Cracking the Code for Residential New Construction: Using End-Use Metered Data to Revise Energy Estimates of Compliance Models

Clark Bernier, RLW Analytics
Jarred Metoyer, RLW Analytics

Abstract

To qualify for the 2002-03 and 2004-05 California Energy Star® Homes programs, a home has to have an annual energy consumption 15-20% below code baseline as estimated by its code compliance model. Because the results of these model runs are collected from the entire program population, they would be invaluable tools for obtaining extremely accurate estimates of program savings if they are accurate. However, the models are based on a number of assumptions about consumer behavior and environment that may or may not hold true in practice.

As part of the evaluation for the 2004-05 program, we conducted extensive end-use metering of cooling, heating, and water heating energy usage of 101 single family and 99 multi family units. These data were used to adjust the site usage estimates obtained from the compliance models to more accurately reflect the energy consumption of the three program-impacted end uses (cooling, heating, and water heating) in the participant homes.

Our findings show that the compliance models are not accurate predictors of average annual energy usage. With the exception of single family homes in coastal climates, the models routinely over-predict the annual energy usage for all three program-affected end-uses. For single family homes, the models over-predicted usage by 25-70%, depending on end-use. Multifamily overestimates were much larger, though less statistically reliable. A number of possible explanations are offered for these results and possibilities for future studies are explored.

Introduction

This study arose out of the evaluation, measurement, and verification (EM&V) studies of the 2002-03 and 2004-05 California Energy Star® Homes programs. Tracking savings for the program were estimated using the outputs of individual compliance models for each participant housing unit. These compliance models are complex engineering models that estimate load for cooling, heating, and water heating end uses based on the layout and characteristics of the homes and a set of standardized historical weather specific to the climate region of each home. Their purpose is to allow for a performance-based as opposed to prescriptive or measures-based code to determine structure compliance. The models themselves, under the 2001 code that the program was based on, were built in one of two software packages, both of which estimate structure energy usage according to the rules and equations laid out in the *Residential Alternative Calculation Approval Manual.*[1]

Code compliance of a structure is determined by its overall annual energy usage (across all end-uses) being no greater than the same size structure would consume under a set of prescriptive baseline components. This baseline set of characteristics varies from climate zone to climate zone within the state. The difference between this estimated baseline consumption and the estimate based on the as-

[1] CEC, 2001 (2).

modeled characteristics, expressed as a percentage of baseline consumption is termed the compliance margin.

A compliance margin greater than 0% indicates that a structure with the proposed characteristics would consume less overall energy than if it had baseline characteristics, and indicates achievement of code compliance. A compliance margin greater than 15%, meaning that the software estimates the home to use 15% less energy than baseline, is required to achieve Energy Star® Home status. To receive the program incentive, builders must submit the specifications of the model to a plan check registry who, in turn, build a comprehensive database of every participant structure built under the program.

If these models provide accurate estimates of average energy consumption by end-use, then these registries become an invaluable tool for obtaining extremely accurate estimates of program savings. Furthermore, if accurate, they allow the utilities to make accurate estimates of the impact that new residential construction will have on future energy needs.

However, the models are based on a number of assumptions about consumer behavior and environment—such as constant thermostat set points, homogeny of occupancy patterns between multi and single family units, water heating demand that scales linearly with floor area,[2] and that future climate will be the same as the climate of 1970-2000—that may or may not hold true in practice. No prior study has sought to directly compare the estimates produced under the compliance guidelines with the actual average energy usage observations/measurements. For this reason, as part of the program evaluation, we conducted extensive end-use metering of cooling, heating, and water heating energy usage of 101 single family and 99 multi family units. These data were used to adjust the site usage estimates obtained from the compliance models to more accurately reflect how the three program-impacted end uses (cooling, heating, and water heating) were used in the participant homes.

This paper reports the findings of that end-use consumption adjustment. The following section outlines the data that we collected in order to make the comparison between actual site usage and compliance model estimates. The third section outlines the methods employed in interpreting and analyzing these data. The fourth section presents the results of transforming the compliance models to actual-year weather data and compares those to the metered usages in that year by end use. Ratio estimates of metered to modeled usages are also reported there. Finally, the concluding section offers some observations and possible interpretations of these results, concluding with a discussion of further research that might be conducted to better understand the results.

DATA

Sample Design

A sample of 101 single family homes were selected for metering from the population of participant homes approved into the program in 2002 or 2003. They were randomly selected from five regional strata[3] in proportion to the number of participant homes in each region.

Because there is much more variation in size among multi family sites, and because budget constraints limited us to a smaller sample (25) of multi family projects, we chose to further stratify our multifamily sample by conditioned floor area to ensure a more size-representative sample in each of the regional strata. At each site, we used simple random sampling to choose four dwelling units for inspection and metering. While four units are not likely to be adequately representative of a site of many dozens of units, budgetary constraints limited us to this approach.

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[2] Though with a hard usage cap at 2500 square feet.

[3] The strata were based on the regional zones used in the baseline evaluation report for the program. Each was composed of 2-5 of the state's 16 climate zones and were chosen in such a way as to group roughly similar climates together

Metered Data

From each of 101 single family homes and 99 multi family units in 25 sites, we collected interval meter data from the following equipment:

- Central and wall air conditioning units
- Domestic hot water heaters and boilers
- Central and wall heating systems

For AC and heat pump units, we metered system amperage and took field measurements of voltage and power factor which were used to compute 20-minute kWh data. For water heaters and hydronic systems, we collected average 90-second flue gas temperature readings using a thermocouple. The temperature differential between burn and non-burn periods allowed us to determine hourly runtimes. Based on the nameplate gas input rate of the units, BTU consumption per hour was then computed. For gas heating systems, we connected an interval runtime meter to a relay that was slaved off the thermostat call for heating signal. This enabled us to compute precise estimates of runtime, which coupled with nameplate-rated gas input rates, allowed us to calculate hourly heating gas usage.

A total of 92 AC units, 94 water heating systems, and 87 furnaces were ultimately included in the single family analysis. All single family sites in the sample had a split AC, storage tank water heating unit, and a gas furnace. Two sites were dropped from the analysis because we were unable to obtain their compliance models for comparison.

Multifamily cooling systems were predominantly split systems, though there were a significant number of package terminal units and heat pumps in the sample. A total of 81 units were ultimately included in the analysis (16 units had no AC unit and two had bad data).

Multifamily water heating was predominantly served by storage tank water heaters. Some of the storage tanks had fan-powered flue vents (PVNT), which could use a slaved relay to measure runtime in the same way as the furnaces. Central boiler systems served the sites that did not have either of the two storage water heater types. Ultimately, data representing 74 units pass quality assurance and were included in the analysis.

Heating system types in multifamily homes varied widely, and included hydronic systems (40%), gas furnaces (23%), split heat pumps (20%), package terminal heat pumps (8%), gas wall furnaces (4%) and electric baseboard heaters (4%). A total of 91 units' data were ultimately included in the analysis.

Inspection-Adjusted Compliance Models

Every single and multifamily participant was modeled in either of two code compliance software packages in order to qualify as program participants. We obtained the model files for 99 of the 101 metered single family homes and all 25 of the multifamily projects. During installation of the metering equipment, we conducted inspections of the units to determine if their models, as submitted, accurately reflected their as built characteristics. We then adjusted the compliance models to reflect the characteristics actually found on site.

Weather Data

The compliance software packages utilize weather data files for each of California's sixteen climate zones to compute energy budgets for compliance simulations. These files were developed from historical data over the past 30 years and are representative of a typical climate year. However, this study's metering was conducted during 2005 and 2006, and there are significant weather variations from year-to-year that in turn have a significant impact on heating and cooling end-uses in the compliance models. Therefore, it was necessary to adjust the model outputs to account for the actual weather conditions during the metering period.

To this end, we obtained hourly temperature, precipitation, wind speed, and solar radiation data from the Western Regional Climate Center's (WRCC) Remote Automatic Weather Station (RAWS) system. Additionally, RLW obtained hourly temperature, precipitation, and wind speed data from major California metropolitan airports from the WRCC. For each single family and each multifamily site in the respective samples, we chose the nearest RAWS to provide hourly solar data, and the nearest RAWS and/or airport to provide temperature, wind, and precipitation data. For each site, a full year of weather data (beginning with the day after meter installation) was extracted from the chosen weather files. Each site had a customized set of weather data prepared for it.

Analysis Methods

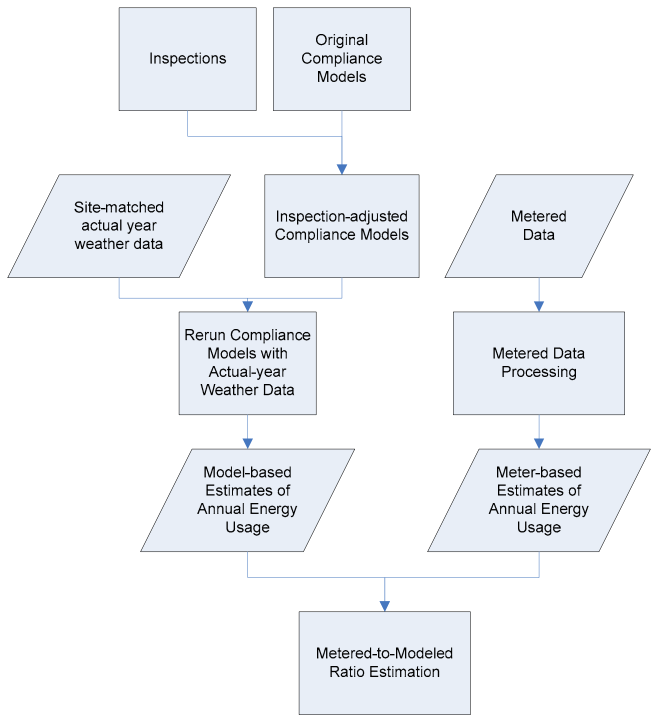

Figure 1: Analysis and Data Overview

Rerun of the Compliance Models with Actual-year Weather Data

We obtained a custom weather-packing utility from one of the two compliance software producers (Software 1) that transformed these weather files into a form compatible with custom model runs. For sites modeled in that software (100 out of 101 single family sites and 12 out of 25 multi family sites), we were able to rerun the models with the site-specific weather file for the metering period. The output from these reruns was a compliance-model estimate of annual energy usage by end-use under the same weather conditions the houses experienced during end-use metering. The units of the output were source kBTU.[4]

[4] Source kBTU is equal to either the amount of gas energy consumed at site, or to an estimate of the total energy consumed to generate the electricity consumed on site. The ratio of source to site energy for electricity is assumed to be 3-to-1 (CEC 2001 (1) and (2)).

For the 13 multifamily and 1 single family sites modeled in the other compliance software (Software 2), we were unable to arrange for custom weather packing due to budget restrictions. An alternative method was devised to estimate the impact of changing these models from the standard weather to actual-year weather. The homes whose reruns were processed in Software 1 tended to have similar percentage changes in heating and cooling energy usage as homes remodeled using the weather data from the same RAWS/airport data combination. Based on this observation, we used Software 1 models with custom weather files to estimate the percentage change in usage that the Software 2 models would have faced if fed the actual-year weather files. For each Software-2-modeled site, we chose a Software-1-modeled site that had the most similar building characteristics. Each of this representative site's Software 1 models (ranging from 3-10 structures per site) were then run in the climate zone the Software 2 site was originally modeled in and then run again using the custom weather chosen for the site. The average percentage change of the models' heating and cooling energy budgets was then calculated and applied to the original Software 2 usage estimates for the structures at the site.

For the single family sites, these model outputs already represented site-total energy usages by end use. For the multifamily sites, which had multiple structures, the end-use estimates for each structure had to be totaled to produce the site-total energy usage by end-use.

Metered Data Processing

The metered data were collected and processed into kWh and BTU usage figures as described in the previous section. For split terminal ACs and Heat pumps, which did not have fan usage metered, we used DOE-2-derived performance curves to estimate runtime based on the percentage of capacity used during each 20-minute metering period. Spot metering of the fan unit during meter installation was used to convert these runtimes into fan energy usage for each unit. For ACs, these were added to the kWh of the rest of the unit to yield total cooling energy. For HPs, analysis of the usage profiles allowed us to split out cooling usage from heating usage, producing a separate estimate of kWh for each. These kWh outputs were then totaled into annual usages and then converted to kBTU by multiplying by 3.412. To adjust for transmission and generation losses associated with electricity use, the usage figures were also multiplied by 3 to yield an estimate of source kBTU; the output unit of the compliance software.

Furnace usage data and basic water heating data were totaled across the metering year to yield annual energy usage. No transformations were necessary to produce source kBTU. For hydronic systems, an analysis of summer months for each site was used to determine an average daily baseline water heating energy usage. A ratio analysis of summer usage to winter usage across all domestic water heating systems was then used to true this baseline up to represent winter baseline usage. Any daily usage in excess of this baseline during a six-month winter period was labeled as consumed heating energy, the rest being allocated to the water heating end use. These daily figures were then totaled over the metering year to produce estimates of annual heating and water heating energy usages for each unit.

For single family sites, these energy estimates per dwelling unit were directly comparable to the modeled structure as there was only one unit per "site." For multifamily sites, there could be many dozens of units despite the site being represented by between three and four dwelling units worth of available meter data. Having measured the square footage of each metered unit during the site visits, we determined the total amount of metered floor area by adding the floor areas of each metered unit at a site. We then took the total square footage of the site as per the models and divided by the total metered area, yielding the per-metered-square-foot weight. Each metered unit's usage was then weighted up by the square footage of the unit times this weight. The sum of these weighted metered usages gave the total site usage for each end use. For central water boilers, weighting was done based on the proportion of total site floor area to floor area served by the metered boiler unit.

Metered-to-Modeled Ratio Analysis

Due to the differences between the larger, desert-located cooling sites and the rest of the inland data and the difference between coastal and inland results seen in the data, we broke out the analysis into three climate zone groups of the 16 state climate zones: the group coastal-adjacent climate zones, the non-coastal or inland climate zones, and the single desert climate zone. These distinctions were used throughout the single family portion of the metered-adjusted ratio analysis of the heating and cooling end uses. Since water heating is not weather-dependent in the compliance models, its adjustment factor was not separated out by climate zones.

For the single family estimates, we used stratified ratio estimation to weight our sample up to the program's single family participant population and calculated the ratio of metered usage to real-weather modeled usage.[5] The sample was projected up to the total population by the compliance code climate zones, such that each climate zone's available sample sites for each end use were treated as a simple random sample of the participants in that climate zone. Once those weights were assigned to the sample homes, ratio estimation was used to calculate the average ratio and precision of metered energy usage to modeled energy usage by inland, coastal, and desert and by end use.

The multifamily sample of 24 sites, however, was too small to adequately represent all 16 climate zones. The next largest driver of variability in metered usage among multifamily units after climate zone was thought to be compliance-modeled estimates of site savings. Therefore, instead of stratifying by compliance code climate zones, the sample was projected up to the total population by compliance model-predicted savings using model-based statistical sampling (MBSS) methodology.[6] Strata were chosen such that the total variation of each was equal, and weights assigned so that the sample sites with data in each stratum were weighted to represent the population of sites in that stratum. Those weights were then used in stratified ratio estimation to produce the ratio estimates.

Analysis Results

Results of Model Reruns

The impact of real-weather remodels on cooling and heating energy estimates varied greatly by site location, weather station, and metering period. Changing the weather had no impact on domestic hot water energy demand.

Figure 2 shows the relationship between the original modeled single family cooling energy using the standard weather data compared to the same homes modeled using the weather file corresponding to their location/metering period. Some homes use considerably more or less energy under real weather conditions than under their base historical-weather climate data. Most homes, however, moved a small amount to either side of the y=x line (which denotes actual-weather reruns predicting the same energy usage as historic weather (base) runs). The large outliers on the upside are the three homes in climate zone 15 (the high southern desert). The outliers on the downside tended to be homes that were near the inland/coastal or inland/desert dividing lines, and thus saw significant changes to their energy budget when remodeled with weather data closer to their true location than the representative city of their climate zone.

[5] A detailed explanation of stratified ratio estimation can be found Chapters 12 and 13 of TecMarket Works 2004.

[6] Refer to TecMarket Works 2004, pg 337-338 for more information on MBSS.

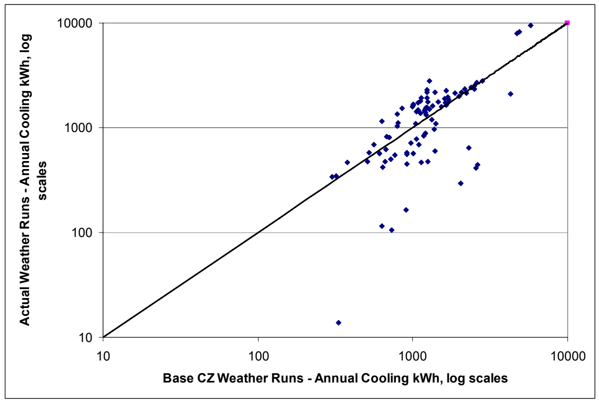

Figure 2: Single Family Cooling Base Weather Results Compared to Real Weather Reruns

The multifamily sites generally showed less sensitivity to the change from standard climate zone data to actual-year weather data. Figure 3 shows the impact on model estimates of cooling usage. Total demand for a few high-usage sites dropped due to milder temperatures, while a few lower-usage sites' demand increased due to more sun and higher temperatures in their climate zone during the metering period. Overall, however, the conversion to actual-year weather had a relatively small impact on the cooling budgets of multifamily sites.

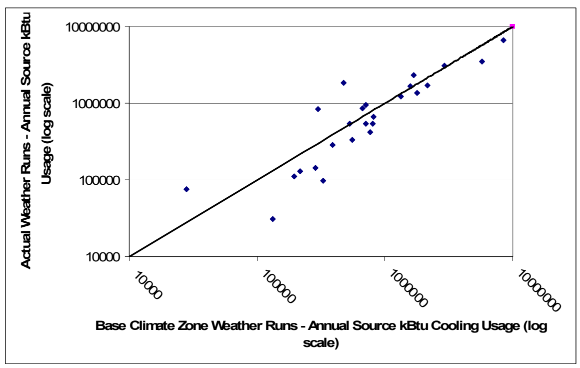

Figure 3: Multi Family Cooling Base Weather Results Compared to Real Weather Reruns

Single family heating usage estimates all tended to be higher under real weather conditions than using the historic weather to represent the climate zone, as can be seen in Figure 4. In part this was due to a colder-than-average February and March 2006 across much of California. Another key difference, however, was that the solar energy for the winter months tended to be higher in the standard weather files than in the real-year weather data obtained from the WRCC. Several individuals with experience in solar data have confirmed the solar numbers that we used in the remodels, and it is thought that the data simply reflect a lower-than-average year for total winter solar gain due to it being one of the rainiest winters in recent history.

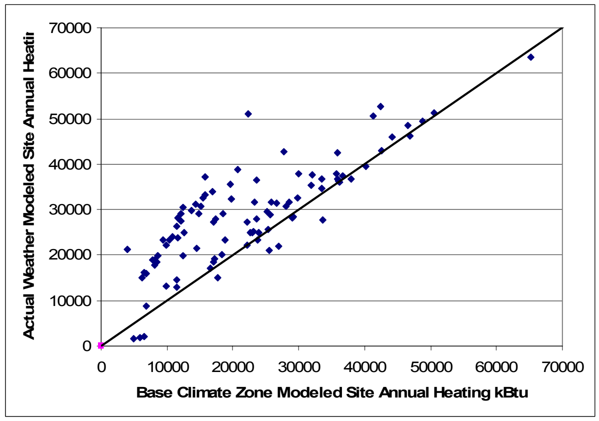

Figure 4: Single Family Heating Base Weather Results Compared to Real Weather Reruns

The impact on heating usage was slightly more pronounced on a percentage basis, for multifamily units, as can be seen in Figure 5. There does not, however, appear to be the predominantly upward correction seen in the single family remodels. The heating remodels are about equally split between sites that increased and sites that decreased usage relative to historic weather (base weather) for their climate zone.

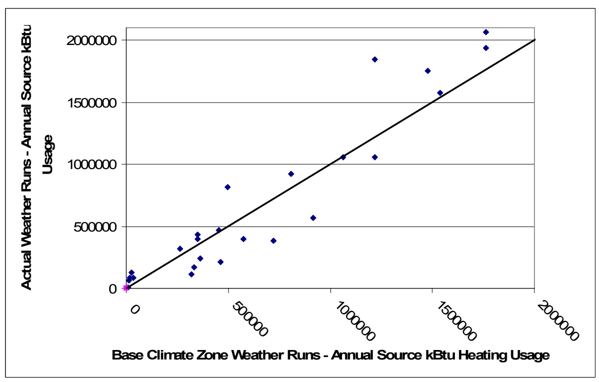

Figure 5: Multi Family Heating Base Weather Results Compared to Real Weather Reruns

Ratio Estimation Results

Single Family Meter-to-Model Comparison

As expected, the variation in actual usage was greater than the variation in modeled estimates—after all, the models are meant to represent a home under standardized usage conditions. Figure 6 shows the single family cooling metering results plotted against the cooling load predicted by the models.

Most of the sites have a metered usage less than the modeled usage, falling underneath the y=x line in the plot. There are a handful of sites that exhibited considerably higher annual usages than the models predicted. Some of these sites are standard sampling outliers; larger users that are statistically balanced out by smaller users in the sample. However, most of the 14 homes located in coastal climate zones lie above the line, indicating that, generally, coastal-dwellers used more AC energy than the compliance model indicated.

The three desert sites with high model-predicted cooling load used considerably less AC than the model predicted. This is to be expected, as it is in very hot climate zones that the impact of the models' constant thermostat set point assumption is going to have the greatest impact on usage estimates.

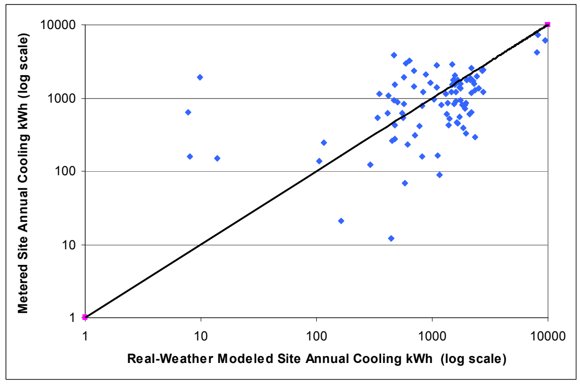

Figure 6: Single family Metered Annual kWh Cooling Compared to Modeled kWh Cooling, log scale

The heating results more consistently show that metered usage is less than the modeled usage. Figure 7 shows that just over a dozen sites logged usage greater than the amount the compliance model predicted for them. The rest of the sites fall below the y=x line, indicating that the model over-predicted heating demand relative to what the homeowner actually used during the metering period.

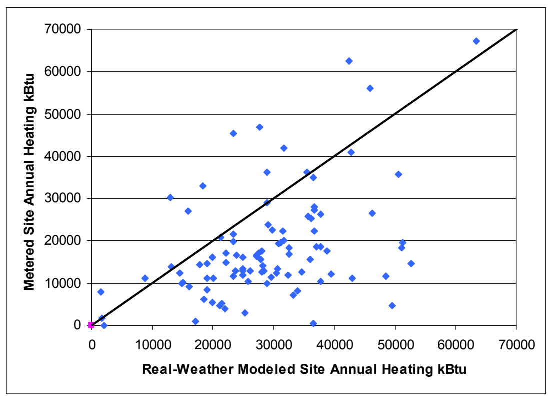

Figure 7: Single family Metered Annual kBtu Heating Compared to Modeled kBtu Heating

The greatest variation among the metered results vis-à-vis the modeled usages was seen in the hot water results. As Figure 8 shows, the models predicted annual consumption between 19,000 and 30,000 kBtu for the homes, whereas actual metered usage ranged from just above 0 to 45,000 kBtu—with one home topping 60,000 kBtu. Despite the large spread, the majority of the homes showed metered usage less than the model-predicted annual usage. In fact, most of the homes had metered usage under 19,000 kBtu, the smallest model-predicted usage among our sample homes.

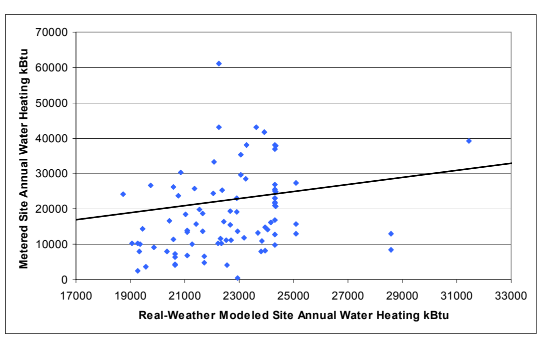

Figure 8: Single family Metered Annual Water Heating Compared to Modeled Water Heating

Single Family Meter-to-Model Ratio Analysis Results

Table 1 shows the results of the single family ratio analysis.

Table 1: Single family Metered-to-Modeled Ratios by Location and End Use[7]

End Use	Climate	Sample n	Ratio Meter Usage to Modeled Usage	Relative Precision
AC	Coastal	14	1.752	49.0%
	Inland	72	0.797	14.3% *
	Desert	5	0.664	18.3% *
Heat	Coastal	14	0.589	28.9% *
	Inland	76	0.614	11.6% *
	Desert	6	0.837	25.3%
Hot Water	N/A	87	0.813	10.3% *

* Indicates statistically significantly different from ratio = 1

As was observed in the graphs of metered versus modeled energy usage, coastal cooling usage was, on average, 75.2% higher than modeled usage for coastal homes. Despite its size, however, this ratio is not statistically significantly different from 1, and thus does not represent a statistically significant difference between coastal metered and modeled usage. The ratios for inland cooling and desert cooling, however, are both statistically significant, both having relative precisions under 20%. The inland homes, on average, used 79.7% of the cooling energy predicted by the models. The desert homes used 66.4% of the predicted energy. Overall, there is good statistical evidence that the compliance model overstates cooling energy demand for inland and desert single family homes.

The heating ratios reflect even greater overestimation of usage. Coastal metered usage was 58.9% of modeled projections while inland homes' usage was 61.4% of their models' estimates. Both results were statistically significant. Desert homes also used less heating energy than modeled—83.7% less—but this difference was not statistically significant, owing to the small sample size of desert homes.

The hot water ratio also reflects the results shown in Figure 8, showing an average metered usage of 81.3% of modeled usage across all homes at a 10% relative precision.

Multi Family Meter-to-Model Comparison

Figure 9 shows the metered cooling load plotted against the modeled load for the 21 multifamily sites with good AC data. This graph has both axes on a log scale, and thus even the small distances between points still represent considerable absolute differences between figures. There are two sites that were modeled to use very little cooling energy but actually consumed a considerable amount, and two sites that were modeled to have very high consumption that did not use nearly that much. The rest of the sites were modeled to use between 0 and 2,500,000 kBtu apiece; only one of which was estimated to have used more than 500,000 kBtu. Overall, the multifamily sites appear to be using considerably less cooling load than predicted by the compliance models.

[7] All relative precisions were computed at the 90% level of confidence. The relative precisions indicate what percentage of the estimates the error bounds represent. If the estimate plus or minus that error bound does not include 1, then the estimate is determined to be statistically different from 1. A ratio of 1 would indicate that the model accurately predicts average energy usage.

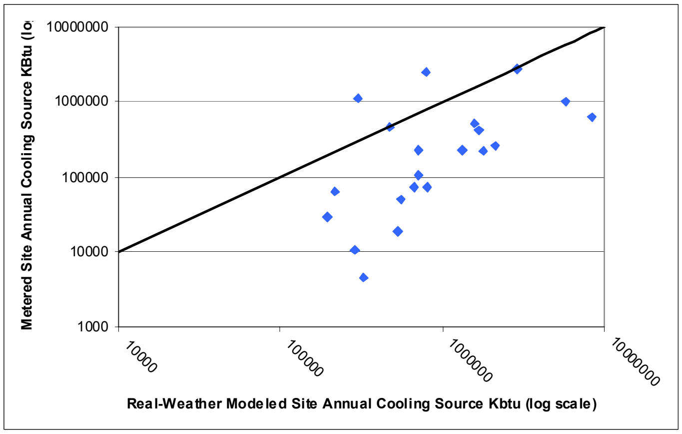

Figure 9: Multifamily Metered vs. Modeled Annual kBtu Cooling, log scale

This trend is also reflected in the heating data. Figure 10 shows that both modeled and metered heating usages fall within a narrower range than the cooling data. With the exception of two sites, however, all of the sites used significantly less energy than the models predicted.

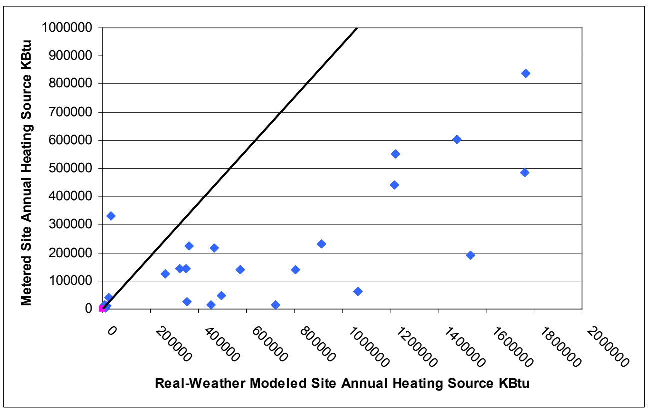

Figure 10: Multifamily Metered vs. Modeled Annual kBtu Heating

The water heating data further reflects the significant model overestimation seen in the other two end uses. In Figure 11, again, only two sites saw metered usage above that predicted by the compliance models.

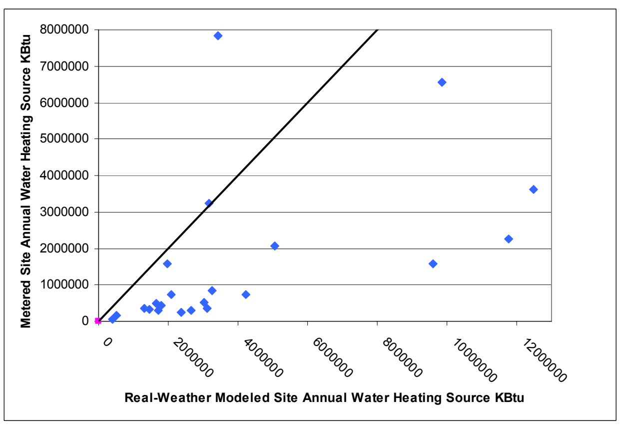

Figure 11: Multifamily Metered vs. Modeled Annual Water Heating

Multi Family Meter-to-Model Ratio Analysis Results

The multifamily sample had only one site in the desert region, so the "desert" climate zone was not broken out from "inland" for the calculation of the MF mete-to-model ratios. The results of ratio estimation are shown in Table 2.

Table 2: Single family Metered-to-Modeled Ratios by Location and End Use[8]

End Use	Climate	Sample n	Ratio Meter Usage to Modeled Usage	Relative Precision
AC	Coastal	6	0.118	77.5% *
	Inland	15	0.397	45.8% *
Heat	Coastal	10	0.161	36.0% *
	Inland	12	0.212	68.8% *
Hot Water	NA	22	0.301	25.2% *

* Indicates statistically significantly different from ratio = 1

All of the multifamily meter adjustment factors were found to be statistically significantly different from 1. Metered cooling energy usage was 11.8% of modeled usage in coastal regions and 39.7% of modeled usage in inland regions. Heating ratios were equally low. Coastal dwellers used 16.1% of the model-projected heating energy. Multifamily sites in inland areas used 21.2% of modeled heating energy. These very low ratios for cooling and heating indicate that the assumptions made in the compliance software significantly overstate the space conditioning demands of multifamily residents.

Water heating is similarly overstated in the multifamily models. The metered sites indicate that true usage is 30.1% of that predicted by the compliance models for an average multifamily site. Like space conditioning, this is a much lower ratio than was estimated for single family homes.

Conclusions

Single Family Conclusions

The meter-to-model ratio results indicate that the compliance models are not accurate predictors of average annual energy usage. Single family coastal homes' cooling usage is under predicted by the models, though the result is not statistically significant due to the small coastal sample size. All other end-uses are significantly over-predicted by the models. Water heating model predictions average 23% (1- 1/0.813) higher than the homes actually consume. Cooling estimates from the models average 25% - 50% higher than reality. Heating estimates are even more overstated by the models at a 70% over-estimate for coastal and 63% for inland homes. Insomuch as these usage estimates are used to estimate program savings, estimates of savings will be similarly overstated.

The models still have value as compliance tools, however. Since these over estimates are likely the results of occupancy and climatic differences between reality and model assumptions, they should have a comparably-sized impact on the models' estimate of baseline for each home. Thus, the metric used for code compliance and program gatekeeper—compliance margin—is potentially still a reasonable indicator of relative savings. This study can say nothing one way or the other about the compliance models' validity in that regard.

[8] All relative precisions were computed at the 90% level of confidence. The relative precisions indicate what percentage of the estimates the error bounds represent. If the estimate plus or minus that error bound does not include 1, then the estimate is determined to be statistically different from 1. A ratio of 1 would indicate that the model accurately predicts average energy usage.

There are many reasons why the models may overstate savings. The first, and relatively unlikely scenario, is that there are errors in the engineering models and assumptions at the heart of the compliance models. In general, these relationship are well documented and researched, and not likely to be wrong.

The more likely explanations are the less tested (and more difficult to test) occupancy and environment assumptions inherent in the models. For instance, under code, all living spaces must be modeled as having a constant cooling temperature set point of 78˚F and a heating set point of 68˚F during the day and 60˚F during the night.[9] Homeowners do not always keep a constant set point due to a combination of factors such as not being home 24/7, choosing alternative ventilation strategies (i.e. opening windows at night) in set-point-marginal conditions, and having different comfort preferences.

Another occupancy assumption that may play a role in over-predictions is the relationship between floor area and the number of people inhabiting the home. These assumptions are incorporated into the equations scaling energy usage with increases in floor area. As average house sizes continue to increase and average household sizes stay the same or even decrease, these assumptions would tend to over predict usage of all three end uses, as the model would implicitly be assuming more people live in the homes than actually do on average.

The single family results indicate conclusively that the compliance models overstate energy usage compared to what occupants actually use. More work is needed to explore some of the possible reasons raised here. Further exploration could help identify if this overstatement can be easily characterized by a simple meter-to-model adjustment to usage, or if fundamental changes to compliance code modeling assumptions are necessary to provide accurate results.

Multi Family Conclusions

The multi family results were significantly different from the single family ratios. The modeled cooling results overstated usage by 150% inland and 750% coastally. Heating usage was over estimated by 520% coastally and 370% inland. Water heating model estimates averaged 230% larger than the metered usages. These differences are of a different order of magnitude than the single family results, and represent, if true, less a misestimate of usage than a complete misstatement of usage.

However, it's difficult to say how accurate these estimates are. Due to budgetary constraints, multi family sites were represented by only three or four metered units worth of data. This introduces a level of uncertainty to the metered usage estimates used to compute the ratios. However, even with this uncertainty, the magnitude and consistency across sample sites of the results indicate that there is still a larger difference between metered and modeled usage for multi family sites than for single family sites.

We think that a large part of the discrepancy between the multi and single family heating and cooling meter ratios can be explained by the fact that occupants of multifamily units tend to spend less time at home, on average, that occupiers of single family units. Thus, in practice, multi family per-unit space conditioning loads are lower than modeled loads by a factor greater than their single family counterparts.

Another factor that drives the multi family ratios lower is the economic differences between multi- and single family homeowners. Since multifamily residents have lower incomes on average than single family residents, they are prone to have less disposable income to spend on space conditioning, and thus more economically pressured to engage in conservative behavior such as having a higher cooling or lower heating thermostat set point.

Also, multifamily units tend to have packaged-terminal ACs (PTACs) for cooling and either packaged-terminal heat pumps or hydronic heating (which tend to have only one or two blower coils) for

[9] CEC 2001 (2), page 4-2.

heating. The upshot of this is that multifamily space conditioning tends to be much more space-targeted that single family homes. Instead of needing to heat or cool an entire 2000+ square-foot house in order to keep a single occupant comfortable, the inhabitant of a multifamily unit may only need to (and be able to) heat/cool a single room of living space. Thus, for any given level of personal comfort, the energy needs would be much lower.

Finally, multifamily structures' cooling and heating loads are estimated without regard to interaction between occupied spaces; for the purposes of computing total conditioned load, occupied spaces are pooled into one total volume. The potential problem with this approach is that in reality the ability to leach heating or cooling through neighbor's walls may create more thermostat-marginal dwelling units where people can choose to accept a slightly higher cooling "set point" or lower heating "set point" if it means they do not need to expend any cooling or heating energy themselves.

Water heating is similarly overstated in the multifamily models. The metered sites indicate that true usage is 30.1% of that predicted by the compliance models for an average multifamily site. Like space conditioning, this is a much lower ratio than was estimated for single family homes. RLW thinks that this is partly due to the same occupancy patterns discussed above—being home less often, multi family occupants use less hot water per square foot than single family occupants.

Finally, the size of the units may come into play here. The compliance software estimates more water heating energy usage for every square foot of floor space, but caps this increase at 2500 square feet. Few multi family units are this large, but roughly 40% of the single family units we metered were. Thus, the difference between multi and single family water heating meter ratios may be less a result of lower multi family metered usage than the result of more highly overstated multi family model usage on account of the cap on the model-based estimate of 40% of the single family homes.

The low sample rates of unit per site mean that the multi family estimates of meter-to-model ratios are not precise estimates of these ratios. That said, their large difference from one implies that there is some truth to their implication that the multi family compliance models overstate usage by a large amount. These differences can be explained in part by the fact that the assumptions developed for simpler single family structures are applied to the more complex multi family buildings. This could mean that compliance code models for multi family structures should have their own, specific set of assumptions developed that incorporate a better understanding of the differences between single family and multi family structures, occupants, and occupant behavior.

Next Steps

This report has raised a lot of questions about the accuracy of compliance models' energy usage estimates. While it has proposed a number of possible answers, it is out of the scope of the present study to investigate them. It has, however, pointed to numerous areas of the compliance models' assumptions that may require investigation, including:

- The relationship between the number of people in a unit and its floor area
- The occupancy patterns, including time-of-day and average vacationing, of home occupants
- These patterns' impact on thermostat settings, including whether space conditioning units are turned off during occupant absence, and whether set points are used
- Thermostat set points during unit occupation
- A separate study that collects the same information for multi family occupants so that differences between them and single family occupants can be better understood

Altering the models to provide more accurate usage, and thus savings, estimates isn't the only option. It might be simpler to accept that while compliance models are useful for relative applications such as performance-based compliance or relative-performance-based program participation, they may not be the best tools for estimating energy usage. Evaluators and program sponsors could rely on the standard techniques of statistical sampling, site/end-use metering, and more complex modeling. While these techniques would provide more *accurate* estimates, they will not be able to rival the relatively cheap *precision* that collecting the modeling results from the entire program population[10] can potentially provide. If some of the studies mentioned above were explored, and compliance software's assumptions adjusted accordingly, then program sponsors would potentially have an extremely precise and accurate of their residential construction programs' savings, with the only evaluation cost being that of confirming the models' continued accuracy.

References

California Energy Commission 2001 (1). "California Energy Commission Residential Manual (for Compliance with the 2001 Energy Efficiency Standards for Low-Rise Residential Buildings." Energy Commission Publication No. P 400-01-022.

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TecMarket Works 2004. "The California Evaluation Framework." California Public Utilities Commission.

[10] As is currently done for this residential new construction program.