Energy Characteristics and Code Compliance of California Houses

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The California Energy Commission (CEC) and the California DSM Measurement Advisory Committee (CADMAC) conducted an energy monitoring study in 1993 and 1994 to evaluate the characteristics of new homes and their compliance with the 1992 residential building standards. Over 1200 CF-1 compliance forms were collected from building departments in 4 inland climate zones where most of the new housing development was found. A detailed audit was then performed in 100 houses to verify the building energy efficiency measures installed. Indoor air temperature was also monitored for 30 days to determine space conditioning equipment operation in each house compared to the schedules assumed in the CalRes model. Finally, CalRes[1] input data were established and three CalRes simulation runs were performed to estimate the magnitude of the energy impact of over-compliance or under-compliance with the standards.

The first set of simulation runs for the audited houses were based on the January 1993 fenestration U-values requirements of the standards. The second simulation runs were based on the stricter July 1993 fenestration U-value requirements. A final set of simulation runs used the actual thermostat set points, the actual fraction of the time the occupants operated their space conditioning systems and the July 1993 fenestration U-values. Results of these runs show that the overall rate of compliance is low. The paper will discuss in detail the areas of inconsistency between the submitted compliance forms and the actual installations. The paper also discusses the energy impact, space conditioning equipment operation and margin of compliance for the 100 homes.

BACKGROUND AND METHODOLOGY

The California Energy Commission (CEC) awarded a contract to Berkeley Solar Group (BSG) to conduct independent field survey of residential buildings to verify the building characteristics and code compliance. The results, based on the data derived from this field testing, were used to assess the accuracy of the modeling assumptions used in the development of the Residential Buildings Standards (Standards). The survey sample size and field audits were expanded due to a cooperative effort with the California DSM Measurement Advisory Committee (CADMAC). The primary purpose of the project was to determine the energy use and occupancy characteristics of new single family houses built in hot valley climates which comply with the 1992 residential building energy standards and which do not participate in utility sponsored rebate programs. The main tasks were as follows:

(1) CEC planned to obtain 750 Compliance Form 1R forms (CF1s) from the building departments in Climate Zones 10, 12, 13, and 14 but later expanded to 1,500 forms due to increased funding from the CADMAC. The CF1 describes the new house's energy efficiency features and shows how the house complies with the Standards. BSG worked with the CADMAC utilities to screen out CF1s for houses which were participants in utility new construction conservation incentive programs. 1,230 CF1s were entered into a database and analyzed to determine the self-reported energy efficiency measures and characteristics of new houses meeting the 1992 residential building standards.

(2) BSG conducted 100 field audits and monitored the heating and cooling activities of the new houses in four climate zones. An independent verification of the energy efficiency measures was performed. BSG then compared the measured characteristics of the audited houses[2] to the characteristics reported by their builders on the CF1s to check for inconsistencies.

(3) BSG performed an independent compliance analysis based on as-built building information using the CalRes model to determine whether it complied with the 1992 California Standards.

(4) BSG performed a second set of independent compliance analyses based on a set of more stringent window U-values that became effective July 1, 1993 because it was unclear which window U-values were used when the permit was issued by the building officials.

(5) BSG measured heating and cooling set points at each audited house for a period of one month. BSG then performed a third set of compliance analyses based on

customized heating and cooling system operation and thermostat setpoints at each audited house for a period of one month. This analysis also added the effect of site shading and the measured thermostat schedules for both the proposed and standard designs.

(6) Results of other tests conducted by BSG, including a new simplified duct leakage measurement and Short Term Energy Measurement (STEM) test, are not discussed here.

Issues Related to the Research Sample

CF1 Data. The sample of CF1 forms was voluntarily submitted by building departments in response to a request from the CEC and direct phone contacts by BSG with all known building departments in the target climate zone. Building departments were guaranteed anonymity, asked to provide copies of CF1s for all houses which received a final inspection during the study period, and were paid $3 per CF1 to cover their costs. Several building departments declined to participate. The CF1 sample is therefore not a random sample of all new houses in the climate zones and may be biased. If so, it is likely to be biased by having a higher representation of CF1s from building departments who may be routinely checking the building plans to verify energy efficiency measures.

Field Audits and Sample Selection. The houses recruited for audits were from a random sample of the CF1 database for each climate zone using standard procedures to reduce sample bias. We believe that the audit data is representative of the CF1 data. This study was focused on building activity in four hot inland climate zones with heavy new construction activity. The results are not necessarily applicable to houses in other climate zones nor to the state as a whole.

RESULTS

Compliance Forms Versus As-Built Houses

Comparison of the data gathered in the field audits with the data in the CF1s submitted by the builders of the audited houses revealed many serious discrepancies. Table 1 lists the houses whose characteristics for five important measures were significantly different from those reported in the CF1s. The table also shows that nearly as many houses understated their efficiency levels as overstated them. Sixty-six of the 96 audited houses overstated the efficiency of one or more of the five measures. All 96 audited houses overstated the efficiency of at least one efficiency measure, thereby failing to comply with the administrative requirements of the standards.

Comparison of the data also revealed other characteristics which were frequently reported inaccurately on the CF1s. For example, only 48 CF1s stated conditioned floor area accurately within five percent of the conditioned floor area which BSG measured in the field. In 16 audited homes, the stated conditioned floor areas were 15 to 35 percent different from those measured in the field. It appears that CF1s for some or all of the houses with large errors in conditioned floor area were actually prepared for a different house plan.

Mandatory Measure Discrepancies

Mandatory measures are those which the energy efficiency standards require in all new houses and which are not allowed to be traded-off in performance calculations. There

Table 1. *Comparison of Data from Field Audits and from CF1s for Five Measures*[3]

	Accuracy of CF1 Statement of Efficiency		
Measure	No. Overstates	No. Correct	No. Understates
Furnace Efficiency (AFUE)	6	30	43
Air Conditioner Efficiency (SEER)	14	26	41
Attic Insulation (R-Value)	41	37	13
Glazing (number of panes)	31	54	4
Glazing Area	27	35	29

is significant non-compliance with the mandatory measures in only two areas. Hot water pipes are required by the Standards to be insulated for the first five feet or until they pass through a conditioned wall. This insulation was found to be missing in 20 houses. High efficacy fluorescent lights are required by the Standards in all kitchens and bathrooms, with its switch at the entrance of the room. This condition was found to be missing in 50 percent of the houses.[4]

CalRes Building Compliance Simulation

A set of CalRes files were created of the audited homes to determine if the as-built homes comply with the California energy standards. The input for the CalRes files was taken directly from the audit forms when possible. The CF1 forms for the houses were used when information was not available in the audits.

Three sets of CalRes files were prepared to examine the effects different assumptions have on the simulations. The first set (1/93 Glazing Rules) applied CEC window default U-values in effect from January 1, 1993 to July 1, 1993 to the windows found in the field (based on number of panes, thickness of air space, frame material etc.), and used interior window shades as stated on the CF1 form. The second set of files (7/93 Rules) used current CEC default U-values which went into effect July 1, 1993, and interior window shades as stated on the CF1 form. The final run (Custom) used the current default window U-values and the actual installed interior window coverings. The final set of runs also included custom thermostat and shading schedules which will be explained below.

Most of the audited houses were built in 1993 under the 1992 residential building standards, with a few constructed in 1994. During the first six months of 1993, builders were allowed to use less stringent U-values for dual-glazed metal framed windows. After July 1, higher default U-values went into effect. Since there is no way to determine when a home was permitted from the CF1 forms it is not possible to determine which window U-value guideline should have been followed. The reasoning for completing two separate runs was to see what effect the different window U-values had on overall energy consumption.

January 1993 Rules Compliance Analysis

The pre-July default U-values allowed a U-value of 0.65 to be used for all dual glazed aluminum frame windows in climate zones 12, 13 and 14, and a U-value of 0.75 in climate zone 10. These U-values were used for all dual glazed aluminum windows found during the audits in this set of CalRes files. In addition, the interior window shades were set to match what the builder claimed on the CF1. Table 2 shows the number of houses that comply in each climate zone. Climate zone 10 has the highest compliance rate at 77 percent. Altogether, just over half of the audited houses comply.

Table 3 shows the average standard and as-built energy use by climate zone. The houses comply as a group in climate zones 10 and 13, but do not comply in 12 and 14, where the average house as-built energy consumption is 2 percent to 5 percent higher than the standard design. The energy consumption of the as-built house in all four climate zones is about equal to that of the standard house.

The compliance margins were also analyzed. The compliance margin is the difference between the as-built house energy use and the standard house energy use expressed as a percentage of the standard house consumption. If the house has a positive margin it passes; a negative margin means it fails. Table 3 and Figure 1 show this compliance margin analysis. It can be seen from Figure 1 that the amount of energy saved by those houses that comply is about equal to the amount of energy the failing houses used over the allowed budget.

July 1993 Rules Compliance Analysis

The July 1993 default U-values are lower than the previous default U-values and depend on a variety of factors including window type, thermal breaks, gap width, Low-E glazing, and dividers. These U-values were used for all applicable windows in this set of CalRes files. The interior window shades were also set to match what the builder claimed on the CF1 for this set of runs.

From Table 4 it can be seen that by applying the stricter U-value requirements to the simulations an additional eleven houses fail the performance compliance. This brings the

Table 2. *Performance Compliance of As-Built Audited Houses (1/93 Rules)*

Zone	Comply	Don't Comply	Total	% Complying
10	20	6	26	77%
12	10	14	24	42%
13	15	7	22	68%
14	4	20	24	17%
Total	**49**	**47**	**96**	**51%**

Table 3. *Compliance Margin of As-Built Audited Houses kBtu/sf-yr (1/93 Rules)*

Zone	Energy Consumed		Margin			
	As-built	Standard	Average	Std. Dev.	95% Conf.	% Margin
10	32.2	33.8	1.5	2.9	1.1	4.6%
12	33.9	33.1	−0.7	3.4	1.4	−2%
13	37.6	38.4	0.8	2.4	1.0	−2%
14	42.3	40.4	−2.0	2.9	1.2	−5%
Total	**39.5**	**39.4**	**−0.1**	**3.3**	**0.7**	**0%**

Figure 1. *Distribution of Compliance Margin of Audited Houses As-Built*

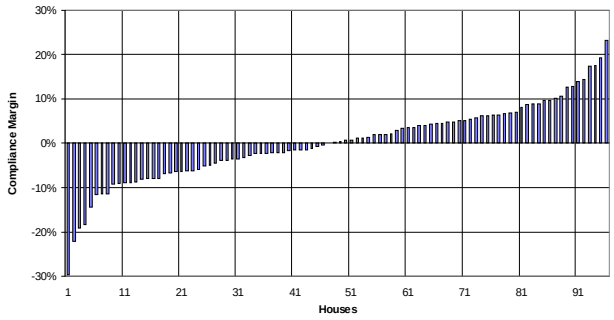


Table 4. *Performance Compliance of As-built Audited Houses (7/93 Rules)*

Zone	Comply	Don't Comply	Total	% Complying
10	18	8	26	69%
12	7	17	24	29%
13	11	11	22	50%
14	2	22	24	8%
Total	**38**	**58**	**96**	**40%**

overall passage rate for all climate zones down to forty percent.

Climate zones 10 and 13 still have the highest passage rate although from Table 5 it can be seen that climate zone 10 is the only one that still passes as a whole. The margins of failure for the other three climate zones vary from one to eight per cent with the average margin of failure for the entire group at three percent. The average energy consumption of the as-built houses has increased by 1.3 kBtu/sf-yr. Since more houses passed under the more lenient U-value assumptions, most of the houses were probably permitted under the earlier default U-values. This set of simulations also shows that the U-values assigned to the windows have a significant impact on the amount of energy used.

The compliance margin graph shown in Figure 2 shows that the amount of energy used above the budget is much greater than the energy used by the houses below the budget. The passing houses are not passing by as great a margin and the failing houses are failing by a much greater margin.

Custom Analysis

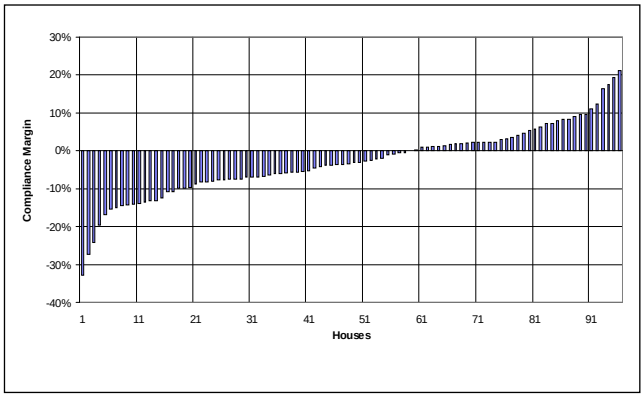
The custom analysis changed several of the input variables in an attempt to reflect the actual occupied house operation more accurately. The current default U-values for windows was used, the same as in the July 1993 analysis. The actual installed window coverings were used, as opposed to what was claimed on the CF1. The shading coefficients for indoor window coverings listed in the CEC Residential Manual were applied to the window coverings observed during the audits.

Custom site shading files were also developed to be read into CalRes to simulate the effect of shading from neighbor-

Table 5. *Compliance Margin of As-Built Audited Houses kBtu/sf-yr (7/93 Rules)*

	Energy Consumed			Margin		
Zone	As-Built	Standard	Average	Std. Dev.	95% Conf.	% Margin
10	32.7	33.8	1.1	2.9	1.1	3%
12	35.2	33.1	−2.1	3.6	1.4	−6%
13	39.0	38.4	−0.5	2.4	1.0	−1%
14	43.8	40.4	−3.4	3.1	1.2	−8%
Total	**40.8**	**39.4**	**−1.3**	**3.5**	**0.7**	**−3%**

Figure 2. *Distribution of Compliance Margin (7/93 Rules)*



ing houses on the audited house. The external shading file lists a minimum and maximum altitude angle for the obstruction at every fifteen degrees of azimuth.

During the audits, three temperature loggers were installed at each house; one was located near the thermostat, a second was located inside a supply register and the third was located outside in an area shielded from direct sun. Each of these loggers recoded the temperature at its location at two minute intervals during the entire monitoring period. Looking at this data, one can easily determine when the occupants heated and cooled each house and when the temperature was allowed to float.

When a house is being heated, the temperature in the supply register climbs suddenly to a value much higher than the room temperature. The supply air temperature either stays elevated or displays a cycling pattern while the room temperature increases to and is held at the desired heating setpoint. When a house is being cooled, the temperature in the supply register drops rapidly to a value much lower than the room temperature. The supply air temperature either remains low or cycles to hold the room temperature at the cooling setpoint.

BSG analyzed the logger information from each set of houses in order to determine the typical hourly setpoints and the typical fractions of time spent conditioning. In order to determine setpoints, they identified the periods when the HVAC system was on or cycling for each hour of the day, and found the average of the indoor temperatures while conditioning as well as the total number of minutes spent conditioning for each hour of the day. They then counted the number of minutes for each hour of the day when the HVAC system was off and the indoor temperature was outside the calculated setpoint, i.e. the number of minutes when the system was intentionally off rather than unneeded. To determine the fraction of time spent conditioning, they divided the ''on'' time by the sum of the ''on'' time and ''off'' time for each house. For houses with no measured heating they used the average measured hourly heating setpoints and fractions on, and for houses with no measured cooling they used the average measured hourly cooling setpoints and fractions on.

BSG translated this information into CalRes day-of-week thermostat schedules for the custom analysis. Figures 3 and 4 show the measured heating and cooling setpoints compared to the CEC assumptions. The measured heating setpoints follow the CEC assumptions closely except for the large nighttime setback which did not take place in actual operation. There is a slight decrease in the heating setpoint temperatures overnight. The cooling setpoint data hovers around the CEC assumed setpoint temperature of 78 degrees.

Figure 5 shows the average fraction of the time the heating and cooling systems are on. This data does not support the CEC assumptions of continuous 100 percent conditioning. Occupants condition their homes for a maximum of 60 per-

Figure 3. *Measured Heating Setpoints Compared to CEC Assumptions*

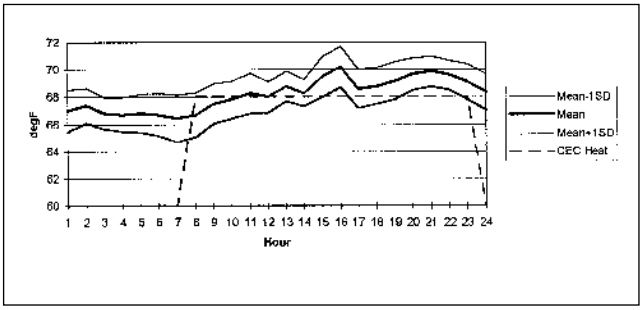


Figure 4. *Measured Cooling Setpoints Compared to CEC Assumptions*

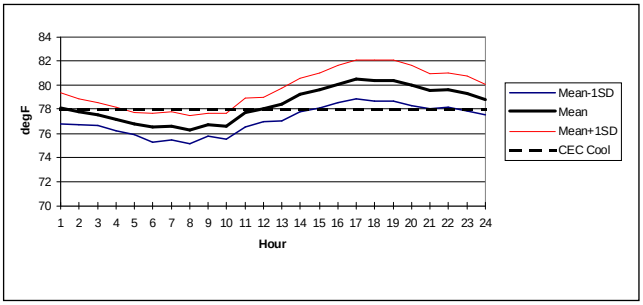
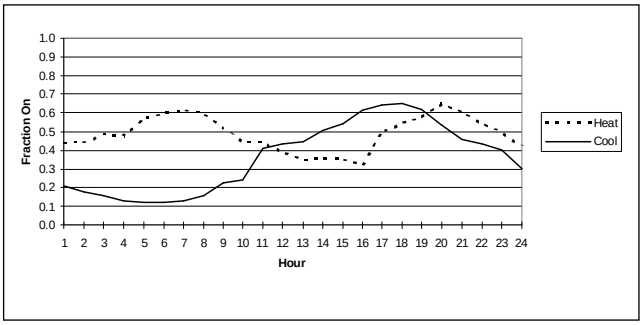


Figure 5. *Average Fraction of Time Heating and Cooling are On*



cent of the time during early morning and late afternoon hours.

The results of the custom compliance analysis are summarized in Table 6 and Figure 6. Although the individual results from each climate zone changed some, the overall compliance of forty per cent was the same as the 7/93 analysis. Climate zones 12 and 14 improved slightly while climate zone 13 had three less houses comply in this simulation. Table 6 shows even though the compliance rate remained unchanged the customized variables had the effect of reducing the actual amount of energy consumed 5.9 kBtu/sf-yr (about fifteen per cent) over the 7/93 analysis. Once again, however, Figure 6 shows that the amount of energy used over the budget by the non-complying houses outweighs the amount of energy the complying houses save.

Figure 7 shows the amount of heating and cooling energy used in the Custom run compared to the 7/93 CalRes run. It can be seen that by adding customized thermostats and shading schedules to the CalRes files the amount of calculated energy needed to cool is reduced by almost half.

CONCLUSIONS

The CF1 forms provided a large set of self reported data on the energy efficiency characteristics of new California houses. Comparison of the data gathered in the field audits with the data in the CF1s submitted by the builders of the audited houses revealed many discrepancies. In some cases, many mandatory measures are being ignored.

The assumptions of daytime heating and cooling setpoints are close to the measured values. However, the measured data does not support the assumption of a large nighttime setback of the heating thermostat. By adding customized thermostat and shading schedules to the CalRes input files, the amount of heating energy is close to the results of the compliance analysis, however, the amount of energy needed to cool is reduced by half. CEC also overestimated the cooling energy use in the CalRes model due to lower operating hours of air conditioning equipment.

The energy compliance analyses revealed that approximately 50 percent of the residential homes complied with the 1992 building standards in an absolute sense. The amount of energy saved by those houses that complied, however, compensated for most of the excessive energy use of the half that did not comply.

ENDNOTES

1. CalRes is a CEC certified computer model to perform Title-24 energy compliance calculation for residential homes in California.

2. Only 96 were ultimately used for final analysis.

3. Efficiency measures that could not be identified were not included in the Table. Total for each measure would not be 96.

4. Detailed measure by measure verification is available in CEC report #P400-91-031CN.

Table 6. *Compliance Budgets of Occupied Audited Houses, kBtu/sf-yr (Custom)*

Zone	Energy Consumed		Margin			
	As-built	Standard	Average	Std. Dev.	95% Conf.	% Margin
10	27.5	28.4	1.0	2.4	0.9	3%
12	31.5	30.3	−1.2	3.0	1.2	−4%
13	31.4	31.1	0.2	2.1	0.9	−1%
14	38.5	35.7	−2.9	2.9	1.2	−8%
Total	**34.9**	**34.0**	**−0.9**	**3.0**	**0.6**	**−3%**

Figure 6. *Distribution of Compliance Margin (Custom)*

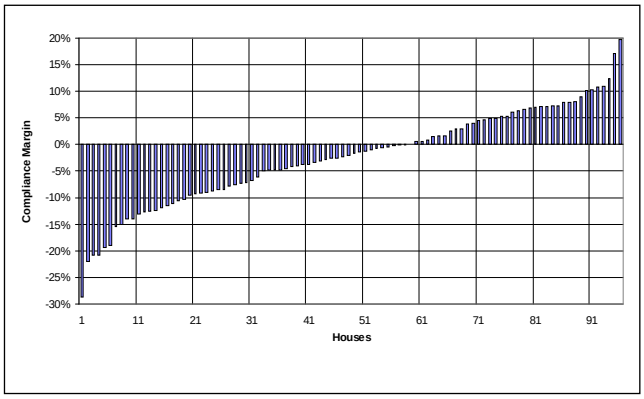
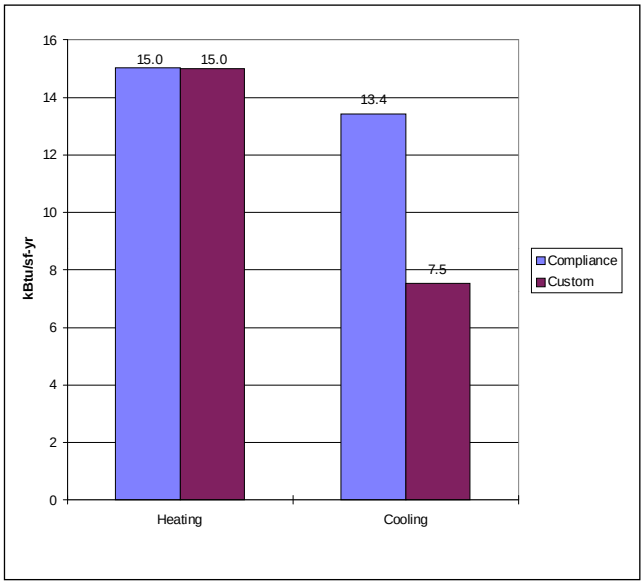


Figure 7. *Average Annual Energy Consumption*



REFERENCE

Berkeley Solar Group, May 1995. ‘‘*Energy Characteristics, Code Compliance and Occupancy of California 1993 Title 24 Houses.*’’ CEC consultant report P400-91-031CN, California Energy Commission.