 30% place-holder value, and improve the accuracy of savings calcuations.

Table 1 displays the building measures that were included in the Title 24 2005 updates.

Table 1. Building Measures Updated in Title 24

Measure	1st Year Savings (GWh)
Residential	
Hardwired lighting	**64.6**
Window replacement	**6.3 (0.3 Mtherms)**
Duct improvement	**5.7 (1.1 Mtherms)**
Multifamily water heating	1.5 Mtherms
Nonresidential	
Lighting controls under skylights	**25.5**
Cool roofs	**14.6**
Bi-level lighting controls	**12.1**
Ducts in existing buildings	**9.7 (1.0 Mtherms)**
Duct testing/sealing in new buildings	**8.0**
Cooling towers	3.0
Relocatable classrooms	2.9

Due to limits on time and resources, our research focused on the largest energy savers, eliminating multifamily water heating (1.5 Mtherms), nonresidential cooling towers (3 GWh), and relocatable classrooms (2.9 GWh) from the study. The remaining measures, highlighted in blue above, account for nearly 90% of total first year savings.

Research Methodology

Our work plan included the following components of data collection:

1) Visits to nine building departments, representing a mix of climate zones across California
2) Reviews of 403 building records, including permits and plans/drawings when available
3) On-site inspections of a sample of 144 building projects drawn from the 403 reviewed records

This methodology was employed with the objective of providing statistically defensible results for each of the identified measures with 90% confidence ±10%. This level of precision was achieved, with absolute precision levels ranging from ± 0.9% to ±10%. Relative precision levels ranged from ± 1.2% to ±24%.

Beyond the noncompliance values themselves, this study also was able to provide valuable insight into the varying building department processes and procedures in place across the state. These findings shed some light on the types of process holes that exist, and their likely impacts on overall building energy code

[1] *Codes and Standards Program Savings Estimate for 2005 Building Standards and 2006/2007 Appliance Standards*, Mahone, June 30,2005.

compliance. These process findings, as well as general lessons learned through this research, are discussed later in this chapter.

Building Department Selection

Building departments were selected to maximize opportunities for viewing permits and plans from a mix of building projects and climate zones across the state. To maintain consistency with the California Energy Commission's *2005 Building Energy Efficiency Standards Compliance Manual*, California's 16 climate zones were grouped into five climate zone clusters for this study. We worked to pull records from those areas with ample building activity to provide a sample of building projects across the five climate zone clusters that were likely to contain our targeted measures.

Figure 1 shows the distribution of the building departments across the state.

Figure 1. Building Department Locations

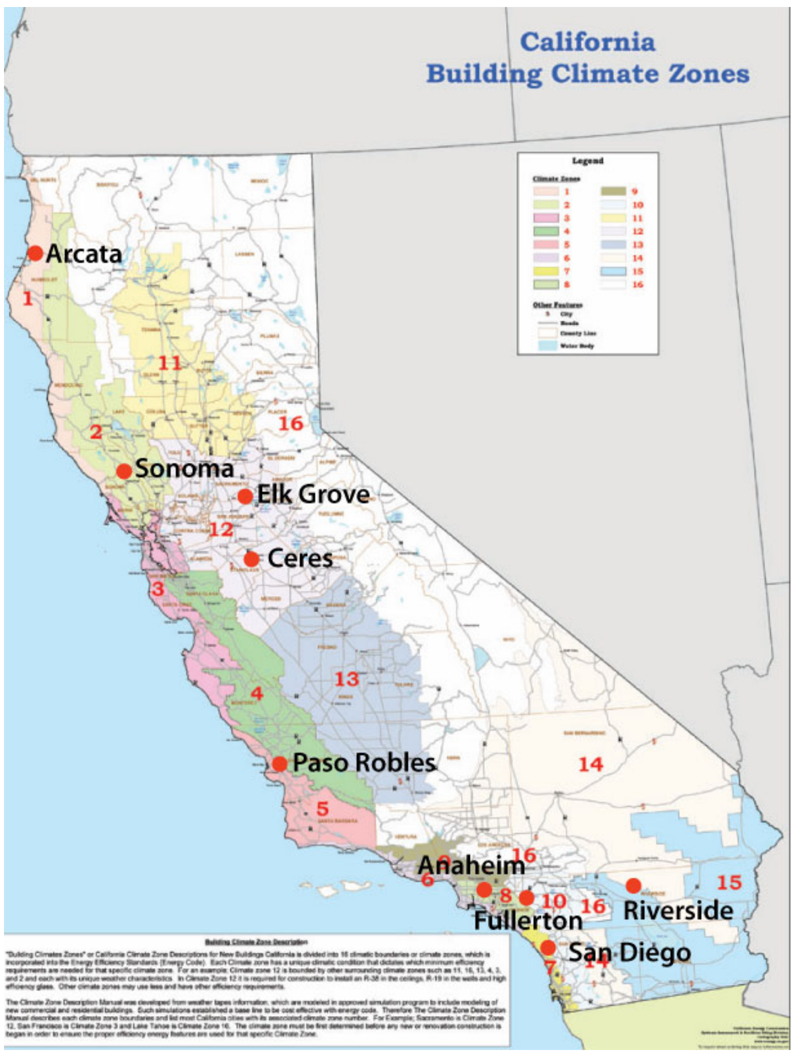

Table 2 displays the nine building departments visited, each department's associated climate zone cluster, and the number of permits that were reviewed at each.

Table 2. Building Department Permit Review Breakdown

Building Department	County	Climate Zone Cluster	Permits Reviewed	Percentage of Total	Residential Permit[a] Volume (County Level)	Percentage of Total Permits	Nonresidential Building Valuation in Dollars (County Level)	Percentage of Total Valuation
Arcata	Humboldt	1, 16	27	7%	326	1%	68,030	0.4%
Anaheim	Orange	6-9	45	11%	6,758	14%	3,688,049	23%
Fullerton			39	10%				
Riverside County	Riverside	2, 10-13	45	11%	21,761	45%	5,551,340	35%
Ceres	Stanislaus	2, 10-13	48	12%	2,039	4%	752,999	4.7%
Elk Grove	Sacramento	2, 10-13	37	9%	5,239	11%	1,492,198	9.4%
San Diego County	San Diego	6-9	70	17%	8,944	19%	3,368,185	21%
Paso Robles	San Luis Obispo	3-5	45	11%	1,344	3%	410,523	2.6%
Sonoma County	Sonoma	1, 2, 10-13 and 16	47	12%	1,594	3%	574,456	3.6%

[a]Residential building permit volume and nonresidential building valuation figures represent the first nine months of 2006.

Building Department Permit Review

At each building department, we reviewed recent permit records and permit lists; typically, the permits studied were filed between November 1, 2005 through June 2006. Permits that were likely to contain one of the study's target measures were selected, and, if available, specific records and plans for those projects were pulled for further review. For each record the following data were collected: permit number, address, owner's name, owner's phone number (when available), type of permit, details of work to be performed, target measure applicability, and various notes on documents in the file, including energy calculation results and comments on construction status to help determine if the project was suitable for a field visit.

For most building departments, we were able to scan a list of permits either provided by staff or retrieved from the departments' databases. After an initial review, those permits likely to contain one of the study's targeted measures were selected for more detailed evaluation, which included an examination of plans. In some jurisdictions, this was done through physical access to the plan room; in others, it involved having the permit staff retrieve plans for us.

Building department permit reviews were followed by 144 on-site or other verifications to determine rates of noncompliance with code. Sample sizes of measures are presented in Table 3. Measures, permits, and site visits reviewed by building department are presented in Table 4.

Table 3. Sample Sizes

Measure	Records of Measures	Permits Reviewed	Field Verification
Residential			
Ducts	84	82	82
Hardwired lighting	216	200	19
Windows	67	65	6
Nonresidential			
Bi-Level	12	0	0
Cool Roofs	17	17	11
Ducts--New	14	12	12
Ducts--Retrofit	11	7	7
Skylights	16	12	7

Table 4. Measures, Permits, Site Visits

Building Department	Total Measures	Sites	Total Permits Reviewed	Field Verification
Anaheim	45	45	36	20
Arcata	29	28	27	3
Ceres	51	48	51	12
Concord	8	8	8	8
Elk Grove	42	37	38	26
Fullerton	40	39	39	16
Paso Robles	47	45	39	4
Riverside	51	51	50	19
San Diego	71	70	62	13
Sonoma	53	47	45	23

Compliance "Scoring"

Each permit reviewed was given a score in each of three possible compliance categories: process, design, and field. ***Process*** reflects the completeness of the information contained in the permit file. ***Design*** represents the compliance level of the submitted blueprints or plans. ***Field*** corresponds to the observations made during the field inspections.

The scores themselves were derived from an evaluation of how close the component came to meeting the code requirement. Complete noncompliance existed when no evidence of knowledge or intent to comply with code existed; in these cases a score of 1 was given, reflecting 100% noncompliance. A partial-compliance score of 0.5 was given when some evidence was found of an attempt to comply with code, but compliance was incomplete. Full compliance existed when the measure was present and either fully documented, fully contained in the design or installed in the building (score = 0).

As an example, a permit record may receive a *process* score of 0 for hardwired lighting if there is a completed MF1-R and a completed WS5-R form in the file. That same record may receive only a 0.5 *design* score if the blueprints show recessed cans in the kitchen, but do not specify those as high efficacy fixtures. Finally, that same record may receive a *field* score of 1 if the fixtures are in fact found to be incandescent throughout the house, and there are no occupancy sensors or dimmers as required in the other areas of the home.

There were two exceptions to the compliance scoring method. The first was with respect to residential window replacements. In most cases, windows lacked U-factor or NFRC[2] labels and could not be verified. However, if during inspection a window tested as low-e[3] and was framed with vinyl, it was considered better than half compliant and was given a noncompliance score of 0.3.[4] The second exception was with regard to hardwired lighting. Though the scoring scheme remained the same, weights were applied to the scores in order to account for differences in construction type and scale. This additional step was applied after it was found that there was a large discrepancy in compliance between production housing and single family housing or additions. It was found that production homes were significantly more likely to be compliant with the code. In order to properly recognize this and to account for the relative impact of each construction type on the residential market as a whole, a weighting factor of 10 was applied to production housing, new single-family homes a weight of 2, and remodels a score of 1. This in part recognizes the large scale repetitive impact of one compliant design being built many times over in a particular subdivision.

Descriptions of the new codes, along with the specifics of what was looked for in the building files, are provided in Appendix A.

In all cases, the final site visit scores were then used to update the initial compliance scores using a Bayesian statistical analysis as described in Appendix B.

Finally, all noncompliance scores were weighted according to building department using building valuation figures for 2005 and 2006.[5] Using the total residential and commercial valuations for the nine building departments we visited for this study, weights were constructed as a proportion of total valuations. For example, the weight applied to residential noncompliance scores in Sonoma County is equal to the residential valuation in Sonoma divided by the total valuation of all nine building departments.

Lessons Learned – The Research Method

Although we expected to find a certain level of procedural inconsistencies between building departments, we were surprised to learn just how unique each building department's policies were. To provide background to the findings in this study, and to help inform future studies, here we describe some examples of the nuances of the data collection effort.

All building departments keep records of permits by address, date and permit number; however, the

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[2] The National Fenestration Rating Council provides energy performance ratings for window products.

[3] Low emissivity (low-e) is an optically transparent coating that allows most natural light to enter, but reflects a significant portion of long and short-wave heat energy.

[4] The 2005 Ducker Worldwide windows market study, *The Distribution of Residential and Nonresidential Windows and Doors in the 2003 U.S. Market*, applied a multiplier of 0.95 to low-e window sales to estimate Energy Star window sales. However, Energy Star requirements vary by climate zone, and Energy Star criteria and code criteria do not always exactly agree in California. Therefore, we used a more conservative estimate of 0.7 (0.3 noncompliance) for the purposes of this study.

[5] California construction valuation figures for 2006 were for the first 9 months of the year. Data were obtained from the Construction Industry Research Board (CIRB).

methods by which they categorize, store, and support projects differ in every jurisdiction. In particular, we found that the level of project detail available for viewing was inconsistent throughout the state. For example, one city may file a permit for a particular project simply as a residential permit with no further detail. In order to learn more about this project, the file must be pulled and the building plans retrieved to obtain even basic details, such as type of residential construction (new subdivision, new single family residence, addition to existing residence, remodel of existing residence, or repair to existing residence). At some departments these broad sub-classifications did exist in the master record or permit list, and most provided at least "new" vs. "existing" distinctions. However, even within those classifications, there were inconsistencies. For example, some departments might catalog a studio addition or "granny flat" as an addition/remodel because there is an existing permit record for that address, while others would call it a new single family residence.

Another interesting permitting nuance lies in the area of subdivision construction. In California, most building departments allow what they classify as "mastered plans," where production builders may submit one complete set of plans for each type of residence they plan to construct within a subdivision. In these cases, if developers can prove, typically via the performance method, that each home type complies with minimum building codes, the master plan is deemed to comply with the code. Prior to actual construction, then, builders need only come into the building department with a plot plan/grading plan to obtain a permit for an individual address. Each building department has a different system for matching these mastered plan approvals to individual permits by address. For nonresidential permits, similar matching inconsistencies exist. For example, tenant improvements are sometimes issued separate permits for mechanical or electrical work. Other times, 'combo' permits are issued that cover both work done by both trades.

Finally, to ensure good customer service, most, if not all, building departments in California offer walk-in service and issue what are known as "counter permits" for many types of construction. To obtain a counter permit, applicants typically are able to simply complete a form and pay a fee, with little or no design or component documentation required. This is a key example of a building department policy that made data collection for this project more problematic than anticipated. One example of how counter permits complicated the review process is in the case of re-roofing. Many times, we pulled permits for these building project types and found that the permit did not describe the type, size or slope of the roof. Similarly, a counter permit can be issued for a replacement HVAC system or replacement windows. For these types of permits, plans and forms typically will not be collected. This issue is exacerbated by the fact that the technicians issuing counter permits typically do not have sufficient training or expertise to review energy compliance documentation or specifications.

In short, the myriad processes and procedures we encountered, together with the wide range of project detail present in the building permits, created a challenging environment in which to make compliance determinations for the targeted measures in this study. More importantly, these inconsistencies will likely complicate future efforts to improve compliance and document energy savings resulting from codes and standards, unless compliance chain issues are further identified and addressed.

It is important to note that although it often appeared that a building project "should contain" one of the study's measures, it was not always possible to make a compliance determination from the available records. This was due to a few different factors, including the type of measure (mandatory, prescriptive, or credit) and the presence or absence of plans containing finer project details. Here we discuss how three different variables – type of measure, availability of data, and varying building department policies – influenced the process of researching current building practices and making noncompliance appraisals for the measures studied.

Type of Measure

In the standards, there are three types of requirements: mandatory, prescriptive and credit. ***Mandatory measures*** are required each time the measure is included in a building design. For example, all appliance standards are considered mandatory measures. There are no exceptions and no tradeoffs. Documentation usually consists of confirming via a check mark on a form that the measure exists in the design. Residential hardwired lighting is another mandatory measure, although documentation of compliance with this measure is somewhat more involved, typically requiring completion of one or more special forms.

Prescriptive measures are prescribed as part of the base-case design for a particular climate zone. Insulation requirements, for example, are prescriptively set for different climate zones. However, if and when a prescriptive requirement begins to restrict the building's design, that requirement can be "traded off" for another measure that saves approximately the same amount of energy. These substitutions, and the subsequent determination of project compliance with the energy code, are done via the ***performance compliance method***. The performance method requires that a certified computer program be used to model the building's overall energy use. The results of the computer model are then used to prove that the building meets the allowed energy use for a building of that type and configuration.

This trading off of measures to meet the energy requirements via overall building performance came into play during our analysis. For example, a prescriptive requirement like lighting controls under skylights in large warehouses is often traded off with other measures, and therefore may not have been present in the file or shown in the blueprints. However, the building as a whole may well have remained in conformance with the code, if the designer chose to add another feature (e.g., a more efficient HVAC unit) in order to make up for the energy lost due to the absence of skylights with lighting controls.

Lastly, ***credits*** are present in the code as a means to encourage adoption of newer technologies. For example, the installation of dimming ballasts and dimming controls on fluorescent lamps provides a control credit in the form of a Power Adjustment Factor. This factor provides a compliance credit for using that technology, and allows a designer the option of utilizing a higher lighting power than is ordinarily allowed in the code. There is no incentive for the designer to claim credit for a measure in the Title 24 documentation unless that credit is necessary to meet code. Therefore, it is possible that the frequency of a measure may be greater than the documentation may reveal.

Availability of Data

The prevalence of permits applicable to our project varied significantly by measure. A total of 418 records were selected at nine building departments representing 437 measures. Of those, a total of 395 measures had permits that were available for complete review. This discrepancy in number of permits reviewed is due to missing information or the fact that records and plans were unavailable on the day of the visit. For example, some records indicated that a measure was present when it was not, and further investigation ultimately showed that the measure was not required after all. Other times it was not possible to prove that a measure was required based on the information provided. In still other cases, the file was located but not the plans that would have contained the information necessary to verify compliance. These are all examples of permits that were evaluated but ultimately deemed "not applicable" to our study, and represent less than 5% of the total reviews. This is a finding that might be expected given the complicated nature of the system, the limited amount of available support from building department staff, and the time constraints on the building department reviews themselves.

Additionally, in many cases a feature is required only under certain conditions, reducing the number of potential records available to review. For example, cool roofs are only required for commercial re-roof projects where low-slope conditions exist, and even then there are some exceptions to the requirement that make the presence of that measure relatively uncommon.

This study also found that substantially fewer permits exist in the nonresidential sector. While the volume of nonresidential building projects is substantial from a valuation perspective, from a permitting perspective they are relatively underrepresented. Nonresidential buildings are larger, take longer to plan and construct, and are often built in phases with separate permits taken only for specific building components (e.g., unconditioned shell, demolition of previous building, grading, electrical, etc.). The availability of data is further restricted by the fact that contractors and owners sometimes neglect to take out the required permits. This phenomenon was reported to varying degrees at each building department, and appears to happen less frequently in smaller jurisdictions where the building department has a closer link to the community. The frequency of this occurrence anywhere, however, is anecdotal, because those who bypass the permit system cannot be tracked unless their illegal activity is reported to the department by a third party.

Building Department Policies

Building departments, governed by administrations that must answer to councils and boards of supervisors, often set polices that do not adequately recognize or accommodate some aspects of the building energy-efficiency codes. For example, the most current building energy efficiency codes went into effect on October 1, 2005. Any permit, even a permit for a mastered plan, must comply with the new code. As such, each set of mastered plans must be reapproved each time the code changes. However, some jurisdictions are allowing build-out of subdivisions under old standards. This phenomenon, known as "grandfathering," occurs with relatively high frequency and has a large impact on residential construction. As a consequence, hundreds of homes statewide are complying with outdated code requirements.

In addition, the interpretation, application, and enforcement of codes was found to be inconsistent between building departments. For example, some jurisdictions have opted not to require permits (though they should) for commercial reroofs or for replacement of residential windows, rendering it impossible to study compliance for those measures in those departments.

Discussion of Results

We found that rates of noncompliance obtained through this study varied widely by measure, ranging from 28% for hardwired lighting to 100% for nonresidential ducts (both new and retrofit). Given that the previously determined place-holder value of 30% noncompliance was intended to act as an average value – assuming some measures would see lower noncompliance rates and some higher – we were surprised to find only one measure, hardwired lighting, to be in the 30% range, and to find that most of the other measures were considerably higher than this.

As no interviews were conducted with builders, inspectors, or building department staff as part of this study, perspectives of building professionals on the wide variation in noncompliance are unavailable. However, through the research process, we were able to observe conditions in building departments and the field that may point to some reasons why residential hardwired lighting is more likely to be in compliance with the code than, say, residential windows or nonresidential duct sealing. One reason for hardwired lighting's relatively low level of noncompliance may be that it is a mandatory measure required in all new construction and alterations. Additionally, there are specific forms to be filed at building departments to document type of lighting to be installed, with a place to record allotted maximum wattages.

Other measures, such as residential window replacement, are not as straightforward with respect to their requirements. Window replacement, being a prescriptive measure, is required except in rare cases when it is traded off with another measure. As such, we were surprised to find so few windows permits in the reviewed records, even given that they apply to alterations only. The dearth of windows permits was found to be partially attributable to the fact that not all building departments required them, even though the code does. In addition, window replacement permits were often found to be issued as "counter permits," which typically require little or no design or component documentation. Similarly, counter permits can be issued for replacement HVAC systems, which may be a factor leading to the lack of duct testing/sealing documentation we commonly observed in the field for this measure.

In short, this study found that building noncompliance rates in California are idiosyncratic and highly measure-dependent. The diversity of processes and procedures employed at California building departments, a lack of training among counter permit technicians, and the range of levels of requirements in the codes themselves all contribute to the variation of observed noncompliance rates in this study.

We do note that, since this study began relatively shortly after the implementation of the updated 2005 building codes, utility-sponsored training and education (T&E) programs aimed at improving compliance rates had not yet been completed. These T&E efforts are carried out through IOU Energy Centers, the Savings by Design program[6], and statewide and local partnership programs. We expect that compliance with the 2005 standards will improve as these training events continue, and building department staff become more familiar with the requirements.

Table 5 summarizes the noncompliance estimates for all measures studied.

Table 5. Summary of Building Measure Noncompliance Estimates

Building Measure	Estimated Noncompliance rate	Absolute Precision of Estimate	Relative Precision of Estimate
Residential			
Hardwired lighting	28%	3%	11%
Window replacement	68%	7%	10%
Duct improvement	73%	0.9%	1.2%
Nonresidential			
Lighting controls under skylights	44%	10%	24%
Cool roofs	50%	3%	6%
Bi-level lighting controls	n/a	n/a	n/a
Ducts in existing buildings	100%	2%	2%
Duct testing/sealing in new buildings	100%	1%	1%

6 Savings By Design is a program to encourage high-performance nonresidential building design and construction, and is sponsored by four of California's largest utilities under the auspices of the Public Utilities Commission.

Appendix A: Code Description and Research Protocol by Measure

Residential Measures

Hardwired Lighting

Code summary: This measure is the most universally applicable of all the measures researched, as it is applicable to all residential new construction and alterations. It is a mandatory measure, so it cannot be traded off for another feature with equal or greater energy savings potential. Permits reviewed for this measure included all residential construction, including single and multifamily projects and subdivisions.

Research protocol: In the permit file, we looked for a MF-1 form and a WS5-R form. These forms document the designer/owner's intent to install the required lighting and to document that incandescent lights installed in the kitchen do not exceed the allotted maximum wattage. When reviewing plans, we looked for a lighting or electrical drawing that indicated location and types of fixture and controls. In the field, we observed and recorded the types of fixtures and controls that were installed.

Window Replacement

Code summary: This is a prescriptive measure that applies to the replacement of windows in the residential sector. While the measure is universally applicable, except in rare cases where the requirement is traded off for another, only a small number of permits were located at the building departments. This is due to two factors: (1) window replacements represent a small subset of the residential market (alteration only), and (2) window replacement permits are not required by all building departments. Some departments require permits for all replacements, while others only require permits when there is a change in window size. Still others don't require them at all. Windows often are replaced in conjunction with another type of alteration, and the permit details may not always reveal whether windows were included in the scope of the alteration work.

Research protocol: In the permit file, we looked for a certificate of compliance and/or window specifications. These forms document the designer/owner's intent to install windows that conform to the U-factor and SHGC requirements specified in the code. Window replacement permits are often issued as counter permits, which limited the prevalence of documentation (e.g., drawings indicating location, size or type of windows to be replaced) that would have informed this study. In the field, we looked for window labels indicating type and U-factor. In the absence of a window label (window labels typically are removed shortly after final inspection), we recorded the window and frame type.

Duct Sealing for Residential HVAC Replacement

Code summary: This is a prescriptive measure that applies only to the replacement of a major component of the HVAC unit in certain climate zones (2 and 9-16). The requirement includes performing a duct test that verifies a maximum leakage rate of 15% (or 10% leakage to the outside), or a 60% leakage improvement over the existing system, verified through a smoke test. In certain areas and under certain conditions, homeowners can choose to install a higher efficiency HVAC unit instead of having the duct test performed.

Research protocol: In the permit file, we looked for a certificate of compliance, duct test results, or the presence of a testing form awaiting completion. These forms document the contractor/owner's notification of the results of the leakage test or the requirement to have a test. Since these are typically counter permits, no sketch or specification is usually provided. In the field, the measure was inspected for test results or the existence of compliance forms that would indicate a test had been performed. If neither was present, we noted the installation quality of the duct system. For this and all of the measures where duct sealing was required, records were checked against the HERS registry which would reveal all sites where data on duct test results were uploaded, as required by the code.

Nonresidential Measures

Skylights

Code summary: Skylights are prescriptive measures that apply to a small number of very large buildings that have a warehouse or retail occupancy designation. For skylights (and future lighting controls to obtain the energy savings from daylighting) to be required, the building must be 25,000 square feet or larger, must have relatively high ceilings, and must have greater than 0.5 watts-per-square foot of lighting installed (or intended to be installed). Skylights are required to provide light to at least 50% of the floor area. Since it is a prescriptive requirement, it can be traded off via the performance method.

Research protocol: In the permit file, we looked for compliance forms that indicated the skylight was required and that it was either present or traded off against another feature. In design plans, we looked for the presence of skylights in qualifying buildings. We then attempted to verify that, if skylights were present, the area and size of the skylights might yield the amount of daylight to the space as required by code (50% of floor area). This is done by calculating the daylit area based on the size and spacing of the skylights. In the field, we verified the presence of skylights and, if lighting was installed, the presence of qualifying lighting controls.

Cool Roofs

Code summary: A cool roof is a prescriptive measure that applies to certain low-sloped roof replacements. The re-roofed area must be ≥50% of the total roof area (or a minimum of 1,000 square feet). If that condition exists, then most roofs must meet the prescriptive requirements of a cool roof, unless the feature is traded off via the performance method or all of the exceptions listed in Section 149 (b) 1 B exist. During field visits, we learned that many roofs and roof repairs are completed without obtaining a permit. One jurisdiction in our study currently does not require permits for this type of construction activity. Another jurisdiction reported that the volume of permit activity for commercial reroofs dropped after the code change; it is suspected that increasingly restrictive requirements sometimes drive contractors away from the process completely.

Research protocol: In the permit file, we recorded the presence or absence of compliance forms that indicated that the applicant was aware that a roof was required to meet the requirements of a cool roof and that the product should be certified by the Cool Roof Rating Council (CRRC)[7]. Likely due to the fact that these are counter permits, we found no cases where any plans, sketches or specifications were found in the file. Occasionally the permit description indicated that a cool roof replacement was intended for that address. During the field visits, we noted the roof color and looked for a CRRC certificate or label.

Bi-level Lighting Controls

[7] The Cool Roof Rating Council (CRRC) is an independent organization that has established a system for providing radiative property data on roof surfaces.

Code summary: Bi-level lighting controls exist in the building energy efficiency codes as an optional control credit that may be taken to allow for increased lighting power. The lighting control credits are calculated in terms of "Power Adjustment Factors," which are multipliers that allow the actual lighting power used in compliance calculations to be reduced, giving a lower adjusted lighting power. This makes it easier to meet the allowed lighting power requirement.

Research protocol: In the permit file, we looked for permits pertaining to new small office spaces or tenant improvements where the lighting control credit may be used. Our study reviewed twelve permits where a bi-level lighting control would have been applicable, but did not locate any building projects that opted to take the credit.

Duct Sealing for Commercial HVAC Replacement

Code summary: This is a prescriptive measure similar to that for residential systems. However, this measure was found to be required less frequently in nonresidential applications because duct systems are often located in conditioned spaces, or they serve an area greater than 5,000 square feet. The existence of either one of these features exempts a building from the requirement. In addition, building owners may choose to install a higher efficiency HVAC unit in some cases, in order to exempt them from the duct sealing requirement.

Research protocol: In the permit file, we noted the presence of compliance forms, a complete or incomplete duct test report, or other information indicating that the applicant intended to seal and test the duct system. Once again, this measure requires only a counter permit, so plans and sketches are typically absent. In the field, we looked for a duct test report. If one was not present, we noted the quality of installation of the duct system. As previously noted, all projects containing measures where duct sealing was required were checked against the HERS registry.

Duct Sealing for New Commercial HVAC

Code summary: This is a prescriptive measure that applies to HVAC systems serving relatively small zones (5,000 square feet or less) that have greater than 25% of the ducts located in unconditioned space. When a project meets the applicability criteria, very often these systems are installed as part of small tenant improvement permits and the requirement is traded off against the lighting requirement via the performance method. If a "mechanical only" permit is pulled, typically the duct system is required to be sealed and tested.

Research protocol: At the building department, we noted the presence of compliance forms, a complete or incomplete duct test report, and other information indicating that the applicant intended to seal and test the duct system. Since these are counter permits, no plans or sketches are typically present for review. In the field, we looked for a duct test report. If one was not present, the reviewer noted the quality of installation of the duct system. For all of the measures where duct sealing was required, records were checked against the HERS registry.

Appendix B: Bayes Theorem

Bayes' Theorem

Revising probabilities when new information is obtained is the foundation of Bayes' Theorem. Often we begin an analysis with an initial or *prior* probability estimate for a specific event (in this case the probability that a building measure is noncompliant). Then as additional information is obtained, we update the prior probability values by calculating revised probabilities, referred to as *posterior* probabilities. Bayes' Theorem provides the means of computing these probabilities.

For this study, we obtained a sample of building permits from which we estimated the prior probabilities of noncompliance. We then obtained another sample comprised of site visits and database verifications for selected buildings from the initial review. The probabilities of noncompliance estimated from the site visits were then used to revise the priors to estimate the posteriors.

The initial estimated proportion of noncompliance and its corresponding standard error are computed as follows:

$$p_1 = \frac{\sum_{i=1}^{n_1} x_i}{n_1}$$

and

$$s_1^2 = \frac{p_1(1-p_1)}{n_1}$$

where x_i is the score (0 to 1; with 1 indicating 100% noncompliance) of a measure for a particular permit and n_1 is the number of permits reviewed for the measure in question.

This is the *prior* estimate, since it is the result of information collected at the outset of the study and is subject to updating by a subsequent sample. The prior estimate represents what is believed to be true about noncompliance until more detailed information can be collected to either support or refute those estimates. Once the site visit scores are incorporated, we then have *posterior* estimates, calculated as follows:

$$p = \frac{\dfrac{n_2^2}{1-p_2} + \dfrac{n_1}{1-p_1}}{\dfrac{n_2^2}{p_2(1-p_2)} + \dfrac{n_1}{p_1(1-p_1)}}$$

and

$$\sigma^2 = \frac{p_1(1-p_1)p_2(1-p_2)}{n_2^2 p_1(1-p_1) + n_1\, p2(1-p2)}$$

where p_2 is the estimated rate of noncompliance estimated from the site visits (calculation is the same as for the prior estimate), and n_2 is the number of site visits for a given measure.