Comprehensive Evaluation Study of 12,000 California Mobile Homes

Anne Blankenship, Robert J. Mowris, and Ean Jones, Robert Mowris & Associates
Dave Robison and Howard Reichmuth, Stellar Processes

ABSTRACT

This paper presents findings from a comprehensive study of an innovative third-party mobile home program in California implemented by American Synergy Corporation and CAL-UCONS (ASC 2002).[1] The program installed 82,808 measures in 12,000 mobile homes, and met its objectives to deliver measurable savings for hard-to-reach mobile home customers while undergoing the scrutiny of a comprehensive evaluation. The program installed the following cost-effective energy efficiency measures: air conditioner tune-ups; duct sealing; infiltration reduction; programmable thermostats; compact fluorescent lamps (CFLs); efficient showerheads and aerators; water heater blankets; and pipe insulation. The paper summarizes findings from 3,900 field measurements of air conditioner refrigerant charge and airflow, duct leakage, building envelope leakage, lighting wattage and use, and showerhead and aerator flow rates. It provides load impact and process evaluation findings and recommendations for improvement.

Introduction

There are roughly 6.8 million mobile homes in the United States and they use 16 billion kWh/yr for space cooling, 0.21 quadrillion Btu for space heating, 0.08 quadrillion Btu for water heating, 9 billion kWh/yr for refrigerators, and 35 billion kWh/yr for appliances and lighting (EIA 2001). The potential savings from energy efficiency improvements in mobile homes varies from 25 to 75 percent depending on the end use. The ASC mobile home program provided comprehensive no-cost energy efficiency improvements at 12,000 mobile homes or approximately 2 percent of the total mobile homes in California (CDF 2000).[2] The program installed 82,808 measures including: air conditioner (AC) tune-ups; duct sealing; infiltration reduction; compact fluorescent lamps (CFLs); Energy Star programmable thermostats; water saving showerheads and aerators; water heater blankets; and pipe insulation. The assumed ex ante (i.e., a priori) savings for the program were 9,432,729 kWh, 6,336 kW, and 348,867 therms per year.

This paper presents findings from an evaluation, measurement, and verification (EM&V) study of the program. The paper summarizes 3,900 measurements performed at three hundred mobile homes and provides load impact and process evaluation findings. The paper also provides recommendations for improvement.

[1] The Comprehensive Hard-to-Reach Mobile Home Energy Saving Local Program was designed and implemented by ASC and CAL-UCONS in 2002 and 2003 and funded under the auspices of the California Public Utilities Commission. The program provided comprehensive no-cost energy efficiency improvements at 6,000 mobile homes in the PG&E service area, and 6,000 mobile homes in the SCE and SCG service areas.

[2] As of the year 2000 there were approximately 585,090 mobile homes in California.

EM&V Approach

The EM&V approach included on-site inspections, field measurements, and process surveys to verify measure installations, investigate operational characteristics of the program, and develop specific recommendations regarding operational and cost effectiveness. Process surveys included questions to evaluate retention of energy education information provided to participants by the program as well as questions to evaluate customer satisfaction and the program delivery process.

Approximately 300 mobile home participants were randomly selected for on-site audits to measure energy efficiency performance, quality, and persistence of installed measures. Participant process surveys were conducted in-person at the audit sites. The on-site inspections included verification and pre- and post-measurements for the following measures: combustion appliance safety; AC tune-up Energy Efficiency Ratio (EER); duct leakage; infiltration reduction; compact fluorescent lamp (CFL) wattage and use; programmable thermostats; showerhead and aerator flow rates; water heater blankets; and pipe insulation. EER was derived from enthalpy (i.e., return/supply drybulb/wetbulb temperatures), airflow, and power measurements (i.e., fan plus compressor) based on refrigerant charge and airflow adjustments. Field measurements, measurement equipment, and tolerances are provided in **Table 1**.

Table 1. Field Measurements, Measurement Equipment, and Tolerances

Field Measurement	Measurement Equipment	Tolerances
Temperature in degrees Fahrenheit (°F) of return and supply wetbulb and drybulb and outdoor condenser entering air	4-channel temperature data loggers with 10K thermisters. Wetbulb and drybulb temperatures were checked with sling psychrometers.	Data logger: ± 0.1°F Thermisters: ± 0.2°F Sling psychrometer: ± 0.2°F (wetbulb and drybulb)
Pressure in pounds per square inch (psi) of vapor and suction line	Compound pressure gauge for R22 and R410a.	Refrigerant pressure: ± 2 % for R22 and ± 3 percent for R410a
Temperature (°F) of vapor and suction lines	Digital thermometer with clamp-on insulated type K thermocouples.	Digital thermometer: ± 0.1°F Type K thermocouple: ± 0.1% °F
Temperature (°F) of actual and required superheat and subcooling	Digital thermometer with clamp-on insulated type K thermocouples.	Digital thermometer: ± 0.1°F Type K thermocouple: ± 0.1% °F
Airflow in cubic feet per minute (cfm) across air conditioner evaporator coil	Digital pressure gauge and fan-powered flow hood, flow meter pitot tube array, and electronic balometer.	Fan-powered flowhood: ± 3% Flow meter array: ± 7% Electronic balometer: ± 4%
Ounces (oz.) of refrigerant charge added or removed	Digital electronic charging scales.	Electronic scale: ± 0.5 ounces or ± 0.1% whichever is greater
Power in kilowatts (kW) of air conditioners or CFLs	True RMS 4-channel power data loggers and 4-channel power analyzer.	Data loggers, CTs, PTs: ± 1% Power analyzer: ± 1%
Duct Leakage in cfm at 25 Pascal (Pa)	Digital pressure gauge, controller, fan, extension duct, and flow conditioner.	Fan flow: ± 3%
Building envelope leakage in cfm at 50 Pa and Effective Leakage Area (ELA) in square inches.	Digital pressure gauge, controller, fan, and blower door.	Air leakage and ELA: ± 3%
Flow rate in gallons per minute (gpm) and flowing pressure (psi) of showerheads or aerators	Flow meter and flowing pressure gauge. Handheld flow device.	Flow rate (0.5 to 15 gpm): ± 7% Flowing Pressure (0 to 160 psi): ± 7% Micro-Wier (0 to 4 gpm): ± 1%
Carbon Monoxide (CO) in parts per million (ppm).	Digital Combustion Analyzer.	CO: 0 to 2,000 ppm

Load impacts for weather-sensitive measures are based on field measurements, engineering analysis, and EZ SIM and eQuest/DOE-2.2 building simulations calibrated to billing data (Hirsch 2002; Robison 1999; Robison 2000; Stellar 2002). Load impacts for CFLs are based on wattages of old incandescent lamps versus new CFLs and hours of operation based on participant-reported information and lighting loggers installed at a random sample of sites. Load impacts for showerheads and aerators are based on deemed savings times the ratio of the ex ante assumed flow rate divided by the ex post average measured flow rate. Load impacts for pipe insulation and water heater blankets are based on deemed savings and the proportion of verified measures found during field inspections. The load impact evaluation followed the International Performance Measurement & Verification Protocols (US-DOE 2002).

Modeling Approach

The modeling approach for weather-sensitive measures involved building simulation analyses for a subset of 68 buildings within the 300 audit sites. Building models were developed independently using EZ SIM and eQuest/DOE-2.2. EZ SIM models were calibrated to monthly billing data and eQuest/DOE-2.2 models were calibrated to annual cooling and heating energy consumption developed using the PRInceton Scorekeeping Method (PRISM, Fels 1995). Obtaining historical billing data was a challenge since many mobile home parks are master metered and do not maintain billing data in electronic format. For the eQuest/DOE-2.2 models approximately 86 percent of sites were calibrated to site-specific electricity UEC data and 54 percent of sites were calibrated to site-specific gas UEC data. For the EZ SIM models 56 percent of sites were calibrated to a set representing at least pre- or post-retrofit consumption data. The remainder had only partial consumption records. If more consumption records were available, the modeling results would be improved. Future studies should attempt to make sure pre- and post-retrofit billing data can be obtained for the entire audit sample.

Energy Education

Inspectors evaluated the energy education efforts of the program by conducting process surveys with participants and non-participants. Each participant received an *Energy Education Tips* pamphlet and a *Test-in and Test-out Certificate* showing pre- and post-retrofit measurements of combustion appliance safety, airflow, duct leakage, refrigerant superheat or subcooling, refrigerant ounces added or removed, infiltration, and CFL lamp wattages. Customers signed the test-in and test-out certificate acknowledging receipt of energy education information and measures. Energy education tips included a step-by-step guide to smarter home energy use with information customers could use on a daily, weekly and monthly basis.

Combustion Safety Testing

Inspectors measured carbon monoxide levels using a digital CO analyzer at a sample of 121 randomly selected mobile homes. All combustion appliances and equipment within the home were tested and all randomly selected homes passed the CO test.

AC Tune-up

Inspectors of AC tune-up measures found a few problems with incorrect tune-ups at sites where quality control checks were not performed. All sites receiving quality control passed inspections. Inspectors made EER measurements before and after refrigerant charge and airflow corrections at 50 randomly selected air conditioners out of the population of 3,188 participants. Inspectors measured return and supply temperatures inside the respective plenums and measured temperature and power at one minute intervals. Inspectors measured airflow before and after improvements were made to supply/return ducts, opening vents, or installing new air filters. Return and supply enthalpies were calculated from temperature measurements. Field measurements were made to evaluate the relative change in efficiency. All measurements of air conditioner performance were made within minutes of any efficiency improvements, and average measurements were taken at least 15 minutes after any refrigerant charge adjustments.

Many customers used swamp coolers as their primary cooling source and would have benefited from swamp cooler repairs rather than AC tune-up measure. This is a measure worth considering in the future since repairing poor performing swamp coolers can provide low-cost, high-yield savings.

Duct Test and Seal

Inspectors measured duct leakage on a sample of 294 randomly selected duct systems out of the population of 8,575 participants. Duct leakage (cfm) was measured at a system pressure of 25 Pascal using digital pressure gauges. Calibration was checked on the installation technicians' digital pressure gauges. Measurements were double-checked with accurate digital pressure gauges to ensure pressure and flow measurements were properly reported. Pre- and post-measurements were made at random sites to verify reported duct leakage. Evidence of duct leakage was visually checked to verify proper materials and installation (see **Figures 1** and **2**).

Figure 1. Before Sealing Ducts

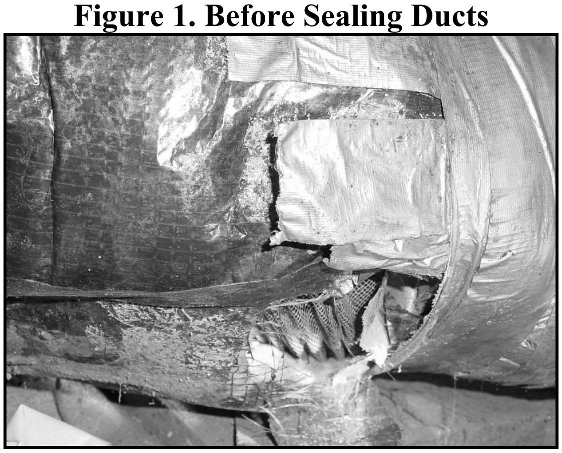
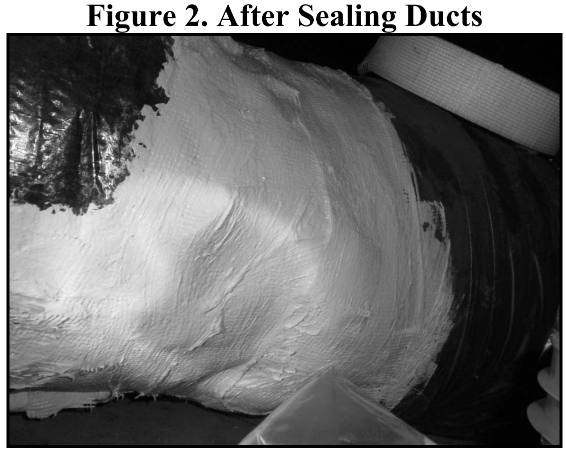


Figure 2. After Sealing Ducts



Most participants who received duct leakage improvements had floor supply systems with un-ducted direct returns to the air handler. Many mobile homes have ceiling supplies and floor returns with non-ducted, multiple-register floor returns using either panned floor joists or intentionally sagging vapor barriers to allow airflow around the joists and back to the air handler. The evaluation studied the potential for duct leakage improvements on these systems and found very high leakage in the range of 500 to 1,000 cfm or more. Several approaches were evaluated and the most successful approach involved installation of single-duct returns to completely eliminate return leakage, sealing abandoned floor registers, and sealing register boots in the ceiling. This approach costs three times more than the average duct leakage budget per home, but average savings are typically three or four times greater than floor supply systems. Future programs should consider budgeting duct leakage measures on a per cfm basis (e.g., $1.65 per cfm reduction). This would allow treatment of ceiling supply and floor return systems and achieve significant cost-effective savings.

Duct leakage problems in new mobile homes could be cost-effectively eliminated with upstream incentives or codes and standards. For new mobile homes (1994 or later), the average duct leakage was 35 ± 7 percent at the 90% confidence level. Mobile/manufactured home energy efficiency is regulated by the United States Department of Housing and Urban Development (HUD 1994). Current codes do not include minimum duct leakage requirements. Codes should be revised to require measures affecting cooling use such as duct leakage, radiant barriers, envelope leakage, and low-e windows.

Infiltration Reduction

Inspectors measured infiltration leakage on a sample of 98 randomly selected mobile homes out of the population of 175 participants. The Effective Leakage Area (ELA) and cfm (CFM50) were measured at a system pressure of 50 Pascals using a blower door and digital pressure gauges (Sherman 1980). Measurements were made before and after sealing building envelope penetrations (see **Figures 3** and **4**). Significant building envelope leakage was found in new and old homes at attic flue and floor pipe penetrations in the air handler closet and the length of the home where the manufactured home sections are joined together. The measured return duct leakage reduction due to sealing attic flue and floor pipe penetrations was 60 to 300 cfm or 5 ± 2 percent of total system airflow. Infiltration problems could be cost-effectively eliminated at time of construction with upstream incentives or codes and standards. For new homes (1994 or later) the average envelope leakage was 1214 ± 102 CFM50 or 0.34 ± 0.06 air changes per hour. Current codes do not include minimum envelope leakage requirements.

Figure 3. Before Infiltration Reduction

Figure 4. After Infiltration Reduction

Compact Fluorescent Lamps

Inspectors verified CFL installations during the on-site inspections. Hours of operation were verified with participant-reported information and lighting loggers installed at a random sample of sites. Power usage for a sample of units was measured using true RMS power meters.

Programmable Thermostat

Inspectors verified proper installation and operation for a random sample of programmable thermostats. All inspected thermostats were found to be properly installed, programmed, and operational. Average pre-retrofit heating and cooling schedules are based on participant-reported data. The Energy Star thermostat schedule is programmed into the read-only-memory (ROM) chip required for Energy Star labeled programmable thermostats. Savings are reliable due to the ROM program since if the unit losses power the furnace and air conditioner cannot operate. When re-powered the ROM program is re-established. Energy Star programmable thermostats are difficult to program for average users, and if temporarily adjusted by occupants, they go back to their ROM program within an hour.

Water Saving Showerheads and Aerators

Inspectors measured a random sample of 989 showerheads out of a population of 8,530 showerheads and a random sample of 375 aerators out of the population of 8,600 aerators. Measurements of flow rates (gpm) and flowing pressure (psi) were made with flow meters as per ASTM A112.18.1M-1996 (see **Figure 5**). These measurements were checked using a micro weir. The average pre-retrofit showerhead flow rate was 3.0 ± 0.1 gpm at 37 psi flowing pressure and the average post-retrofit flow rate was 1.8 ± 0.03 gpm at 45.8 psi. The average pre-retrofit aerator flow rate was 3.3 ± 0.2 gpm at 36.5 psi and the average post-retrofit flow rate was 1.72 ± 0.06 gpm at 45.9 psi. The average pre-retrofit aerator flow rate was greater than anticipated because many old aerators were missing their flow restrictors as shown in **Figure 6**.

Figure 5. Flow Testing a Showerhead

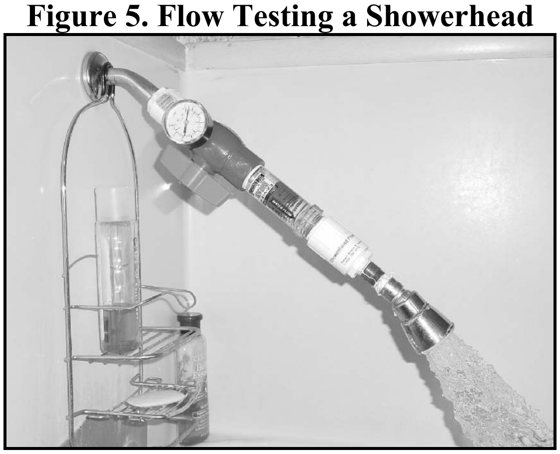


Figure 6. Old Aerators Missing Restrictors

Water Heater Blankets

Inspectors verified proper installation and operation of water heater blankets for a random sample of 123 participants. Blankets were applied to water heaters with dry fittings and the anode, relief valve, and control were left exposed for routine maintenance.

Pipe Insulation

Inspectors verified proper installation and operation of water heater pipe insulation for a random sample of 150 participant sites. Pipe wrap was applied on the first 5 feet of pipe, or up to the first bend to reduce distribution losses caused by thermal siphoning.

Load Impact Results

The total measures installed by the program, EM&V sample sizes, program target values, EM&V findings, 90 percent confidence intervals, coefficients of variation (Cv), and target descriptions are provided in **Table 2**. The EM&V findings exceed the program targets for all measures except airflow, low-flow showerheads, and CFLs.

Table 2. Program Measures, Target Values, and EM&V Findings

Measure	Program Measures	EM&V Sample	Program Target	EM&V Finding	90% Confidence Interval	Cv	Target Description
AC Tune-up Airflow	3,188	181	+6%	+5.5%	0.3%	0.17	6% improved airflow
AC Tune-up Refrigerant	3,188	181	+13%	+14.2%	2.7%	0.52	13% improved EER
Duct Test and Seal	8,370	202	-14%	-18.0%	1.6%	0.60	14% reduced leakage
Infiltration Reduction	143	98	-3%	-17.9%	2.1%	0.65	3% reduced CFM50
CFL Fixture 13-35W	9,707	202	-78W	-55W	6W	0.96	75% reduced Watts
CFL Interior 15-35W	36,491	696	-79W	-58W	4W	1.2	67% reduced Watts
CFL Ext. 13-35W	7,663	57	-77W	-57W	14W	1.1	71% reduced Watts
Programmable T-Stat	1,101	127	-8.5%	-10.0%	7%	0.24	8.5% Savings
Low-Flow Showerheads	7,711	989	-2.7	-1.2	0.1	0.19	50% reduced gpm
Faucet Aerators	8,268	375	-1.1	-1.58	0.2	0.47	34% reduced gpm
WH Blankets	81	89	-3.3%	n/a	n/a	n/a	3.3% savings
WH Pipe Insulation	85	73	-2.6%	n/a	n/a	n/a	2.6% savings
Energy Education Tips		227	100%	100%	0.6%	0.06	100% satisfaction
Total	**82,808**	**3,497**					

Average ex ante and ex post measure savings and realization rates are summarized in **Table 3**. Gross realization rates are greater than one for the following measures: AC tune-up; duct test and seal; infiltration reduction; programmable thermostats; and faucet aerators. The gross realization rate for infiltration reduction is significantly greater due to the combined influence of two EM&V findings: 1) average passive infiltration reduction was 17.9 percent; and 2) average return duct leakage reduction was 5 percent (due to sealing attic flue and floor pipe penetrations). Return air temperature measurements before sealing attic flue penetrations in the air handler closet were in the range of 90 to 100 °F. After sealing these penetrations the return air temperatures ranged from 75 to 85 °F and this is more typical of the overall air temperature inside the home. Future programs should seal flue and pipe penetrations inside the air handler closet to reduce return duct leakage.

Table 3. Average Annual Ex Ante and Ex Post Measure Savings and Realization Rates

Description	Ex Ante Measure Savings			Ex Post Measure Savings			Gross Realization Rate		
	kWh	kW	Therm	kWh	kW	Therm	kWh	kW	therm
AC Tune-up	140	0.31		247	0.29		1.76	0.94	
Duct Test and Seal	226	0.21	24	347	0.21	70	1.54	1.00	2.92
Infiltration Reduction	4	0.004	8	128	0.15	35	32.00	40.54	4.38
CFL Fixture 13-35W	153	0.078		68	0.028		0.44	0.36	
CFL Interior 15-35W	128	0.079		73	0.026		0.57	0.33	
CFL Ext. 13-35W	254	0.077		72	0.005		0.28	0.06	
Programmable T-Stat	96	0.11	17	136	0.16	44	1.42	1.45	2.59
Showerhead-Gas			17			7.6			0.45
Showerhead-Electric	337	0.047		151	0.021		0.45	0.45	
Faucet Aerators-Gas			5			7			1.39
Faucet Aerators-Elec	33	0.005		46	0.006		1.39	1.29	
WH Blankets-Gas			5			5			1.00
WH Blankets-Electric	103	0.014		103	0.014		1.00	1.00	
Pipe Insulation Gas			4			4			1.00
Pipe Insulation Elec	87	0.012		87	0.012		1.00	1.00	

Program ex ante and ex post net lifecycle load impacts and realization rates are summarized in **Table 4**. The ex post net first year load impacts are 7,680,754 ± 622,052 kWh per year, 3,695 ± 660 kW, and 672,143 ± 143,545 therm per year. The net lifecycle load impacts are 79,886,314 ± 8,131,343 kWh and 9,395,565 ± 2,139,034 therm. The net realization rates are 0.81 ± 0.08 for kWh, 0.58 ± 0.10 for kW and 2.13 ± 0.49 for therms. The realization rates have confidence intervals ranging from 10 to 23 percent. This indicates the level of uncertainty associated with the load impact analysis due to variability in the participants' energy consumption.

Table 4. Program Ex Ante and Ex Post Net Lifecycle and 1st Year Load Impacts

Description	Qty	Ex Ante Net Lifecycle Load Impacts				Ex Post Net Lifecycle Load Impacts			
		EUL	kWh	kW	therm	EUL	kWh	kW	therm
AC Tune-up	3,188	10	3,972,248	880		10	7,008,180	823	
Duct Test & Seal	8,370	15	25,253,127	1,564	2,681,748	15	38,773,607	1,564	7,821,765
Infiltration Reduction	143	15	7,636	0	15,272	15	244,358	19	66,817
CFL Fixture 13-35W	9,707	16	21,190,097	678		15	9,421,940	242	
CFL Interior 15-35W	36,491	8	33,364,898	2,574		8	18,912,947	854	
CFL Ext. 13-35W	7,663	8	13,831,850	527		6	3,901,080	34	
Programmable T-Stat	1,101	11	1,034,764	108	183,239	11	1,465,915	157	474,267
Showerhead-Gas	7,604	10			1,150,485	10			514,335
Showerhead-Elec	107	10	320,925	4		10	143,464	2	
Faucet Aerators-Gas	8,257	10			367,437	10			510,737
Faucet Aerators-Elec	11	10	3,231	0		10	4,494	0	
WH Blankets-Gas	71	10			3,160	10			3,160
WH Blankets-Electric	10	10	9,167	0		10	9,167	0	
Pipe Insulation Gas	84	15			4,486	15			4,486
Pipe Insulation Elec	1	15	1,161			15	1,161		
Lifecycle Load Impact	**82,808**		**98,989,104**		**4,405,827**		**79,886,314**		**9,395,565**
1st Year Load Impact			**9,432,729**	**6,336**	**348,867**		**7,680,754**	**3,695**	**672,143**
Net Realization Rate							**0.81**	**0.58**	**2.13**

The kWh and kW realization rates are impacted by CFLs having 49 percent lower annual savings and lower operation during the peak period. CFLs also had somewhat lower effective useful lifetimes (EUL) than originally anticipated. Therm savings are significantly higher than forecast based upon the ex-post measure savings, specifically due to higher therm savings from duct sealing, infiltration reduction, programmable thermostats; and faucet aerators. As a result, the overall program was cost effective with a benefit cost ratio of 1.52 based on the total resource cost test (CPUC and CEC 1987).

Process Survey Results

Interviewers conducted participant process surveys with the same 300 randomly selected participants who were audited. Interviewers also conducted non-participant process surveys with 138 non-participants. Results from these surveys were used to obtain general feedback and investigate operational characteristics of the program. The participant survey results indicate very high customer satisfaction based on average responses to the eight customer service related survey questions shown in **Table 5**.

Table 5. Participant Satisfaction Survey Questions and Responses

#	Question	Response
1	Please rate the courteousness and professionalism of the crew on a scale from 1 to 100?	96.4 ± 0.9
2	Rate your satisfaction with work being scheduled and completed on time from 1 to 100?	99.1 ± 1.1
3	Please rate the presentation of the Energy Saving Tips on a scale from 1 to 100?	93.5 ± 1.2
4	Please rate the usefulness of the Energy Saving Tips on a scale from 1 to 100?	93.7 ± 1.1
5	Please rate the accuracy of the Energy Saving Tips on a scale from 1 to 100?	94.0 ± 1.3
6	How would you rate the overall service you received on a scale from 1 to 100?	98.0 ± 1.0
7	How would you rate the program in terms of increasing your understanding of the linkage between energy efficiency, bill savings, and comfort on a scale from 1 to 100?	91.2 ± 1.7
8	Please rate your satisfaction with measures installed by the program on a scale from 1 to 100?	96.6 ± 1.4

Participant survey results indicated 66 percent (i.e., 135 of 206) shared information about the program with 2,423 neighbors or friends. As a result of sharing information, 895 additional customers decided to participate in the program. Another 64 percent of participants provided positive comments such as “great, marvelous, terrific program,” “really happy with program,” “keep up the good work,” or “please continue the program so more of my neighbors can participate.” The average age of participants was 71 ± 1.4 years, average occupancy was 2 persons per household, and the average income was $25,700. All participants owned their mobile home, all participants spoke fluent English, and all resided outside major metropolitan areas such as Los Angeles, San Francisco, or Sacramento. Many participants did not have the physical ability, funds, skills, or knowledge required to retrofit their own homes. Many indicated that their air conditioners did not work properly and were unable to maintain comfort levels prior to receiving services from the program. Others expressed disbelief that program services were provided free of charge from public benefit funds.

Non-participant survey results indicate approximately 70 percent would have participated if they had known about the program, and most indicate better advertising (i.e., telephone, fliers, or mailers) would have helped. The most often sited barriers to participation were lack of information about how to save energy (59%), performance uncertainties (26%), and hassle costs (12.1%). The average age of non-participants was 66 years, average occupancy was 2 persons per household, and the average income was $24,500. All non-participants owned their mobile home, spoke fluent English, and resided outside major metropolitan areas.

Conclusions

The program installed 82,808 measures in 12,000 mobile homes, and met its objectives to deliver measurable savings for hard-to-reach mobile home customers while undergoing the scrutiny of a comprehensive evaluation. The ex post net first year load impacts are 7,680,754 ± 622,052 kWh per year, 3,695 ± 660 kW, and 672,143 ± 143,545 therm per year. The net lifecycle load impacts are 79,886,314 ± 8,131,343 kWh and 9,395,565 ± 2,139,034 therm. The net realization rates are 0.81 ± 0.08 for kWh, 0.58 ± 0.10 for kW and 2.13 ± 0.49 for therms. The realization rates have confidence intervals ranging from 10 to 23 percent. This indicates the level of uncertainty associated with the load impact analysis due to variability in the participants' energy consumption. The realization rates for kWh and kW are impacted by CFLs having 49 percent lower annual savings and lower operation during the peak period. The CFLs also had somewhat lower effective useful lifetimes (EUL) than originally anticipated. Therm savings are significantly higher than forecast based upon the ex-post measure savings, specifically due to higher therm savings from duct sealing, infiltration reduction, programmable thermostats; and faucet aerators. As a result, the overall program was cost effective with a benefit cost ratio of 1.52 based on the total resource cost test.

Future studies should obtain more billing data for the entire audit sample to improve the load impact results. Future programs should consider budgeting duct leakage measures on a per cfm basis (e.g., $1.65 per cfm reduction) to allow treatment of ceiling supply and floor return systems. The program did not seal many of these systems due to higher costs compared to floor supply systems, but significant cost-effective savings are available. Future programs should also seal flue and pipe penetrations inside the air handler closet to reduce return duct leakage. Efforts should also be made to seal all seams where manufactured home sections are joined together to reduce building envelope leakage. Installation crews should install CFLs in hard-to-reach fixtures since these are difficult for elderly citizens to reach and are often used more frequently than floor or table lamps. Many customers had swamp coolers and would have benefited from swamp cooler repairs. This is a measure worth considering in the future since repairing poor performing swamp coolers can provide low-cost, high-yield savings. Participants provided high marks for the *Test-In/Test-Out Certificates* and *Energy Education Tips*. The EM&V study found a high level of persistence and retention due to these efforts.

Process evaluation findings indicate the program provided valuable energy efficiency services to participants, and measures were generally found to be properly installed. Inspections of duct sealing and AC tune-up measures found a few problems at sites where no quality assurance checks were performed. However, all sites receiving quality assurance passed inspections. Future programs would benefit by having EM&V services provided earlier in the program implementation phase to reduce or eliminate quality control problems. Random inspections found installation crews exhibiting a high-quality service ethic and keen interest in providing quality installations. Participants appreciated this and responded with very high satisfaction ratings with respect to the crews for courteousness and professionalism.

The process evaluation found the majority of participants shared information about the program with neighbors or friends. As a result of sharing information a large number of additional customers decided to participate in the program. The average age of participants was

71 years and the average income was $25,700. All participants owned their mobile home, all participants spoke fluent English, and all resided outside major metropolitan areas. Most participants did not have the ability, funds, or knowledge required to retrofit their own homes. Many indicated their air conditioners did not work properly prior to receiving services from the program. Others expressed disbelief that program services were provided free of charge. Most participants provided positive comments about the program such as "keep up the good work," and "please continue the program so more of my neighbors can participate."

Acknowledgements

This paper was made possible with funding from American Synergy Corporation and CAL-UCONS through a joint contract with Southern California Edison (SCE), Southern California Gas (SCG), and Pacific Gas and Electric (PG&E) under the auspices of the California Public Utilities Commission (CPUC). Field research at customer sites was made possible with the cooperation of mobile home customers and park managers throughout California. We are grateful for the cooperation of technicians and staff of ASC and CAL-UCONS, Eli Kollman and Peter Lai of the CPUC, Mona Yew of PG&E, Herb Emmrich and Frank Spasaro of SCG, and Marjorie Hamilton, Marian Brown, and Alan Schaffer of SCE.

References

American Synergy Corporation (ASC) and CAL-UCONS. 2002. *Comprehensive Hard-to-Reach Mobile Home Energy Saving Local Program.* Hayward, Calif.: American Synergy Corporation. Kirkland, Wash.: CAL-UCONS.

California Department of Finance (CDF). 2000. Sacramento, Calif.: California Department of Finance.

California Public Utilities Commission (CPUC) and California Energy Commission (CEC). 1987. *Standard Practice Manual: Economic Analysis of Demand Side Management Programs*. P400-87-006. Sacramento, Calif.: California Energy Commission.

Energy Information Agency (EIA). 2001. *A Look at Residential Energy Consumption in 2001*. DOE/EIA-0321 (2001). Washington, D.C.: Energy Information Agency.

Fels, M., Kissock, K., Marean, M., Reynolds, C. 1995. *PRISM Advanced Version 1.0 User's Guide*. Princeton, New Jersey. Princeton University, Center for Energy and Environmental Studies.

Hirsch, J. J. 2002. *eQuest and DOE-2.2 Building Energy Simulation Program.* Version 3.37, Copyright J.J. Hirsch. Camarillo, California.

Robison, D. 1999. *Performance Evaluation of Commercial Construction Using a Billing Simulation Tool.* International Energy Program Evaluation Conference Proceedings.

Robison, D. 2000. *Use of a Billing Simulation Tool for Performance Measurement and Verification.* In the *Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings*. Washington, DC.: American Council for an Energy-Efficient Economy.

Sherman, M., Grimsrud, D. 1980. *Measurement of Infiltration Using Fan Pressurization and Weather Data.* LBL-10852. Berkeley, Calif.: Lawrence Berkeley National Laboratory.

Stellar Processes (Stellar) 2002. EZ Sim Building Simulation Tool, Version 6.0. Available online: www.ezsim.com. Portland, Oregon.

United States Department of Energy (US-DOE). 2002. *International Performance Measurement & Verification Protocols: Concepts and Options for Determining Energy and Water Savings. Volume I.* DOE/GO-102000-1132. Washington, D.C.: United States Department of Energy.

United States Housing and Urban Development (HUD). 1994. Code 24 CFR 3280.500. Washington, D.C.: United States Department of Housing and Urban Development.