How Insulated Are California's Homes?
Field Inspection and Survey Data on Residential Insulation

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In 1986, trained inspectors conducted 3,474 field inspections to produce a representative sample of the weatherization levels of California's residences. For the first time, we have detailed, comparable measurements of residential weatherization levels in all vintages, regions and building types. The paper links the presence of weatherization measures to building types, building age, geographic distribution, appliance stock and socioeconomic data.

Relationships among key variables, such as the levels of insulation and HVAC equipment types, showed that imputing values for missing variables was possible. They also showed that weatherstripping and caulking should not be treated as a combined measure, since they are not closely related. Finally, we found that homes with high levels of ceiling and wall insulation were also the most likely to have high levels of low cost measures.

A final section compares the "Statewide" results with a northern California on-site inspection conducted at the same time and with recent utility mail surveys. The two on-site inspections largely validate each other and are significantly different from the mail survey results on key insulation variables. For example, wall insulation was found in 43-45% of the field study homes, but was reported in 56% of the comparable published mail survey and in 69% of the raw survey results. In other key finds, the "Statewide" data confirmed that electric heating was being over reported in northern California, but that respondents were relatively accurate on electric central air conditioning.

Conclusions are presented on how field inspection data can be used to adjust mail survey results and some of the pitfalls of questionnaire construction which can limit usefulness of the responses.

HOW INSULATED ARE CALIFORNIA'S HOMES? FIELD INSPECTION AND SURVEY DATA ON RESIDENTIAL INSULATION

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This project used data from on-site inspections to verify residential weatherization levels in the Energy Commission's forecasting model and tested the reliability of common mail/telephone survey variables. Since the Energy Commission's residential model is driven by end-use characteristics, we examined weatherization measures relative to geographic location, housing type, housing vintage and space conditioning fuels. Income distribution data are presented here briefly for the benefit of other researchers.

THE DATA

The 1986 Statewide Saturation Survey on Weatherized Dwelling Units ("Statewide"), conducted under CPUC sponsorship by California's large investor-owned utilities, provides a unique benchmark for conservation features of existing housing. Data were collected statewide from a statistically valid sample of all dwelling units, with 3,474 dwelling units participating for a statewide completion rate of 62%. This response rate is much better than the typical energy use survey, but lower than the federal contract requirement of 75% to 80%. Every dwelling unit in the state had an equal chance of being selected through a randomized cluster sample, stratified by dwelling type, percent low income, climate zone, urban/rural and growth rate. Oversampling was applied during the sample selection process to assure the desired degree of precision. The weighting procedure employed during the survey analysis process appropriately reflected the stratified randomized cluster sampling design of the survey. The weight assigned to each survey response was a function of the probability of the participant being selected in the survey and the response rate of the participant's stratum.

Trained inspectors conducted the on-site audits, virtually eliminating reporting accuracy problems. Based on sampling error, statewide findings are accurate to within $\pm$ 5% at a 95% confidence level, and regional findings are accurate to within $\pm$ 10%. Total survey error, which includes nonresponse bias, sampling frame bias and other errors has not been determined.

The data's representativeness was demonstrated by comparing it with Census data. For owner/renter and income distribution, we looked at the 1980 California Census, the 1981-1983 Annual Housing Surveys for selected SMSAs and the 1986 Census Money Income for the Pacific Region (California is 75% of the Pacific region). The "Statewide" 40% renter participation compares favorably with Pacific region statistics of 37% renters and with 1985 national Census statistics of 36% renters. As Table I shows, the income data was also a close match. The geographic and home-type distributions matched the current Energy Commission forecast database.

Table I. Distribution of Income
(adjusted to constant dollars)

Reported Income	"Statewide" All CA	Census Pacific Region	"Statewide" San Diego	Census - San Diego SMSA (1982)
0 - $14,999	31%	33%	32%	34%
$15,000 - $29,999	29%	29%	28%	29%
$30,000 - $44,999	20%	18%	17%	18%
$45,000 or more	20%	20%	23%	20%

In contrast, most Energy Commission data are obtained through biennial mail surveys conducted by the five largest electric utilities. These mail surveys have massive sample sizes and moderate response rates typically ranging from 33% (LADWP, 1983) to 51% (SDG&E, 1983). In the worst case, the sample bias "led to constant errors in excess of 50% for selected appliances" (Archer, et. al., 1988). Thus, a central use of this on-site survey data was to correct the findings from mail surveys.

METHODOLOGY ISSUES

Four key variables of interest - presence of insulation, R-value of insulation, building age, and income - are plagued by large numbers of missing answers in most mail and telephone surveys. "Don't know/no answer/not sure/left blank" can account for from 10 to 60 percent of total responses for these variables. One popular statistical method of handling missing answers is to delete all observations having even partially incomplete responses and hope that the observations remaining form a complete representation of the population. A second alternative is to leave the incomplete responses in the survey data base and report the missing responses as they occur within each appropriate statistical table. A third method is to impute responses where possible.

The first technique of deleting any observation having incomplete responses is valid only if the non-response distribution is randomly distributed throughout the sample. To test this problem we compared the sociological statistics obtained from the entire northern California survey data base with the data base reduced by deleting the incomplete responses. The northern California data base contained 37.3% (unweighted) incomplete observations. When the incomplete observations were deleted, the resulting data were slightly biased, underrepresenting renters, multi-family and older homes. The changes were only a few percentage points, but they reduced the amount of data we had for groups targeted for current policy analysis.

The second method involves leaving the incomplete responses within the data base. This method was selected and is supported here by the fact that we have high quality on-site data. The trained auditors actively participated in obtaining the most accurate results possible. In addition, extensive checking and clean up procedures were performed by the utilities. As we are interested in basic statistical relationships among a large number of variables, the most detailed data base possible seemed preferable.

Imputing values or correcting for the error factor is the preferred technique if there is asystematic bias in the missing answers (Buller, 1984; Holt, 1987; Swanson, 1986; Skumatz, 1986). Holt found that models which delete missing data tend to overestimate unit energy consumption and underestimate income elasticities, because survey respondents tend to be single-family homeowners, older, more educated and larger energy users (Holt, 1987).

Imputing is done by using correlated variables, such as type of residence, number of bedrooms, age of dwelling, other devices in the home, owners or renters, weather, and geographic location (Skumatz, 1986 and Skumatz, 1987). This technique reduces bias from missing answers. The approach is also confirmed by a recent validation of PGandE's 1986 RASS which "strongly support(s) PGandE's continued efforts to impute probable values for missing and suspect responses" (McRae, 1987).

We used the imputing technique to deal with our single largest headache--constructing R-values for ceiling insulation. Imputing responses for the presence of attic insulation is particularly difficult, since a large portion of attics are not accessible for visual inspection or not insulatable. Some roofs may only be insulated at the time of reroofing (e.g.,Spanish tile and flat roof). Others may be physically insulatable but at a very high cost. Still other homes

may be rated as uninsulatable by the owner, yet inspectors may find that insulating is possible (McRae, 1987). In validating the PGandE 1986 mail survey , 36% of attic insulation estimates couldn't be verified because the attic could not be inspected. This high level of inaccessible attics was also found in the "Statewide" survey; 27% of single-family and 41% of all housing had inaccessible attics. The issue gets even more convoluted when dealing with mobile homes (which are almost all constructed without an open cavity) and multi-family units (which may report no access when they mean that another apartment unit is above them).

The two common solutions for assigning a value to this large portion of the housing stock are either to assign them an R-value of zero or to treat them as missing variables and delete them entirely. Neither approach is satisfactory. To deal with the no access problem, we followed PGandE's example and imputed R-values for inaccessible attics. The basic assumption was that no access attics had not been retrofit, but that some insulation might have been installed at the time the home was built. We assumed no retrofit had occurred because the occupant couldn't get into the attic to retrofit it, or believed she/he couldn't, which amounts to the same thing.

Detailed cross tabulations between ceiling insulation and other variables were run. Gas heat, wall/floor furnaces, rental status and no central air conditioning were all associated with lower levels of attic insulation and were more likely for inaccessible attic homes. The most significant indicator was presence of central air conditioning. The comparisons suggested that inaccessible attic homes have fewer attributes associated with insulation than do accessible attic homes.

Because almost all mobile home attics were inaccessible, we could not use imputing techniques. Instead, we looked at data on construction practices by vintage and estimated that 10% of California mobile homes were built with R-19 ceiling insulation, 22% with R-11, 17% with R-7 and 51% were built with none. To compensate for the large number of missing responses on multi-family attic insulation, a statewide multi-family estimate for inaccessible attics was constructed. This was used in conjunction with regional accessible attic data to build the regional multi-family estimates.

WEATHERIZATION CHARACTERISTICS BY HOME TYPE

Context. In this study, the state was disaggregated into three regions, northern California, southern California and San Diego which range in average annual heating and cooling degree days (base 65 degrees) from 3,741 HDD and 738 CDD in northern California to 1,144 HDD and 860 CDD in San Diego. A growing proportion of the population lives in the more extreme inland areas which have a much heavier heating and cooling load.

Nearly two-thirds of California housing was built before 1975, when energy efficiency was not considered important. People were drawn to the Golden State by a belief that the climate was so mild that heating and cooling were not a significant problem. California entered the energy crisis with a stock of leaky houses and inefficient appliances. Since 1975, the state has had a vigorous energy efficiency campaign; building standards for new construction were adopted in 1975 and updated in 1978, 1983 and 1988. Similarly, large state tax credits and utility audit/incentive campaigns pumped $500 million into the economy from 1980 through 1987 to retrofit existing homes. We expected to find that pre-1975 homes had been retrofit, but that they had not reached the insulation level of post-standard homes.

Findings. Table II shows the insulation status of statewide housing stock in 1986. Three-quarters of California housing has some ceiling insulation, with 45% having R-19 or better. This does not vary much across the three regions. One third have wall insulation, and almost none have floor insulation. Caulking and low flow showerheads are the most

Table II. Statewide Housing in 1986
(inaccessible attic R-values imputed)

	Single family detached	Mobile home	2-4 units	5 units or more	1 unit	Multi-family	All
% of stock	66%	5%	8%	22%	71%	29%	100%
Floor insulation							
Have 50%+ insulation	4%	46%	0%	0%	7%	0%	5%
Could have, but don't	46%	19%	12%	17%	45%	16%	36%
Slab floor	49%	35%	88%	83%	48%	84%	59%
Attic insulation							
Have access to attic	77%	3%	33%	26%	72%	27%	59%
Have insulation	81%	51%	68%	62%	79%	64%	74%
R-7	14%	19%	15%	17%	14%	17%	15%
R-11	13%	22%	14%	17%	14%	16%	15%
R-19	47%	10%	37%	26%	44%	29%	40%
R-32	7%	0%	2%	2%	6%	2%	5%
No insulation	19%	49%	32%	38%	21%	36%	26%
Wall Insulation							
Have wall insulation	33%	66%	23%	27%	35%	25%	33%
Low cost measures							
Adequate caulking	64%	82%	53%	48%	65%	50%	61%
Adequate weatherstrip	48%	70%	49%	38%	49%	43%	48%
Set-back thermostat	15%	7%	0%	6%	14%	3%	12%
Wrapped water heaters*	34%	33%	16%	20%	34%	19%	32%
Ceiling ducts insulated	32%	0%	14%	5%	30%	8%	23%
Low flow showerheads	54%	57%	58%	48%	54%	50%	53%

*% of individual water heaters (85% of 5+units and 15% of 2-4 units have central heaters).

1 unit = Single family detached plus mobile homes
Multi-family = 2-4 units plus 5 units or more

prevalent low-cost measures. Fewer houses have weatherstripping, insulated ceiling ducts, wrapped water heaters or setback thermostats. Interestingly enough, the least weatherized homes are located in southern California and not in San Diego. While San Diego's climate is milder, it has much newer housing.

Table III presents results for pre-1975 and post-1975 homes. Homes built after 1975 are much more weatherized than older homes. The first state building standards were implemented in 1975, with substantial upgrades in 1978 and 1983. These can be clearly seen in the levels of R-19 ceiling insulation and the presence of wall insulation. The low percentage of low-flow showerheads and wrapped water heaters in post-1975 housing were a bit surprising, because these are required by standards. We had suspected that the low-flow showerhead standard was being avoided; testing requirements were strengthened in 1986 to plug the gap.

Implications. The 1986 values for pre-1975 housing are considerably below previous CEC estimates. Previously, only 10% of 1-unit homes were counted as having no attic insulation; the new value is closer to 30%. Wall insulation values are down roughly half. Floor insulation values are also lower by a few percent. The only increase came in adding a category for R-32 attic insulation, since it was found that a significant number of northern California pre-1975 homes are now insulated to R-32. The on-site data did support several characterizations in the previous CEC forecast data base. We found that gas-heated homes are indeed the least weatherized, centrally air conditioned homes are the most weatherized, and multi-family homes are less insulated than 1-unit homes.

In the 1988 revised staff forecast, we corrected our current data, used this benchmark along with a decade's worth of trends to reestimate market potential and reduced the trend of probable response to future market signals. If the massive energy price increases and weatherization incentives of the past decade had produced less retrofit than we anticipated, that did not bode well for the probable impact of the next decade's more stable prices and few incentives.

WEATHERIZATION MEASURES BY INCOME DISTRIBUTION

Like other energy end-use models, the Commission's forecast models do not make much profitable use of many socioeconomic variables (Lutzenhiser, 1987). However, because other researchers are interested in these characteristics, we explored the relationships of weatherization measures to income distribution.

Income was missing from 36% of observations in Northern California and 34% in San Diego. (Socioeconomic data were not available from Southern California.) This led to an immediate crossroads on whether to use the income distribution data at all. We also knew that detailed income strata data were questionable. An investigation of the accuracy of PGandE's 1986 biennial survey revealed that only one third of the participants surveyed by mail gave exactly the same income response as when surveyed by phone, and only 77% of the participants answered within one category of their previous answer (McRae, 1987). To overcome the response error problem and take advantage of the fact that an estimated 77% accuracy rate could be achieved by grouping categories, we collapsed the on-site survey responses into four categories. Testing the sample against Census data, as shown in Table I revealed that the reported grouped income strata were in fact representative of the Census population distribution.

Table III. Comparison of Statewide Stock by Age of Housing
(inaccessible attic R-values imputed)

	Pre-1975 stock	Post-1975 stock
% of stock	79%	21%
Floor insulation		
Have 50%+ insulation	3%	6%
Could have, but don't	43%	12%
Slab floor	54%	92%
Attic insulation		
Have insulation	67%	98%
R-7	19%	3%
R-11	14%	13%
R-19	31%	69%
R-32	3%	12%
No insulation	33%	2%
Wall Insulation		
Have wall insulation	33%	78%
Low cost measures		
Adequate caulking	61%	73%
Adequate weatherstrip	48%	65%
Set-back thermostat	12%	18%
Wrapped water heaters*	33%	28%
Ceiling ducts insulated	20%	36%
Low flow showerheads	50%	62%

*% of individual water heaters (85% of 5+units and 15% of 2-4 units have central heaters).

Cross-tabs of insulation variables by income distribution, illustrated in Table IV, did not show as strong a difference as might be expected.

Table IV. Ceiling and Wall Insulation by Income Class
(Reported Incomes Only)

	$0 - $14,999	$15,000 - $29,000	$30,000 - $44,999	$45,000 or more
Have Wall Insulation	36%	43%	56%	50%
Ceiling Insulation				
Not Accessible	56%	46%	31%	34%
R-0	7%	9%	5%	3%
R-9	10%	13%	14%	18%
R-19	25%	27%	35%	37%
R-32	3%	5%	15%	8%

Researchers with a need for income distribution data could investigate whether this indicates that the government and utility low-income weatherization programs have had a measure of success in upgrading low-income housing, whether it is measuring differences in home type, or other possible explanations.

RELATIONSHIPS AMONG VARIABLES

A critical output of this review was investigating links among weatherization characteristics. The biennial survey data which update our data base are often incomplete and suffer from all the bias problems of mail survey data. To the extent that we could find relationships among weatherization measures and key housing characteristics, we would then be able to impute missing data for future surveys and keep our forecast database current. We were particularly interested in the relation of high cost measures (ceiling insulation and wall insulation) to each other, home type and space conditioning. We also looked at the relation between high cost and low cost measures and the relation between high cost measures and occupant characteristics.

We first tested the significance of relationships that occur between each pair of measures by calculating Pearson chi square statistics and using an alpha of .025. With the large sample size and relatively small degrees of freedom, the chi square test became highly sensitive to even slight degrees of dependence. Hence we had the phenomenon of almost everything having a statistically significant dependence with every other variable. Since the chi square test didn't get us very far, we switched to the simpler cross-tabulation approach to document relationships. Again, for our purposes we were not interested in causality but in whether the presence of one easily identifiable variable could be used to estimate or verify the presence of other weatherization measures.

Ceiling insulation as a check on wall insulation. Because survey respondents frequently don't know whether wall insulation is present and they also have a strong tendency to overestimate its presence (McRae, 1987), we wanted to see if the presence and type of ceiling insulation could be used as a wall insulation indicator. The first test was whether wall insulation is associated with accessible attics. We found that attic accessibility is not associated with wall insulation. We then checked to see whether the presence of wall insulation was linked with the level of ceiling insulation measured in homes with accessible attics. As Table V shows, there is a clear link between increasing ceiling R-values and presence of wall insulation. Thus, in interpreting future surveys we can use the ceiling insulation data to improve the quality of wall insulation estimates.

Table V. Presence of Wall Insulation Compared to Ceiling Insulation (Statewide, all housing types)

Ceiling Insulation	Wall Insulation	No Wall Insulation
Not Accessible	36%	64%
Accessible (Verified)	35%	65%
Verified R-values*		
R-0	4%	96%
R-7	17%	83%
R-11	35%	65%
R-19	47%	53%
R-32	57%	43%

*Includes only homes where R-values were measured.

Low cost measures. Weatherstripping and caulking are frequently treated as one measure. We found that adequate weatherstripping was less likely than adequate caulking. If the weatherstripping on a home is adequate, the caulking is probably also adequate. However, if the weatherstripping is poor, a strong inference about the state of caulking cannot be drawn.

Central air conditioning. Estimates of central air conditioning load are a major source of dispute in the forecast process, so we were interested in the characteristics of homes with central air conditioning and if the increasing saturation of central air conditioners could be used as an indicator of changes in high cost weatherization measures such as ceiling insulation and wall insulation. Our current central air conditioner saturation of 23% is growing, because the highest growth is occurring in the hot central valley and central air conditioning is a common amenity in new homes.

At first it looked like a strong relationship existed between the presence of central air conditioning and wall insulation/higher R-values of ceiling insulation. On further analysis we found that the presence of central air conditioning was being confounded with it being in a newer home. The strongest inference was that if central air conditioning were absent in a pre-1975 home, it is likely that wall insulation was also absent. Central air conditioning is probably not as good an indicator as vintage for high cost measures.

High cost/low cost measures. We were also interested in examining the relationship between high cost measures--high R-values of ceiling insulation and wall insulation--and low cost measures--weatherstripping, caulking, water heater blankets, and low flow showerheads. Two main theories have been advanced; that if only low cost measures are put in, high cost measures won't be and that homes which have low cost measures will install high cost measures too.

We grouped them into three categories: high levels of ceiling and wall insulation (R-19 or R-32 in the ceiling and wall insulation), low levels of ceiling and wall insulation (R-0 or R-7 in the ceiling and no wall insulation) and mixed levels (for example, R-19 in ceiling and no wall). As Figure 1 shows, highly insulated homes have more low cost measures than homes with low levels of ceiling and wall insulation or homes with mixed levels.

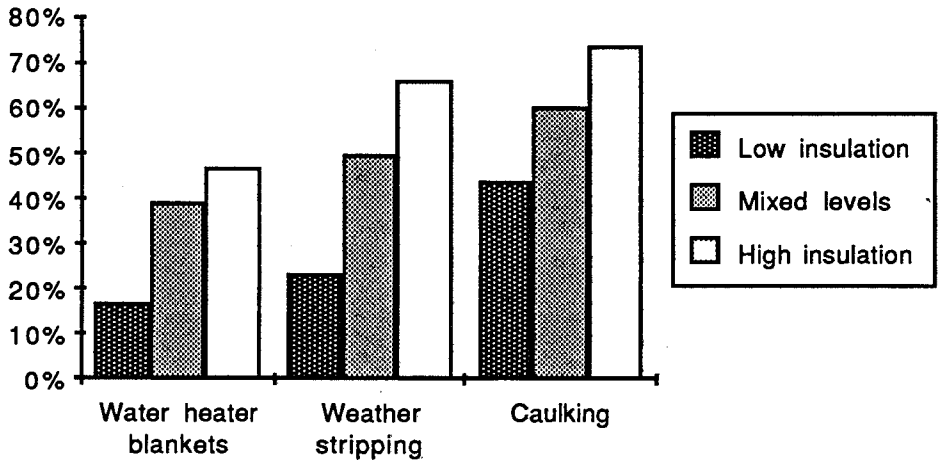

Figure 1. Presence of low cost measures in homes with varying degrees of high cost insulation.

COMPARISON OF FIELD AND MAIL SURVEY DATA

As a final step, we compared the results of this study to another on-site study done for northern California and to the 1985/1986 utility mail surveys on residential appliance saturations. As Table VI shows, the two field studies largely validate each other and are significantly different from the mail survey results on key insulation variables. For example, wall insulation was found in 45% and 43% of the field study homes respectively, but was reported in 56% of the published mail survey. The raw survey results were even more divergent. Raw results are included here to indicate how much statistical clean-up has already been done by California utilities before they publish survey results.

In other key findings, the "Statewide" data confirmed that electric heating was being over reported in northern California. Researchers had suspected that people were misreporting some gas heat as electric heat, because the electricity use patterns didn't reflect large amounts of electric heating. On-site inspections found 5.5% and 7.7% of homes had electric heat, compared to 22% in the raw mail survey results and 9.2% of the cleaned up results. Respondents were relatively accurate on electric central air conditioning. In general, we believe that the on-site surveys produced closer estimates of unknown population parameters than did the mail survey.

Table VI's insulation footnote illustrates the problem that arises from serial questions; comparable statistics cannot be created for a vital section of the ceiling insulation responses. One caveat, the table's statistics came from different surveys whose questions and answers were not consistently defined or necessarily asked in the same context.

Table VII compares the San Diego data from the "Statewide" on-site survey to that reported in the San Diego 1985 mail survey, which had a 49% response rate with 7,368 usable responses. It too shows that electric space heating is somewhat overreported, and that mail survey data on wall insulation and ceiling insulation is highly suspect.

Table VI. Compared Measurements from Two On-Site Surveys and a Mail Survey (northern California - 1985/86)

Variable	On-site Surveys		Mail Survey	
	"Statewide" data for northern CA	Validation data for northern CA	PG&E Mail (Weighted)	PG&E Mail (Raw)
Ceiling insulation present				
Yes	46.7%	50.3%	73.4%	60.0%
No or not accessible	53.3%	49.7%	26.6%	40.0%
Measured Ceiling R-value*				
(calculated from a matrix of insulation type and inches)				
Not available	46.5%	68.5%	n/a	n/a
None	6.8%			
R-7	4.7%	0.9%		
R-11	9.0%	3.8%		
R-19	25.9%	21.3%		
R-30	7.2%	5.6%		
Wall insulation	44.9%	42.9%	55.9%	69.0%
Setback thermostat	12.2%	11.7%	11.3%	20.0%
Caulking	66.3%	67.3%	34.4%	65.0%
Weatherstripping**	52.8%	80.5%	51.9%	75.0%
Electric Heat	5.5%	7.7%	9.2%	22.0%
Presence of central air conditioning				
Electric	25.3%	27.2%	22.2%	31.0%
None	54.1%	53.2%	47.1%	38.0%
Other	20.6%	17.7%	30.7%	30.0%
Missing		1.8%		1.0%

* The CPUC "not available" statistic is comprised of respondents with inaccessible attics; the "none" response indicates a lack of insulation. The Xenergy "not available" statistic contains: those who were not asked (because they did not live in single family or row houses), those whose attic could not accomodate insulation, and those whose attic was not insulated. It was not feasible to separate the above three categories.

* Different criteria were used to determine weatherstripping status. CPUC auditors inspected two outside doors; if both had adequate weatherstripping, the response was yes. Xenergy auditors responded to the general statement: weatherstripping for doors and windows and determined a yes/no response.

Table VII. Key Variables in Mail and On-site Surveys: San Diego

	Mail	On-site
Wall insulation		
Yes	28.8%	36.6%
No	28.0%	63.4%
Not sure	43.2%	--
Ceiling insulation		
No Access	--	37.7%
None	51.6%	9.9%
Less than R-11	0.5%	5.7%
R-11 - R-18	1.7%	9.8%
R-19 or greater	7.6%	36.8%
Yes, but don't know R-value	38.6%	--
Electric space heat	21.0%	17.3%

CONCLUSIONS

Field surveys are a valuable, if expensive, adjunct to mail surveys for key weatherization variables. The statewide on-site survey cost sponsoring utilities roughly $500,000; and the northern California on-site was about $135,000. Field surveys are best used for variables which customers can't observe easily, such as ceiling and wall insulation or for weatherization characteristics whose adequacy may be determined arbitrarily, such as caulking and weatherstripping.

Questionnable mail survey results can be adjusted and better approximated using related variables and statistics from valid field inspection data bases. Imputing responses for missing variables with asymetric distributions can give higher quality statistics than techniques that delete missing answers.

Analytic problems and unclear statistics are generated when portions of the survey are administered to only a subset of the respondents. Ceiling insulation data are particularly vulnerable to this kind of problem, because they frequently are imbedded in long chains of serial questions. Usefulness of both field and mail surveys can be enhanced by including the statistical analysts who will be analyzing the data on the planning team

By permission of the CPUC and the sponsoring utilities, copies of the computer tape containing the data base from this study may be obtained from the California Energy Commission. Inquiries should be directed to Peggy Miller, Demand Forecasting Office, MS-22, California Energy Commission, 1516 Ninth St., Sacramento, California 95814, (916) 324-3091.

Footnotes

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