IS WHAT YOU SEE, WHAT YOU GET?

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Introduction

On-site surveys of 400 new homes in California found that only 38 percent of the homes -- as built -- complied with the state's building energy efficiency standards. A 62 percent rate of noncompliance would be very alarming -- if the number was indeed valid. On average the 400 surveyed homes used annually approximately 4 percent more energy than allowed by the standards.

The study highlights how building energy-use simulations are sensitive to the use of *assumed* values vis-a-vis *observed* values. *What you see* as the result of running an energy-use simulation is *not* necessarily *what you get* as an accurate assessment of a home's energy use. The use of *assumed* values rather than *observed* values for wall insulation, attic insulation and windows significantly affected the study's conclusion that only 38 percent of the 400 surveyed homes complied with the state's building energy efficiency standards.

If data are collected as a home is constructed, an auditor can obtain *actual* values for each of the data points needed to simulate the building's energy use. For example, prior to installation of drywall, an auditor can measure actual values for wall and attic insulation. Once a home has been occupied, however, an on-site auditor faces constraints in gathering all the data needed to validate compliance. The study found that auditors often could not determine wall insulation values or window U-values through direct observation. When insulation blankets covered waterheater nameplates, auditors could not identify model numbers. Furthermore, when homeowners were unwilling to allow access into attics, auditors were unable to measure attic insulation levels or to get nameplate data for split-unit air-handlers located in attics.

When unable to determine *actual* values, the auditors *assumed* the *minimum* statewide values mandated by the state's residential building enery efficiency standards. In more extreme climate zones, however, the default values for exterior wall insulation and windows are often not representative of common building practice. In order to increase the percentage of glazing in proposed homes and still demonstrate overall compliance with the state's standards, builders frequently install walls and windows that are more efficient than the mandatory measures.

Background

In 1975, the State of California Legislature passed a law requiring the California Energy Commission (Commission) to prescribe energy efficiency standards for residential and nonresidential buildings constructed within California. Since being initially adopted in 1976, the energy efficiency standards have been periodically updated to incorporate various energy efficiency measures demonstrated to be cost-effective alternatives to pervasive building design and construction practices.

In 1995 the Commission awarded a $209,000 contract for a statewide survey of 400 homes constructed since July 1, 1989. The two-year project, known as the Post-occupancy Residential Survey, had the following five objectives:

- determine whether the 400 homes, as originally built, complied with the building energy efficiency standards
- determine what post-occupancy changes were made by homeowners which affect the homes' energy use and the persistence of energy-use savings presumed by the energy efficiency standards
- determine why changes affecting energy use were made by homeowners and the source of information relied upon by homeowners when making these decisions
- quantify the energy impacts associated with changes made by homeowners
- compare the results of the statewide survey with two earlier Commission studies conducted in 1990 and 1993

This research paper focuses on the portion of the study which sought to determine whether the 400 homes, as originally built, complied with the state's building energy efficiency standards. The other issues are explored in the following two reports available through the California Energy Commission:

- *Post-occupancy Residential Survey*, P400-94-015CN, March 1997
- *Comparison of Residential Building Standards Projects*, P400-105ACN, March 1997

Options for Demonstrating Compliance

Prior to obtaining a building permit from a local jurisdiction, a builder in California must demonstrate that the proposed building complies with the state's building energy efficiency standards. A builder has two options to demonstrate compliance. First, the builder may choose a *prescriptive* package which specifies all the energy efficiency measures which must be incorporated in a proposed home. There are five prescriptive packages for each of the sixteen climate zones in California. Reflecting each climate zone's unique need for cooling and heating, these five packages mandate the *minimum* energy efficient design features which must be included in the proposed home.

Second, the builder may use a *performance-based* approach, which compares the energy budget in kBtu/sq.ft./year for the proposed home with the energy budget for a "standard design" home. Builders who choose the performance-based approach may design a residential building which includes some features less efficient and some measures more efficient compared to the prescriptive approach, so long as the proposed building uses no more energy overall that the equivalent "standard design" building. Previous Commission studies have determined that approximately 75 percent of residential builders use the performance-based approach to demonstrate compliance, since this method allows the builder much greater flexibility in design. Builders may use any one of several computer software programs to demonstrate compliance using the performance-based approach.

Research Design Methodology

The contract work statement specified that field data would be collected statewide on 400 single-family detached homes constructed since July 1, 1989 -- a date which was six months after the adoption of a major revision to the residential building energy efficiency standards. A further eligibility requirement was that each of the 400 homes needed to have been continuously occupied by the original owner. The latter requirement was necessary so the field auditors could identify all changes made by homeowners since the 400 homes were originally built.

The contract work statement required the field data to be collected on-site through personal observations by trained energy auditors. The on-site audit requirement, although costly in terms of labor, was intended to ensure a high quality of data. A personal interview and field audit avoided the possibility of collecting erroneous or incomplete data through telephone interviews or homeowners' written responses to mailed surveys.

During the period 1990 through 1995, local jurisdictions issued 487,888 residential building permits in California. The Commission specified that the survey methodology should ensure that more homes would be surveyed in the areas of the state having the greatest amount of residential building activity. The Commission also required a minimum of fifteen homes to be surveyed in each climate zone.

The contractor proposed using a proportional allocation, based on residential building activity during the past five years, to determine the sample size for each climate zone. The survey methodology allowed the climate zone-specific results to be weighted by the ratio of climate zone to statewide building activity in order to achieve statistically valid results for estimates at the statewide level. The statewide results have a precision level of 95 percent confidence with a 5 percent margin of error.

After reviewing the survey results for the first 50 homes, Commission staff became concerned that project participants might be biased in favor of energy efficiency. Although *potential* participants were randomly selected, *actual* participants were homeowners who chose to participate in the study. This element of self-selection raised the possibility that post-occupancy modifications made by project participants might be significantly different than post-occupancy modifications made by homeowners who chose not to participate in the study.

Commission staff designed and conducted a separate nonresponse bias study by recruiting and surveying twenty-six homeowners who initially declined to participate in the project. Although the mean standard energy budget for these twenty-six homes was larger, there was no statistically significant difference at the 95 percent level of significance when comparing post-occupancy modifications made by the twenty-six homeowners in the nonresponse bias study and post-occupancy modifications made by twenty-eight other homeowners in the same area who responded to the initial solicitation for participation in the project.

The research design methodology included two other critical elements. First, the field audit collected all the information needed as data inputs for a public domain computer software program, CALRES, which calculates whether a proposed residential building complies with the state's energy efficiency standards. Second, the field audit was required to be physically nonintrusive. No home was to be damaged in any way. The research design methodology recognized that these two requirements sometimes conflicted with each other. If an auditor could not directly observe a needed CALRES data input value -- for example, insulation R-values in the attic or in an exterior wall assembly -- the auditor was instructed to substitute the default *minimum* values mandated by the standards. The auditor was *not* allowed to substitute his or her judgment for a value which could not be directly observed.

As incentives to encourage participation, each homeowner received a $25 check, a checklist of recommended additional cost-effective energy efficiency measures specific to his or her home, and a new furnace filter, which was installed by the field auditor. Each participant also received a copy of the Commission's *Home Energy Manual*.

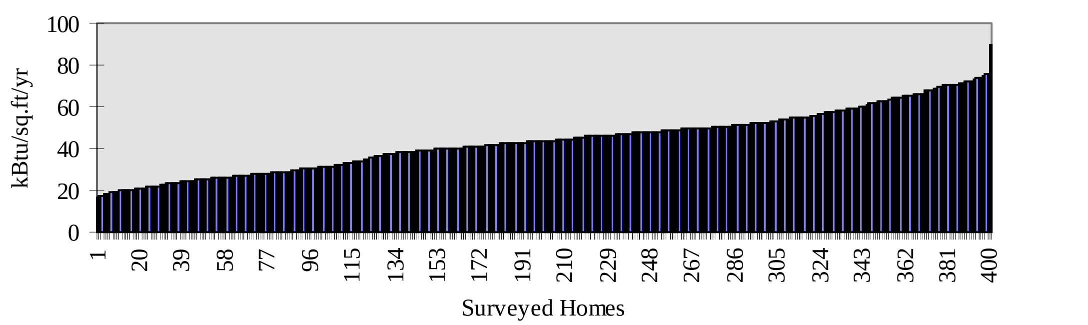
Evaluation of Compliance Results for "As-built" Homes

The project used the CALRES software program to calculate two energy-use simulations for each house in the data base. The first simulation was for the house as originally constructed. The CALRES data input values for the "house as-built" were derived by backing out all post-occupancy changes from the data inputs for the house as observed by the field auditor. The second simulation was for the house as observed by the auditor. This "post-occupancy" simulation reflected all modifications made by the homeowner.

These two simulations were each compared to the "standard design" energy budget specified by the state's energy efficiency standards. The results of the "as built" simulation were compared against the standard design values to determine whether the home, as originally constructed, complied with the residential energy efficiency building standards in effect at the time of construction. The results of the "post-occupancy" simulation were compared against the standard design values to determine whether the home, as subsequently modified by the homeowner, still complied with the original standards.

Figure 1 graphically displays the distribution of the "standard design" energy budgets for each of the 400 homes in the study. The allowable energy budgets ranged from 16 kBtu/sq.ft/year to 89 kBtu/sq.ft./year. This range reflects the significant variation in heating and cooling loads among the sixteen climate zones, as well as the design characteristics of each home.

Figure 1: Standard Design Distribution



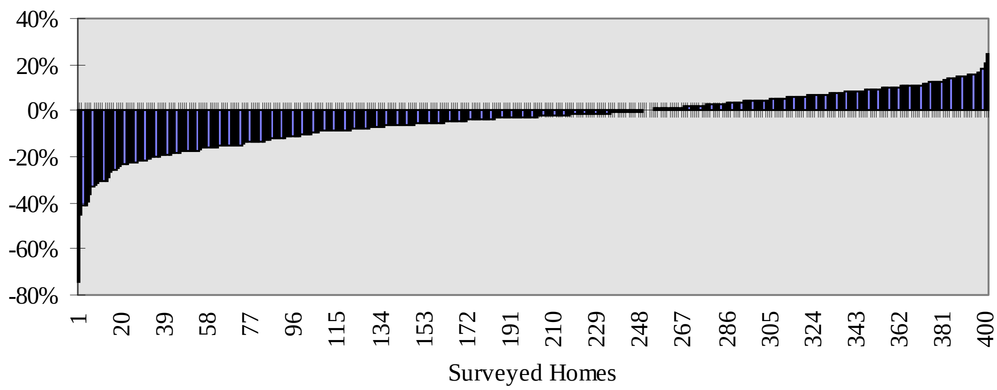
Homes having the lowest energy budgets are commonly located in the San Diego area, which has a year-round temperate climate with a minimum need for cooling or heating. Homes having the highest energy budgets are found in the inland desert areas, which have significant year-round cooling loads. Other homes having high energy budgets are located in areas with a demand for both cooling and heating, such as the Sacramento Valley and the San Joaquin Valley, which experience temperatures above 110° F. in summer and near-freezing temperatures in winter.

The *compliance margin* is the percentage difference between the "standard design" energy budget and the simulated estimate of energy use for a proposed home. A *positive* value indicates that the proposed home uses less energy than the "standard design" energy budget, thus complying with the energy efficiency standards. A *negative* value, however, indicates that the proposed home uses more energy than allowed by the "standard design" energy budget. The study calculated the compliance margins for the 400 homes surveyed in the project.

Figure 2 shows the distribution of the compliance margins for the "as-built" homes prior to occupancy by the homeowner. The survey data shows that 38 percent of the homes on a statewide basis complied with the energy efficiency standards, while 62 percent of the homes failed to comply.

The single factor best explaining this high rate of noncompliance appears to be the use of *assumed* values for data points which could not be directly observed by the field auditors. The survey data shows that 44 percent of the homes had assumed values for attic insulation and 74 percent of the homes had assumed values for exterior wall insulation. In addition, nearly 40 percent of the homes had one or more assumed values for furnace efficiency and air-conditioner efficiency data. Finally, in nearly every case, field auditors assumed the use of default U-values for windows, since nearly all windows in the survey lacked any kind of label specifying window U-values.

Figure 2: "As-built" Compliance Margins



There appears to be a strong correlation between the high rates of noncompliance in specific climate zones and the use of assumed values. For example, there were thirty homes surveyed in two climate zones which have *prescriptive* packages requiring a minimum of R-21 wall insulation. The on-site auditors could only directly observe wall insulation values for one of the thirty surveyed homes, so the research methodology dictated that the statewide mandatory default value of R-13 be used for the CALRES simulation. Normally, no builder in these two climate zones would be able to demonstrate compliance by proposing to use R-13 wall insulation. Consequently, by assuming R-13 wall insulation values for any home where the values could not be directly observed, the study methodology forced twenty-nine of the thirty homes into noncompliance. Staff is currently running new CALRES simulations which assume values reflecting common practice in specific climate zones rather than mandatory default values.

The use of statewide mandatory default values, however, cannot totally explain the high rate of noncompliance. Some homes failed to comply even when all CALRES-input data points could be observed. Other homes complied even though default values were assumed for multiple CALRES-input data points. Commission staff considered other explanations for the high rate of noncompliance. Possible explanations include the following scenarios:

- *the homes, as constructed, failed to comply.* This scenario assumes either that builders failed to include energy efficiency measures modeled in the original energy calculations or, alternatively, that builders modified the house during construction to include additional features which were not modeled. These failures by builders to build homes consistent with the original energy calculations, however, should be noted and corrected by local building department inspectors during the construction phase. Previous Commission studies have determined that many local building departments lack a formal review process which allows building inspectors to detect and correct these type of deficiencies. There is a disconnect between those individuals who review energy compliance documentation and those who review the site plans and those who inspect the homes in the field. Inspectors are usually unaware of the need to verify that the house, as constructed, has the energy features modeled in the compliance documentation and shown on the building plans. In addition, most building inspectors focus on health and safety issues when inspecting homes. They do not perceive their role as ensuring compliance with the state's energy efficiency standards. Commission staff are seeking the original compliance documentation submitted to local building departments for a sample of the homes in the Post-occupancy Residential Survey. Commission staff will review the original documentation to compare data collected during the survey with the CALRES data inputs used by builders to demonstrate compliance.
- *the field auditors systematically collected erroneous data.* This scenario assumes that all three subcontractors -- using trained and experienced auditors -- collected erroneous data. Commission staff considers this scenario to be unlikely. A Commission study conducted in 1993 cal-

culated compliance rates for four of the sixteen climate zones surveyed in this study. The relative ranking of the compliance rates for the four common climate zones is consistent between the 1993 study and the Post-occupancy Residential Survey. Both studies showed homes in the inland desert area as having the lowest rate of compliance and homes in the Riverside and San Bernardino area as having the highest rate of compliance.

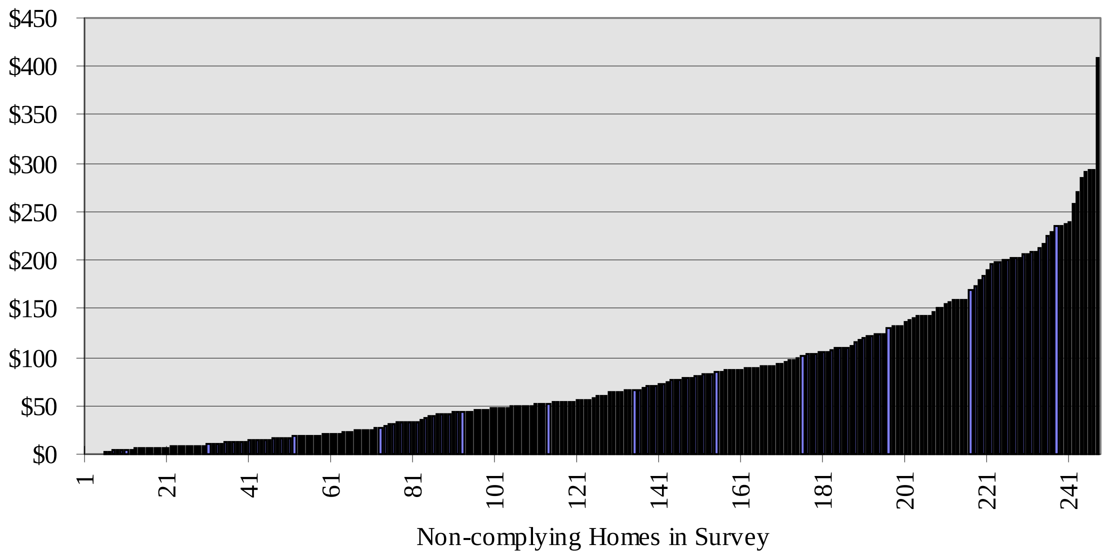
- *the field auditors failed to collect all data needed for the CALRES simulation.* There is some basis for concluding that the field surveys did not collect all data needed to run the CALRES energy use simulations. For example, the survey collected no data on thermal mass. In the absence of field data, the study assumed that homes with slab floors had 20 percent exposed thermal mass. As another example, insulation blankets prevented auditors from reading waterheater nameplates. Some auditors were unable to obtain nameplate data when homeowners denied access to attics where split-unit air-handlers were located. Commission staff are also reviewing the raw data to determine if auditors adequately recorded data on window exterior shading devices.
- *measures were installed but subsequently degraded.* The study data show some basis for concluding that the attic insulation in some homes has degraded since the time of installation. Auditors recorded observed R-33 and R-35 values for attic insulation in climate zones requiring R-38 insulation, and they recorded R-29 values in climate zones requiring R-30 insulation. Since attic insulation values are a direct measurement of depth of insulation, this discrepancy can be explained on the basis that blown insulation has settled over time. Insulation manufacturers specify that installers must allow for settling of blown insulation. Common industry practice, however, installs only the depth of insulation needed to achieve initial visual compliance.
- *builders do not understand how to comply with the standards.* One scenario is that builders construct homes according to their conception of standard practice. They may believe they are complying with the energy code when, in reality, they are not. The study did not collect data which could be used to explore this scenario.
- *subcontractors installed appliances less efficient than those originally modeled.* Previous Commission studies have identified a problem with builders and subcontractors installing furnaces and air conditioners which have lower energy efficiency ratings than units modeled in the compliance documentation. The problem sometimes is due to a modeled unit no longer being available. At other times, the builder, interested in reducing construction costs, buys and installs a less efficient unit because the unit is cheaper. This study did not examine whether the installed furnaces and air conditioners were consistent with the units modeled in the compliance documentation. This issue will be one element of the staff review of the original compliance documentation for a sample of the homes in the study.

Hypothetical Cost of Noncompliance

The study examined the hypothetical additional annual utility bill cost to each of the 248 homeowners living in a home that failed to demonstrate compliance with the energy efficiency standards. On average these non-complying homes used 10 percent more energy than allowed by the standards. Utility-specific marginal utility rates were calculated for each climate zone. Electricity marginal costs ranged from 7.3 cents/kWh to 9.7 cents/kWh. Natural gas marginal costs ranged from 63.1 cents/therm to 63.8 cents/therm. Propane marginal costs were $1/gallon. Since the CALRES results are presented by end-use as source energy in kBtu/sq.ft/year, the CALRES values had to be converted to appropriate units before applying the utility rates. The utility-specific marginal utility rates were applied to each home's energy budget differential ("standard design" minus "proposed design"). This value was then multiplied by the square footage of the house to determine the annual cost to the homeowner for the lack of compliance with the standards.

Figure 3 graphically displays the hypothetical additional annual cost for the 248 non-complying homes in the survey. Additional annual costs for *individual* homeowners ranged from a low of 55 cents to a high of $410. The statewide mean was approximately $80.

Figure 3: Additional Annual Cost for Non-complying Homes



The analysis disclosed that the average additional costs vary significantly by climate zone. The average cost for a non-complying home in the San Diego area was $2.81 per year. The average cost for a non-complying home in the inland desert region was $193.65 per year. The statewide average additional cost was $79.52 per year.

Homes which are not in compliance in milder climate zones incur less additional costs than homes located in more extreme climate zones. This observation seems intuitive. What was surprising was the extent to which the *climate zone* affects costs. For example, the average non-complying house in one southern California coastal area had a non-compliance margin of 6.9 percent with an average additional cost of $21.53 per year. Although the average non-compliance margin for a home in the upper Sacramento Valley was nearly the same at 7 percent, the average additional cost was $71.28 per year, primarily due to a much greater need for summer cooling.

Conclusions

The survey data indicate that only 38 percent of the 400 surveyed homes -- as built -- complied with the state's building energy efficiency standards. The most likely explanation for this low rate of compliance is the use of *assumed* energy efficiency values when the on-site auditors were unable to determine *actual* values for critical energy features. The critical features included wall insulation, attic insulation, windows, air conditioners, furnaces and water heaters.

Building energy-use simulation programs require input data which accurately describe the home and its energy-using components. When unable to observe *actual* energy efficiency values needed for data in-put, on-site auditors must use *assumed* values. Normally, when unable to observe actual values, an auditor would use his or her judgment to estimate the appropriate energy efficiency values. For this project, however, the auditors were required to use the default *minimum* values mandated by the standards, even when common building practice in a climate zone would be to install more efficient measures than required by the standards.

The survey results indicate that the use of minimum efficiency values may be appropriate for mild or temperate climate zones where builders commonly install features having the minimum efficiency levels required by the standards. The survey results also indicate, however, that use of minimum efficiency values is *inappropriate* for those climate zones having more extreme weather conditions, such as year-round cooling loads or a combination of significant heating loads during winter and significant cooling loads during summer. In the more extreme climate zones, very few homes could demonstrate compliance when minimum efficiency values were assumed for wall insulation and attic insulation.

Even though minimum energy efficiency values were assumed for many of the surveyed homes, the 400 homes overall used only 4 percent more energy than allowed by the standards. On average the 248 non-complying homes used 10 percent more energy than allowed by the standards.

The study determined that the statewide mean cost of noncompliance was approximately $80 per year for a homeowner living in a non-complying home. The mean cost of noncompliance varied significantly by climate zone, ranging from a low of $2.81 per year for a homeowner living in the San Diego area to a high of $193.65

per year for a homeowner living in the inland desert region.

The study highlights how building energy-use simulations are sensitive to the use of *assumed* values vis-a-vis *observed* values. *What you see* as the result of running an energy-use simulation is *not* necessarily *what you get* as an accurate assessment of a home's energy use. The use of *assumed* values rather than *observed* values for wall insulation, attic insulation and windows significantly affected the study's conclusion that only 38 percent of the 400 surveyed homes complied with the state's building energy efficiency standards.