Completion of Performance Evaluations of Preproduction Prototypes

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PREPARED FOR:
MIDWEST RESEARCH INSTITUTE,
NATIONAL RENEWABLE ENERGY LABORATORY DIVISION,
1617 COLE BOULEVARD,
GOLDEN, CO
80401-3393

PREPARED BY BUILDING INDUSTRY RESEARCH ALLIANCE (BIRA)
7407 TAM O'SHANTER
STOCKTON, CA 95210-3370
TEL: (209) 473-5000 / FAX: (209) 474-0817
CONTACT: FAITH SHIMAMOTO OR BRUCE BACCEI

TEAM CONSORTIUM MEMBERS:
CONSOL
CENTEX HOMES
CLARUM HOMES
CONTEMPO HOMES
KB HOMES
LENNAR
MORRISON HOMES
NC INVESTMENTS
PARDEE HOMES
PINNACLE HOMES
PREMIER HOMES
TREASURE HOMES
CALIFORNIA LIGHTING TECHNOLOGY CENTER
GREEN INQ.
JZMK ARCHITECTS
BUILDING INDUSTRY INSTITUTE
COLORADO ENERGY GROUP
DOW
RINNAI
LAWRENCE BERKELEY NATIONAL LAB
OAKRIDGE NATIONAL LAB
ROSEVILLE ELECTRIC
SACRAMENTO MUNICIPAL UTILITIES DISTRICT
SOUTHERN CALIFORNIA EDISON
FLUENT, INC
GE ENERGY
POWERLIGHT
SHARP
WSU

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Task 12.C.2: Completion of Performance Evaluations of Preproduction Prototypes

Executive Summary

In 2005, Clarum Homes began construction on four high-efficiency prototype homes in Borrego Springs, CA. Each of the four homes is 1,920 sq. ft. with identical floor plans. . Three of the homes have the same orientation (30° east of south) and the fourth is rotated 270° to face directly west due to site constraints. Two of the homes use DOW Chemical Company's 10" T-MASS®™ wall system, one home uses Structural Insulated Panels (SIP) and the fourth home employs 2x6 frame walls. All four homes have advanced heating and cooling systems that vary.

Working with builder-partner Clarum Homes, the Davis Energy Group (DEG), the National Renewable Energy Laboratory (NREL) and other Building America Program (BAP) partners, the BIRA team evaluated the comparative performance of the wall systems of all four prototype homes. This report focuses on the findings regarding the SIP and 2x6 frame homes.

While the T-Mass homes have marked benefits, the SIP and 2x6 frame homes seem to be much more amenable to production home building and SIPs are 75% less expensive than the 2x6 frame walls.

The comparative performance of these two wall systems is presented, and in some cases compared with the homes constructed of T-MASS concrete sandwich walls.

Introduction

This report describes the performance evaluation results of two prototype homes estimated to provide 44 to 52% whole-house energy savings relative to the Building America Program (BAP) Benchmark without photovoltaics (PV) and 61 to 66% with PV. One home is constructed with Structurally Insulated Panels (SIP) and the second home is constructed with 2x6 wood frame walls that are insulated with spray in foam (2X6 Frame). Working with builder-partner Clarum Homes, DEG, NREL and other BAP partners, the BIRA team evaluated production-scale performance benefits from the advanced systems used in these homes. This report includes:

- an evaluation of the benefits and estimated incremental retail costs of the tested advanced building design concepts
- results of short term whole house performance tests evaluating the impacts and benefits of advanced system designs relative to Benchmark building systems; and
- a summary of measurements and questions answered by the performance evaluation.

Background

Borrego Springs Location

The pre-production houses are located in Borrego Springs, 90 miles northeast of San Diego, CA. Figure 1 is a regional map of the Borrego Springs area.

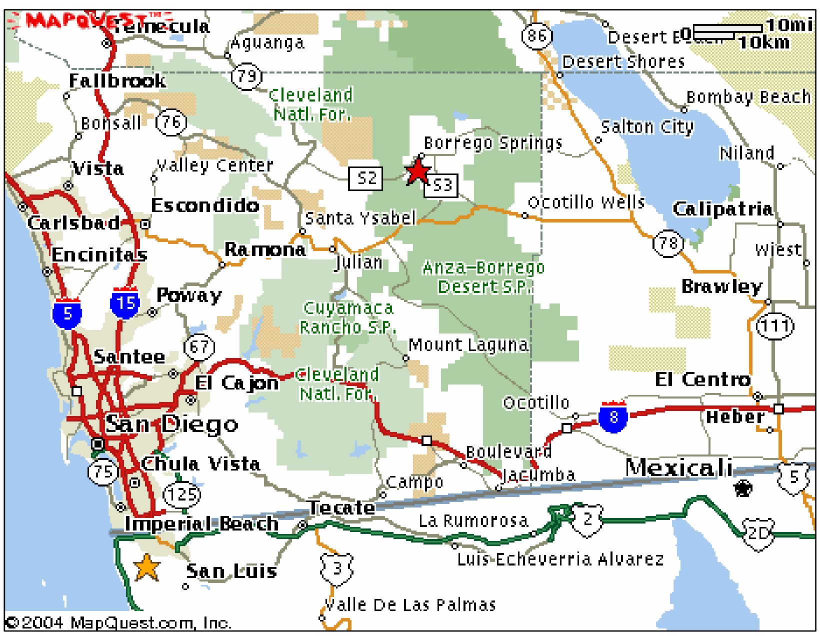

Figure 1: Regional Map – Borrego Springs

Figure 2 is a vicinity map of the Borrego Springs area showing the site locations for all four experimental houses. The two subject experimental houses are located at 3234 Broken Arrow Road (Lot 73), SIP House and 3224 East Star Road (Lot 322), 2X6 Frame House. The two homes using T-MASS®™ wall systems are located at 742 DiGiorgio Road (Lot APN #140-070-03) and 3485 Country Club Road (Lot 96). Some performance comparisons between all four experimental houses are included in this report.

Figure 2: Vicinity Map – Borrego Springs

Climate

Borrego Springs is located in California Climate Zone 15 and has 1,075 HDD and 3,843 CDD, Climate Zone 15 is an extreme hot-dry climate zone that has a period of 4 to 6 weeks in late summer with high humidity. This monitoring project findings will provide information as prototypes for thousands of homes that are expected to be built in similar climate areas in the U.S. Southwest.

Heating Degree Days	1,075 HDD
Cooling Degree Days	3,843 CDD
Average Maximum Temperature	87.3ºF
Average Temperature	72.3ºF
Average Minimum Temperature	57.5ºF

Table 1: Borrego Springs Climate Data

Project Highlights

In 2005 construction began on four high efficiency prototype homes. Each of the four homes is 1,920 sq. ft. The floor plans are the same, three of the homes (East Star, Broken Arrow and DiGiorgio) have the same orientation (front facing 30° east of south) and the fourth (Country Club) is rotated to face west due to sight constraints.. The HVAC systems vary from house to house. This report focuses on the two homes using SIP and 2X6 Frame wall systems. A summary of the key differences in advanced systems for the two study houses is shown below.

Lot	**Broken Arrow Lot 73**	**East Star Lot 322**
Orientation	Front- 30° East of South	Front- 30° East of South
Wall System	**SIP**	**2X6 Frame**
Heating System	**Radiant Floor Heating**	**Radiant Floor Heating**
Cooling System	**OASYS, Conventional AC**	**Lennox AC**

Table 2: Prototype Home vs. Key Advanced Systems

Orientation

The figures below show the site orientation for the Broken Arrow and East Star homes. Both homes face 30° east of south.

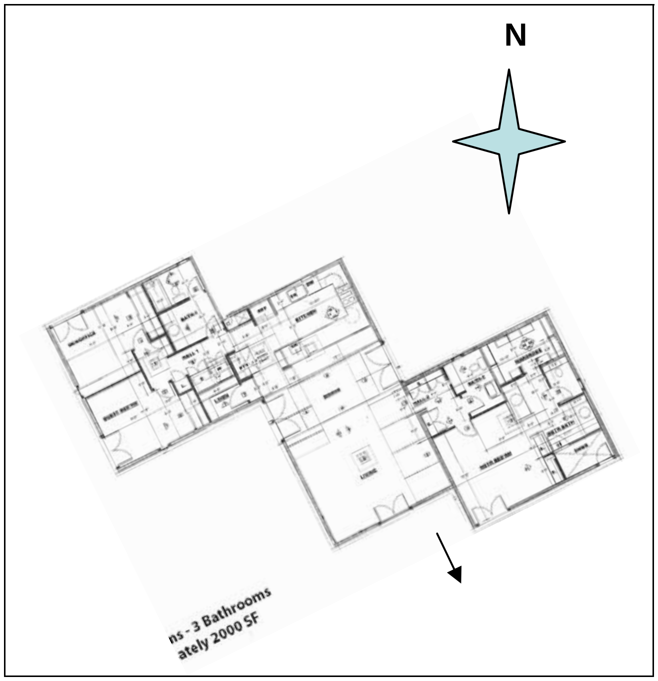

Figure 3 East Star and Broken Arrow Orientation

The orientation of the roofs will also be important for assessing the efficiency of the PV array. The roof orientations are shown in the figure below.

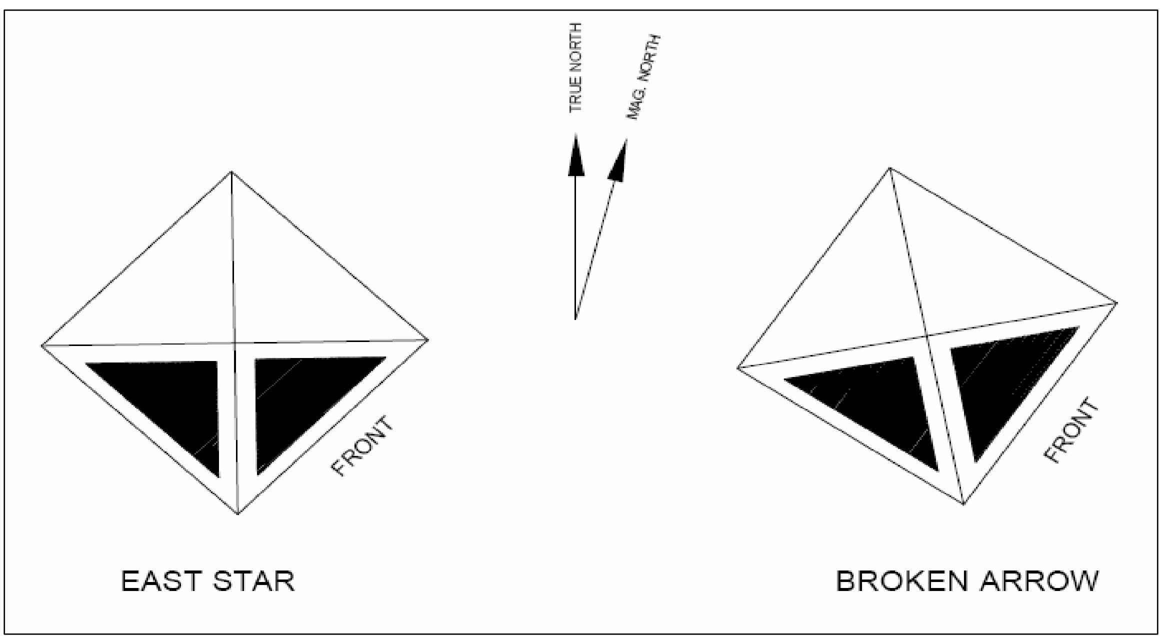

Figure 4: Roof Orientation with PV Array

Calculated Energy Requirements

To achieve 60% minimum energy savings above the base case house, the Prototype BA Houses required the following advanced systems:

	Broken Arrow/SIP Lot 73	**East Star/2X6 Frame Lot 322**
Roof	R-38 w/ radiant barrier	R-38
Walls	Structural Insulated Panels (SIP) R-27	(2X6 Frame) 2x6 wood wall system with sprayed-in Icynene® foam insulation R-18
Windows	Dual pane vinyl frame windows with spectrally selective glass. SL (U = 0.35, SHGC = 0.35), FX (U=0.35, SHGC = 0..35) Patio Dr (U = 0.35, SHGC = 0.35)	Dual pane vinyl frame windows with spectrally selective glass. SL (U = 0.35, SHGC = 0.35), FX (U=0.35, SHGC = 0.35) Patio Dr (U = 0.35, SHGC = 0.35)
Air Infiltration	0.30 ACH	0.30 ACH
HVAC System	OASys Evaporative Cooler + Conventional Ducted AC for periods of high humidity (14 SEER equivalent)	Lennox (19 SEER equivalent)
Water & Space Heating	Tankless w/ Energy Factor = 0.84 & Space Heating	Tankless w/ Energy Factor = 0.84 & Space Heating
Lights	CFL	CFL
Appliances	ENERGY STAR®	ENERGY STAR®

Table 3: Summary of Energy Features

Analyses of Multiple Energy Efficiency Options

The following tables summarize the energy savings derived from major features using Micropas simulation. The detailed analysis is included in Appendix A. The total Building America whole house saving for the SIP house vs. the BA Benchmark is 44%. When PV systems are included, the total savings is 61% over the Benchmark.

	Base Case House (kBtu/yr)	**Broken Arrow/SIP (kBtu/yr)**	**Energy Savings**
Heating (from Micropas simulation)	3,130	2,842	9%
Cooling (from Micropas simulation)	119,981	44,640	63%
Water Heating (from Micropas simulation)	24,941	15,283	39%
Lighting	23,969	7,191	70%
Other Uses/Appliances/Plug Loads	59,213	58,643	1%
Whole House Energy Savings	***231,234***	***128,598***	**44%**
Site Generation (2.4kW DC PV system)		*-38,703*	
Total	**278,600**	**89,895**	**61%**

Table 4: Summary of SIP Energy Savings (Micropas simulation)

The table below summarizes the energy savings for the 2x6 Frame house. The total Building America whole house saving for the 2x6 Frame house vs. the BA Benchmark is 52%. When PV systems are included, the total savings is 66% over the Benchmark.

	Base Case House (kBtu/yr)	**East Star 2x6 Frame (kBtu/yr)**	**Energy Savings**
Heating (from Micropas simulation)	15,245	3,629	76%
Cooling (from Micropas simulation)	155,232	49,440	68%
Water Heating (from Micropas simulation)	24,941	15,283	39%
Lighting	23,969	7,191	70%
Other Uses/Appliances/Plug Loads	59,213	58,643	1%
Whole House Energy Savings	***278,600***	***134,186***	**52%**
Site Generation (2.4kW DC PV system)		*-38,703*	
Total	**278,600**	**95,482**	**66%**

Table 5: Summary of 2x6 Frame Energy Savings (Micropas simulation)

Monitoring

BIRA, DEG, and NREL are responsible for the installation of monitoring equipment in all homes short term testing and on-going analysis of data. The four prototype homes are being monitored in great detail, examining the performance of the both the structure of the homes and the advanced heating and cooling systems. The following table gives the total number of sensors per home:

52	Wagon/Country Club	T-Mass	OASys w/Conventional
46	Broken Arrow,	SIP	OASys + Conventional Ducted AC
42+17=59 51	Di Georgio East Star	T-Mass OVE	Freus(17 NREL sensors) + NightBreeze Lennox
208			

Figure 5 Total Sensors for all Four Homes.

The following summarizes the sensors pertaining to the focus of this report:

Subsystem	Monitoring Points
Wall System: SIP and 2x6 Frame	– Outdoor Wall temp – Interior Wall Temp – Indoor Wall Temp
Floor/Slab system (slab edge insulation) at: 1. center of slab, 2. near edge of slab & 3. ½ way between other two	– Surface Temp – Interior Temp – Temp of ground right below the slab, 12 inches and 3 ft below
HVAC System (OASys cooling in SIP home, Lennox 20.5 SEER in the 2X6 Frame home	– Monthly/Yearly Water Consumption – Monthly/Yearly kW consumption
PV output	– Daily/Monthly generation – Solar Insolation
Indoor/Outdoor Temperature	
Indoor/Outdoor Relative Humidity	
Tankless water heater (space and domestic hot water heating)	– Flow Rate – Gas Usage (therm)

Table 6: Detailed Monitor Points

Performance Measurement and Evaluation

The primary focus of the investigation is on evaluating the whole-house performance and the contribution of the advanced systems to the energy efficiency of the two pre-production homes. Efficiency will be evaluated through total power usage information and by short term detailed monitoring of building components; floors and walls in particular, as well as the heating and cooling systems and the performance of the PV systems.

A second purpose of the evaluation will be to evaluate the cost effectiveness of the advanced systems in supporting energy efficiency with available data to date.

At a minimum, the team anticipates monitoring the performance of the homes as follows:

- Assembling and reviewing ComfortWise inspections and tests for the homes.
- Take the lead in comparing performance of the wall systems in these homes and associated costs. Comparisons will also be made between the three wall systems in the homes.
- Take lead in analyzing ground coupling data derived from the four homes and the interaction of the heating and cooling systems with the ground beneath the homes.
- Analyze utility bills compared with the Building America Benchmark and with each other.
- Conduct detailed short-term monitoring to evaluate the effectiveness of the PV in meeting electrical demand and impact on peak demand.
- Overall PV performance (theoretical vs. actual)
- Overall whole-house performance (theoretical vs. actual)
- Peak analysis
- Impact of orientation vs. peak demand

Inspection Data

Third party test and inspection results are available in Appendix A of this report.

Third-Party testing was done on each home to verify duct leakage and air infiltration. Broken Arrow passed with a leakage of 4.5% and East Star passed with a duct leakage of only 2%. Both homes had problems with air infiltration. Initial tests of the homes resulted in SLA values of close to five. The design Clarum/BIRA goal for these homes required were seeking an SLA's of two. It was determined, after numerous hours of troubleshooting, that both homes had the same problems. The problems were largely the a result of numerous architectural penetrations of all skylights and windows were custom, built on site such as those shown in Figure 6 and 7.

Figure 6: Example Custom, Site Built CeilingSkylight Penetrations

Figure 7: : Architectural Custom Site Built Glazed Areas: Wall Penetrations

It became very apparent that the decorative custom built windows and skylights had not been properly installed and sealed to prevent air leakage. Once the project manager was instructed on proper measures, the homes were re-tested and found to have an SLA of approximately four. This was a marked improvement, but lower than the performance level originally intended. Clarum takes full responsibility and has carefully noted this lesson learned to avoid problems on future projects.

Figure 8 shows the perimeter of the skylight shown above in Figure 5. Essentially, the large 4x4 skylight was not caulked to the drywall allowing air infiltration on all sides coming from the attic space. Once the project manager was instructed on proper measures, the homes were re-tested and found to have an SLA of approximately four.

Figure 8: Close-up View of Skylight Perimeter

On further inspection, the reason for continued air infiltration was found in the baseboards, shown in Figure 9. Air was infiltrating from the attic air space through the stud bay of the interior walls and entering into conditioned space between the gaps created where the interior wall meets the slab. After caulking all the interior wall baseboards, SLA's dropped to reasonable, yet still not our projected level of air infiltration as seen from Test and Inspection results in Appendix A.

Figure 9: Floor to Wall Infiltration Gap

SIP and 2x6 Frame Wall Performance

All materials in homes contain varying degrees of thermal mass, dry walls, concrete floors, furniture, etc. Thermal mass coupled with nighttime cooling to discharge the mass, can result in significant energy savings in homes. In this way thermal mass can be used to store the cool of summer evenings, or off peak AC, and to carry homes comfortably through the heat of summer days. The cooling load in residential buildings is generated mainly by heat flow through the envelope; by internal gains from people and equipment, cooking, etc., and by the solar gain through un-shaded windows. This section examines how well SIP and 2x6 Frame walls insulate the homes and retain the cooling stored by the internal thermal mass listed above.

It should be noted that these homes are unoccupied and unfurnished. The positive side is occupants are not varying the use from home to home. The detractor is that actual occupied homes would have more thermal mass in the form of furniture and some of the floor areas would be covered reducing the contribution of the floor to the effective thermal mass.

Super-Cooling Tests

Short term tests were conducted to determine how well each house coasts thermally through the peak power consumption periods.

Experimental Setup

To perform these experiments, each house was set to a specific temperature profile for the week, described in the Table 7 and show graphically in Figure 10. The temperature set points were maintained for the entire month of August 2006 in three of the four houses (not testing the occupied T-Mass house).

Week Day	Time	Set Point (°F)
Tuesday	12 AM – 12 PM	72
	12 PM -12 AM	85
Wednesday	12 AM – 12 PM	72
	12 PM -12 AM	85
Thursday	12 AM – 12 PM	72
	12 PM – 4 PM	74
	4 PM -12 AM	85
Friday	12 AM -12 AM	78
Saturday	12 AM -12 AM	78
Sunday	12 AM -12 AM	78
Monday	12 AM -12 AM	78

Table 7: Super-Cooling Experiment Set Point Temperatures & Schedule

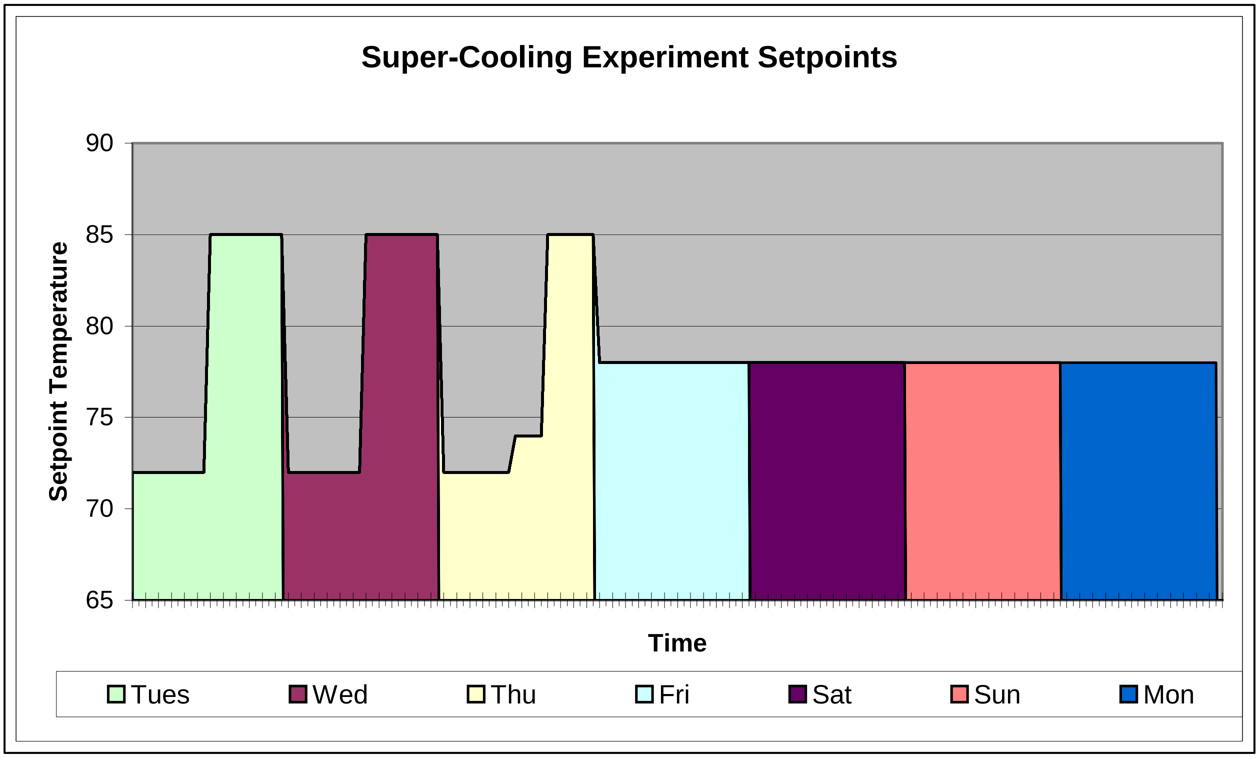

Figure 10: Graphical View of Super-Cooling Experiment Temperature Set Points & Schedule

Super-Cooling Results

The results shown in the following figures are for Wednesday, August 16. The house was in the third week of the experimental cooling cycle and had completed one super-cooling cycle.

Figure 11 shows the interior temperature of the Master Bedroom and Kitchen along with the Condenser Energy Use for the SIP house. Note that when the HVAC system is set to 85°F from12 PM to 12 AM, which includes the afternoon peak hours, the interior temperature rises approximately 4 degrees, but never reaches 85°. The HVAC system does not run during this 85°F-period even though the outside air temperatures climbs to 105°F.

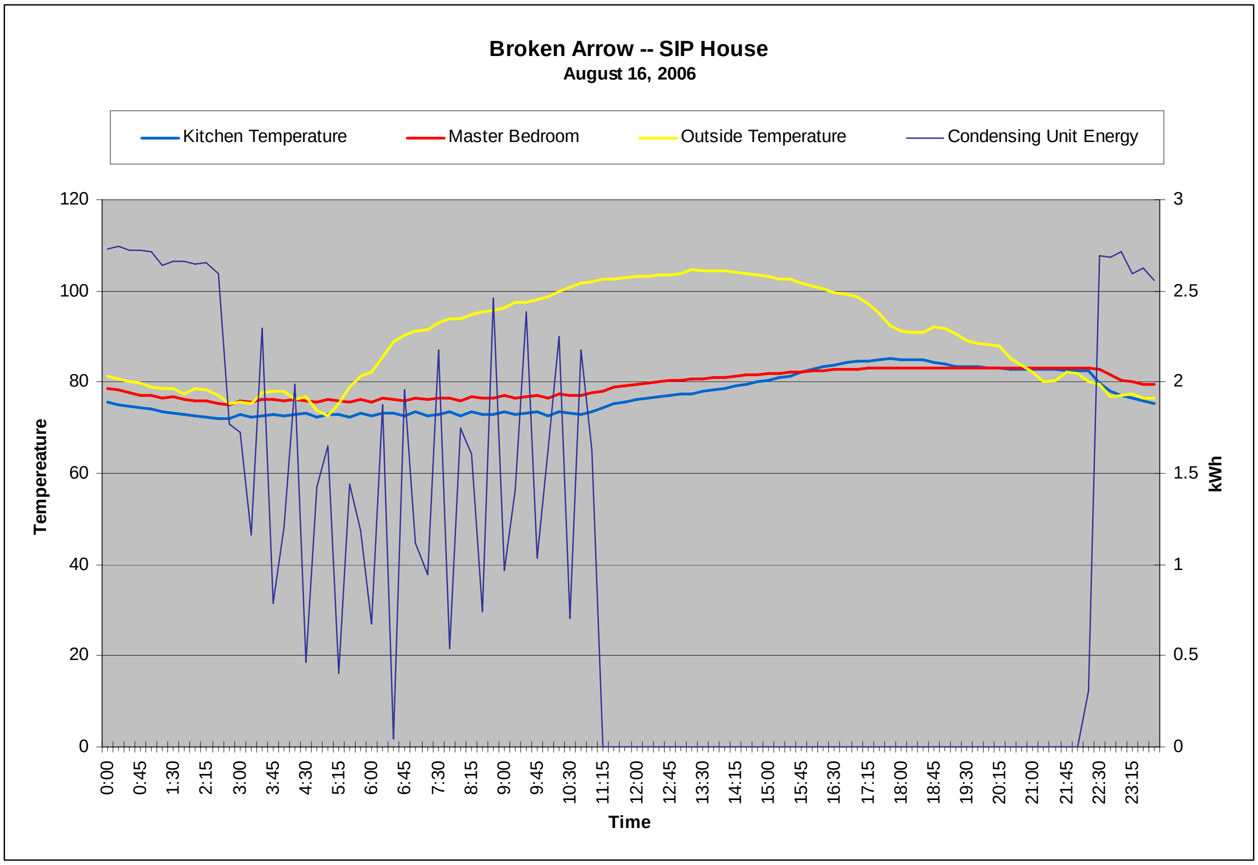

Figure 11: Super Cooling Experiment -- SIP House

Figure 12 shows other interior and exterior wall temperatures of the SIP house during this same period. Both the NE and SW external walls reach peak temperatures of over 120°, even though the outside air temperature peaks at 105°. Recall that the HVAC system is set to 85°F from12 PM to 12 AM, but the interior wall temperatures peak at 84°F.

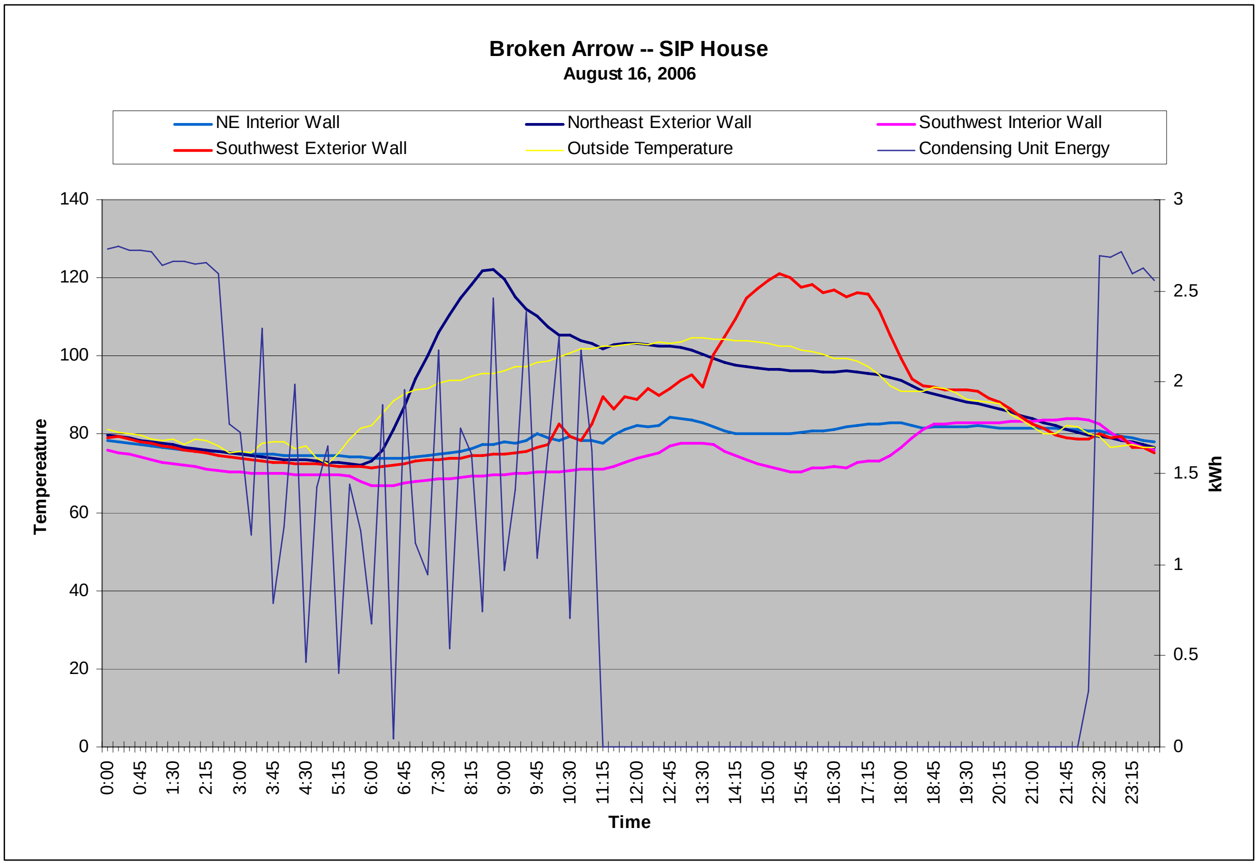

Figure 12: Super-Cooling Results – SIP House

Figure 13 shows the interior temperature of the Master Bedroom and Kitchen along with the Condensor Energy Use for the 2X6 Frame house. In this case, when the HVAC system is set to 85°F from12 PM to 12 AM, the interior temperature change is approximately 8 degrees, but never reaches 85°. The HVAC system begins to run around 4PM and runs continuously though the night.

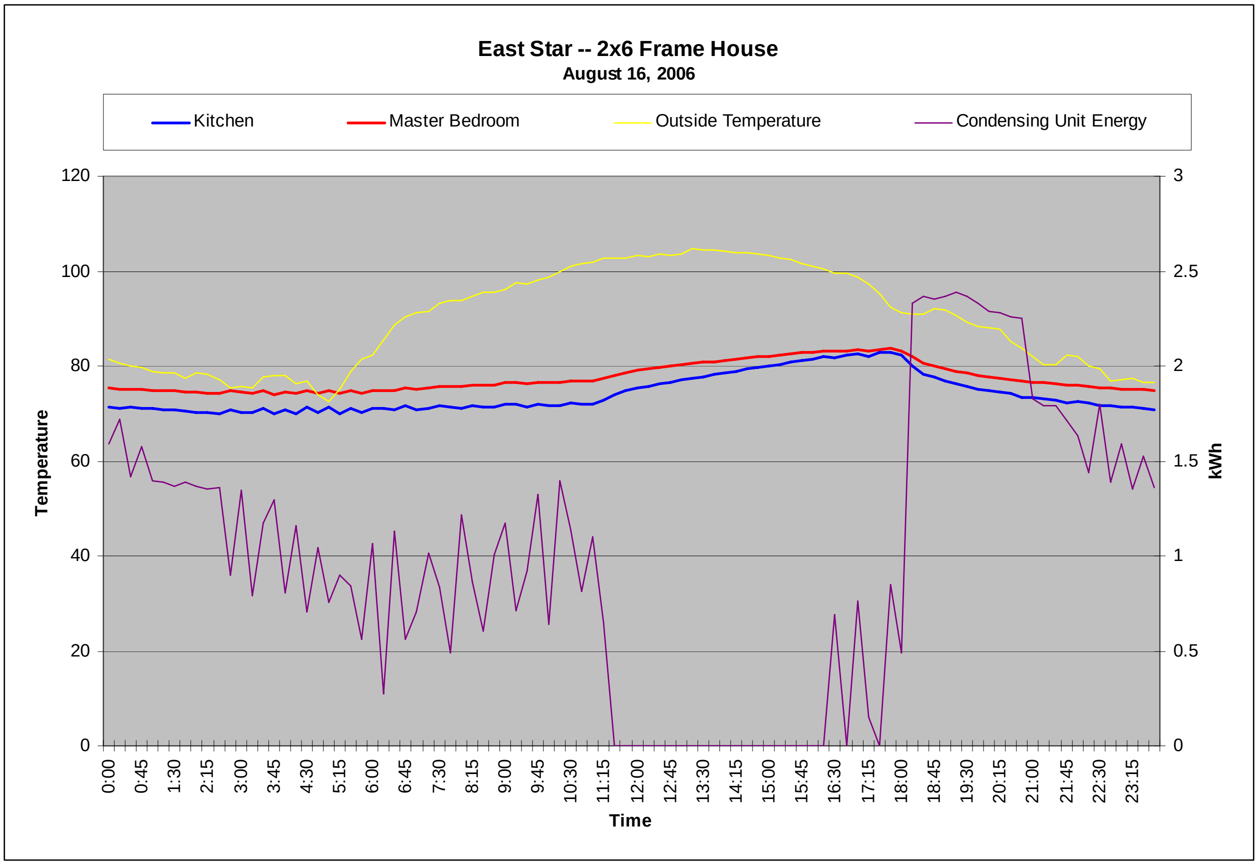

Figure 13: Super-Cooling Experiment – 2x6 Frame House

Figure 14 shows the NE and SW interior and exterior wall temperatures of the 2X6 Frame house during this same period. Both the NE and SW external walls reach peak temperatures of 140° and 134°, even though the outside air temperature peaks at 105°. The NE interior wall peaks at 85.5°. The SW interior wall peaks at 85.6°. Recall that the HVAC system is set to 85°F from12 PM to 12 AM, and while the Kitchen and Master Bedroom temperatures do not reach 85°, the NW interior wall does.

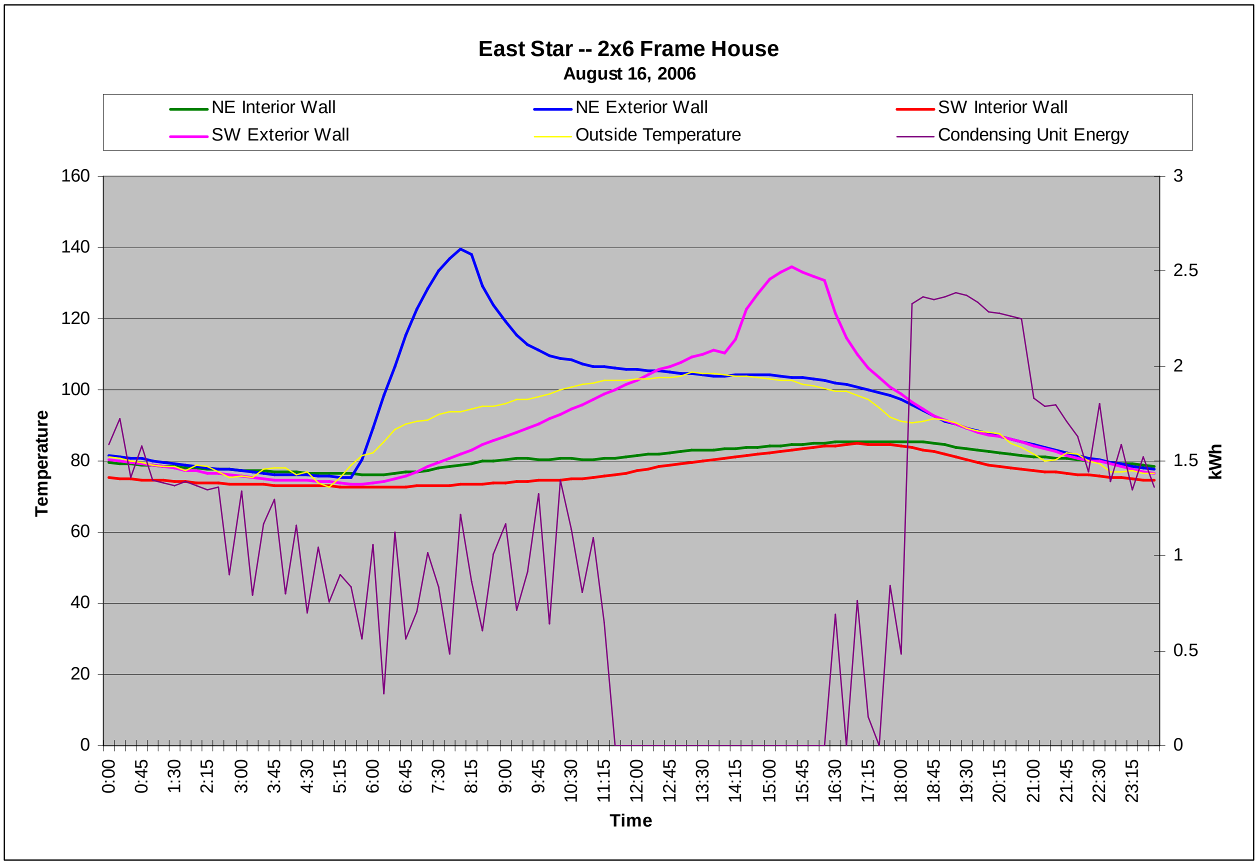

Figure 14: Super-Cooling results – 2x6 Frame House

For comparison, data from the T-Mass house located on Country Club is shown in Figure 15. The SW exterior wall reaches a peak temperature of 121° but the interior walls remain at a relatively constant temperature , changing by 3.5°. during the entire period. The T-Mass house, in comparison, never reaches the 85° set point with the T-Mass walls sustaining the house through the entire 85° set point period. The SIP house never reached the 85° set point and exhibited a temperature change of 8° during the afternoon coast period.. The interior wall temperatures are also less stable than was seen in the T-Mass walls. The 2X6 Frame house, , reached the 85° set point in 4.5 hours and experiences a temperature change of 9° over the 11 hour interval.

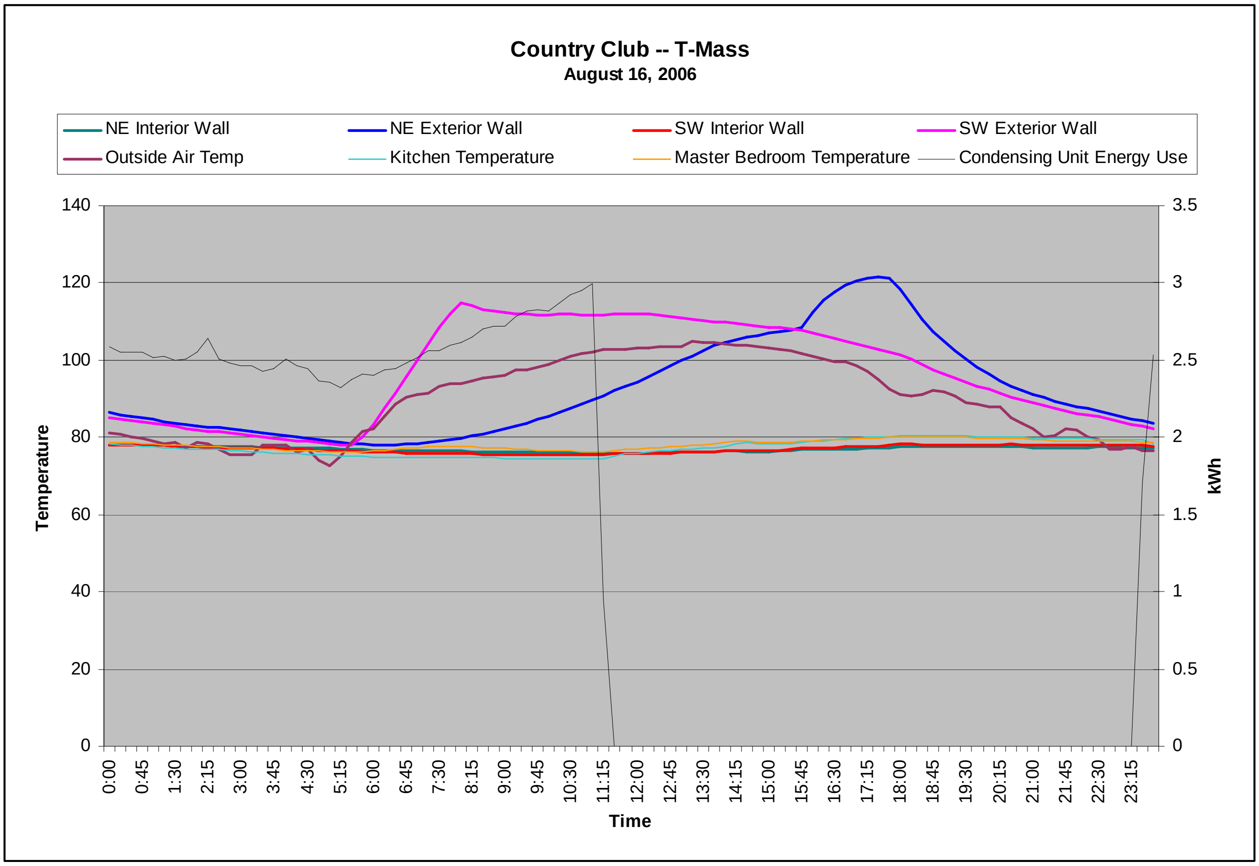

Figure 15: Super-Cooling Results -- T-Mass House

Single Set Point Results

At the end of the 3-day super-cooling cycles, the thermostat is set to a constant 78° for the remainder of the week. The figure below shows how the walls perform during the second day of this constant set point cycle.

The outside air temperature reaches a maximum of 107° between 12 and 1 PM. The NE external wall peaks at a temperature of approximately 126° at 8:45 AM while the internal wall peaks at 87° at 10:15 AM. The cooling system cycles continuously, during the peak from 1:30 to 7 PM and through the evening to maintain the 78° set point. This causes the SW interior wall to drop to a temperature of 66°, while the exterior wall peaks just below 120°.

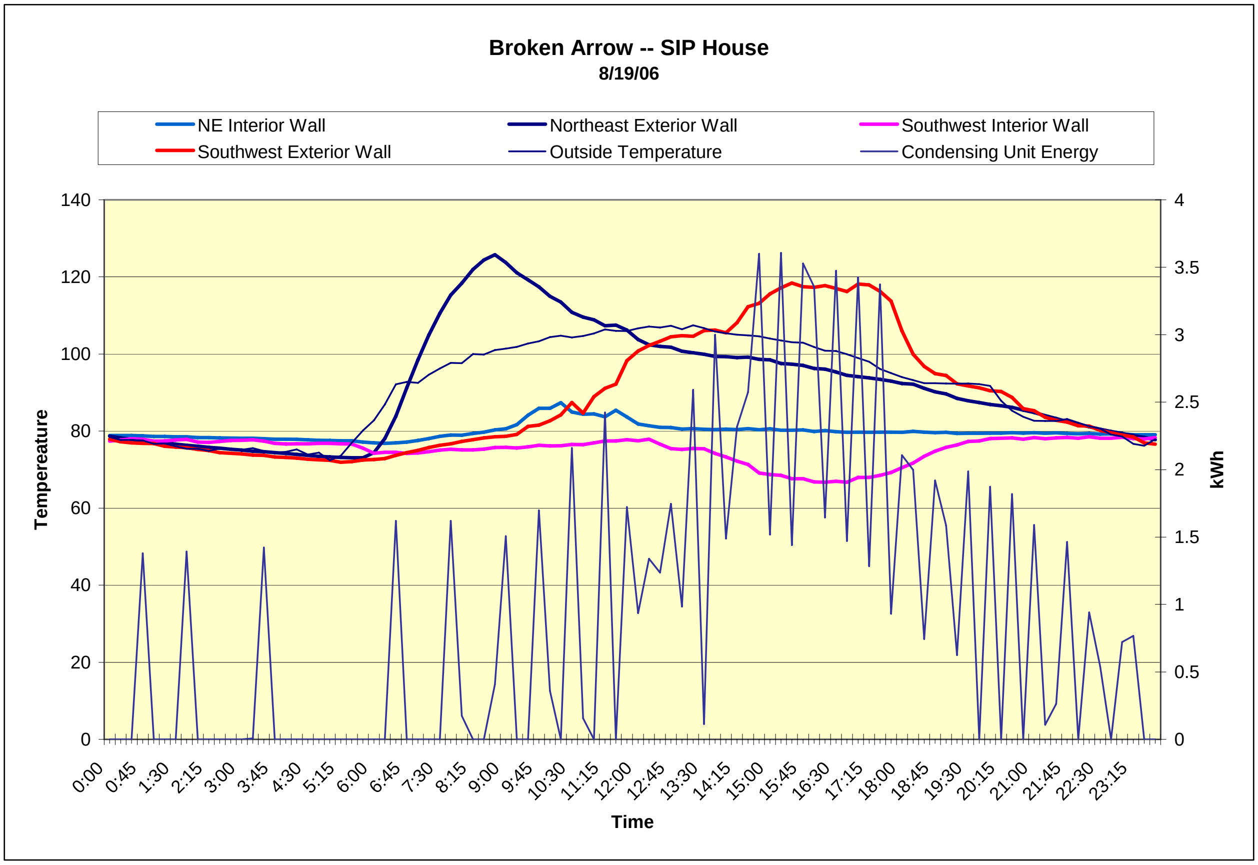

Figure 16: SIP Wall Performance -- 78° Set Point

When compared with the 2x6 Frame house, during peak afternoon hours, the T-Mass cooling system runs from 3PM until 7PM . The 2X6 Frame house begins running at 2PM and run until 9PM to maintain the 78° set point.

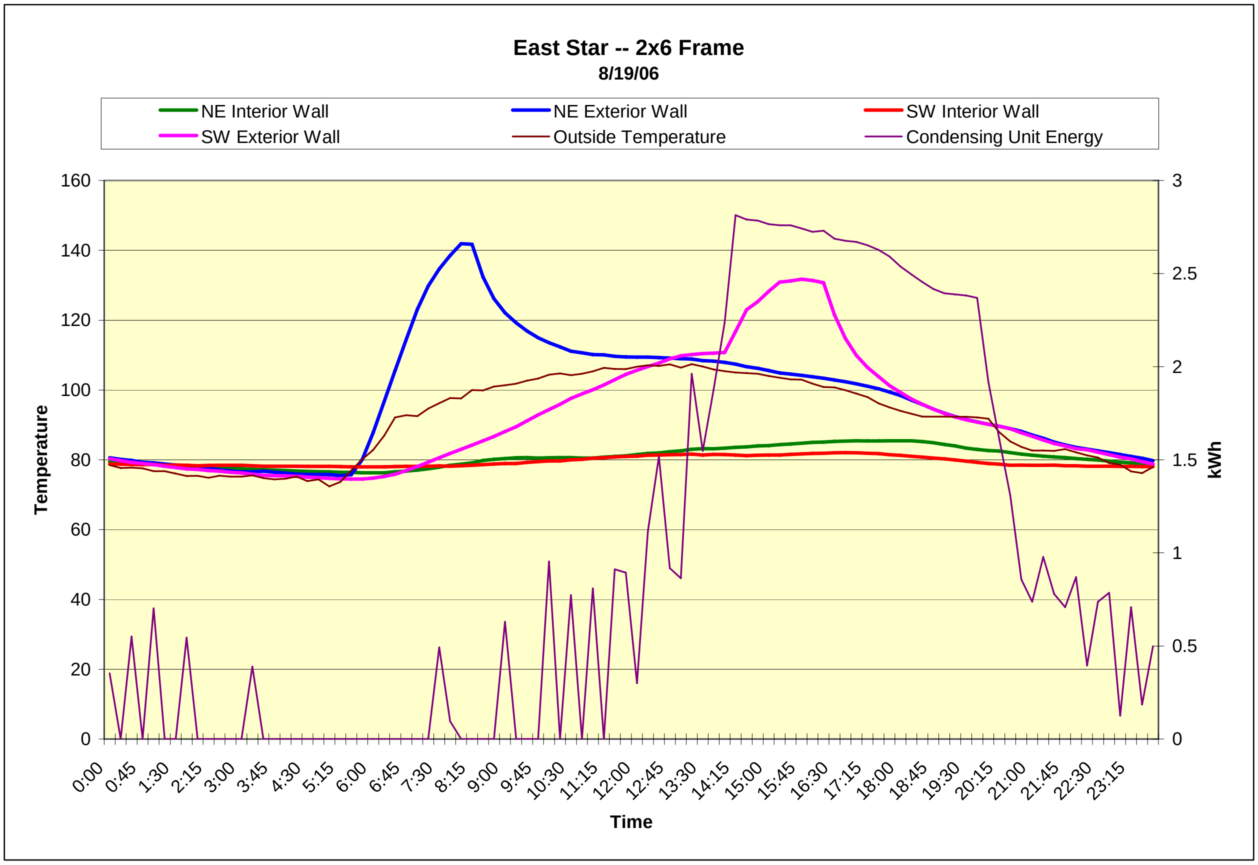

Figure 17: 2x6 Frame Wall Performance -- 78° Set Point

The outside air temperature reaches a maximum of 107° between 12 and 1 PM. The NE external wall peaks at a temperature above 120° while the internal walls maintain a nearly constant temperature near the 78° set point. The cooling system runs, almost continuously from 3 to 7 PM to maintain the 78° set point.

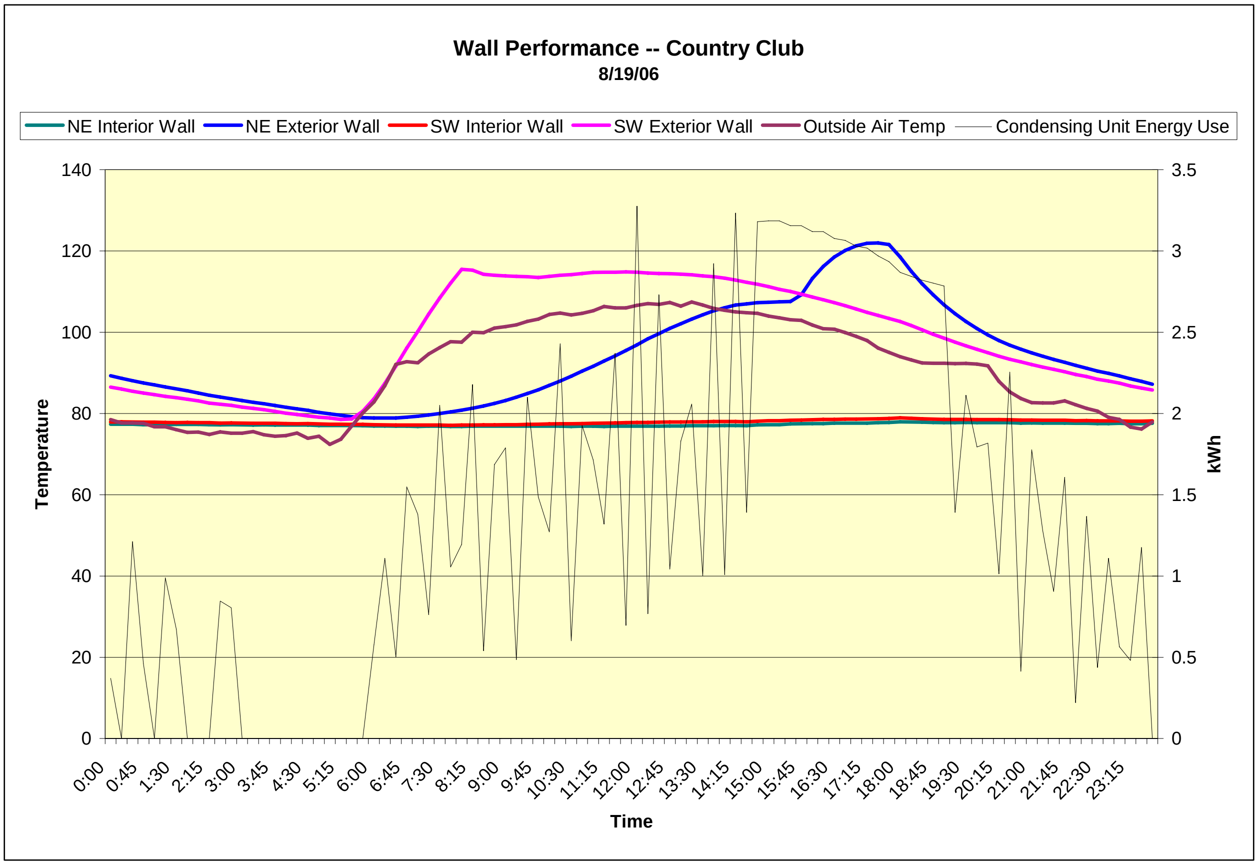

Figure 18: T-Mass Wall Performance -- 78° Set Point

Costs

The builder collected costs to support their planning of other projects under development. These costs were made available to this study and are shown in the table below. Clarum collected and shared costs for their own planning of future projects, for this report and with the explicit purpose of adding useful information for other builders on the Clarum/Borrego Springs Project website. The cost of each wall system and each cooling system is listed below. In that the 2x6 frame house is constructed by more typical means, comparisons of costs are made to that house. The 2x6 frame house also employs the most conventional cooling system, though rated with a very high SEER of 20.5, so it to is used for comparisons. In comparing cooling systems keep in mind that the climate is particularly challenging with a 4 to 6 week period of high humidity in the summer so that the homes with evaporative cooling systems also have conventional air-conditioning to provide cooling during the periods of high humidity.

It should also be noted that these are prototype homes built in a remote location and that costs would expect to come down if produced on a volume basis and in a more easily and less expensively accessed construction site.

The comparative cost show that the T-Mass walls cost 75% more than the 2x6 Frame house. The comparisons also show that the SIP house wall construction is 27% higher than the 2x6 house.

Comparisons of costs of the cooling systems to the high SEER Lennox system are that the Oasys 2 Stage Evaporative Cooler in the T-Mass house on Country Club Drive costs 13% more than the Lennox. As noted above, if these homes were built in other areas of the Hot-Dry climate zone, like Sacramento, CA the cost without the back up conventional AC might be the same or less than the Lennox high SEER. In the case of the second house with Oasys, it also required ducting which is atypical of evaporativly cooled homes and would probably reduce the 33% price increase above the Lennox. The third comparison for cooling is for the DiGiorgio Road, T-Mass house which is cooled with the Freus, evaporativly cooled condenser and NightBreeze system. Here again is another level of duality that adds to the cost and is expected to add significantly to the performance, particularly in Spring and Fall. It is conceivable that this T-Mass house could be cooled only with the NightBreeze in many parts of California's central valley, in areas of New Mexico, Arizona and Colorado. Subsequent monitoring from this project is expected to bare this out.

Energy Features	Site	Comparison Cost
Walls		
SIP w/standard interior framed walls & garage	Broken Arrow Drive	$ 72,674
2x6 w/standard interior framed walls & garage	East Star Road	$ 57,242
HVAC		
Oasys 2-Stage Evaporative Cooler	Broken Arrow Drive	$ 21,009
Lennox	East Star Road	$ 15,846

Energy Features	Site	Costs	Costs Compared to 2x6 Frame	Percent Increase
Walls				
TMass Walls w/standard interior framed walls & garage	Country Club Drive	$99,762	$42,520	74%
TMass Walls w/standard interior framed walls & garage	Di Giorgio Road	$100,301	$43,059	75%
SIPS w/standard interior framed walls & garage	Broken Arrow Drive	$72,674	$15,432	27%
2x6 Frame	East Star Road	$57,242		
HVAC			**Costs Compared to Lennox**	**Percent Increase**
Oasys 2-Stage Evaporative Cooler	Country Club Drive	$17,923	$2,077	13%
Freus+NightBreeze	Di Giorgio Road	$20,440	$4,594	29%
Oasys w/Conventional Ducted A/C	Broken Arrow Drive	$21,009	$5,163	33%
Lennox	East Star Road	$15,846		

Table 8: Builder Costs

Construction Issues

In addition to issues with infiltration discussed in the earlier section on Test and Inspection, the following construction issues were collected by the builder. The table below describes the issues identified by the builder during the construction of the four prototype homes.

Energy Features	Site	Permitting Issues	Construction Issues
Walls			
SIPS w/standard interior framed walls & garage	Broken Arrow Drive	Longer Plan Review	• Difficult installation with seismic requirements for hold downs. • Inadequate provisions for electrical wiring. • Panels cannot accommodate mechanical or plumbing.
2X6 FRAME w/ explanation	East Star Road		• Changed from 2x6's, 24" on center approved and stamped by structural engineer to 2x6's 16" on center. • Radiant Barrier installed but covered by Icynene insulation rendering radiant barrier ineffective
HVAC			
OASys w/Conventional Ducted A/C	Broken Arrow Drive	N/A	
Lennox	East Star Road	N/A	

Table 9: Construction Issues

Conclusion

Off peak cooling at night to discharge the internal thermal mass, can result in significant energy and cost savings in homes benefit both the home owner and utility. Thermal mass can be as little as concrete floors, drywall and furniture or as much as all this plus concrete walls. The benefits of thermal mass are quite significant:

1. Cooled mass acts as a heat sink minimizing temperature rising throughout the peak demand period.
2. Decreases mean radiant temperature significantly enhancing comfort summer comfort when cooled.
3. Energy cost savings for the home owner and utility
4. The mass will also serve to absorb solar heat through windows and skylights in winter to provide stored warmth at night
5. When heated, thermal mass will provide a higher mean radiant temperature that will significantly enhance comfort during under heated periods of the year.

Areas of the country where there is a significant swing in temperature between day and night in summer or in areas with significantly higher electrical rates during peak periods can benefit significantly from increased thermal mass. These two homes with T-Mass walls as the exterior walls and tile covered floors performed significantly better than the SIP and 2x6 frame homes.

While these benefits are significant the cost increases are very substantial. It is conceivable that increased thermal mass above the levels of normal wood frame construction with ½ inch drywall can be achieved less expensively and more effectively than by building entire exterior walls of homes with concrete like the T-Mass walls used in this project.

For example all walls, exterior and interior could have 5/8 inch drywall installed instead of the standard ½ inch. For pre-cooling at night, surface area of thermal mass is more important than thickness, so increased thickness of drywall combined with tile floors may perform well too. Use of thicker drywall, interior plaster walls, even phase change materials in walls and ceilings need to be further tested and may be far more likely to be employed by production builders than exterior concrete walls.

Phase change materials for use in residential construction are available in Europe and Austrailia and DOW Chemical Company has stopped providing the T-Mass product, but is working with Oakridge National Lab. testing products focused on building applications for heating and cooling.

BIRA is following up with recent discussions with DOW representatives to determine the prospect of building prototype homes with phase change materials in walls and/or ceilings.

Appendix A: ComfortWise Test Results

Country Club

Aug 14 06 04:17p Rob Starr 9097950252 p.4

Test Data Collection Form

Rater Name: Rob Starr
Builder: Clarum
Project: Borrego Springs
Address: 3495 Country Club Road
Stage of Construction (circle one): ROUGH FINAL
Phase: ___ Lot: 96
Date: 8-14-06
Plan:
Square Feet: 2001
Number of Floors: 1
House faces: N S E W

Blower Door

Depressurize Target: 50 pascals
Small Fan, ring size: 0 1 2 3
Large Fan, ring size: 0 A B C
House Pressure: 50
Fan Pressure:
Target Infiltration (SLA): 1.5 - 3.8
True Fan Flow (CFM): 288
Measured Infiltration (SLA): 2.9
Pass Fail
Carpet Y N | Y N Holes
Weather-strip Y N #) F.place
Mechanical Ventilation off Y N open closed

Static Pressure

System: 1 2 3

		Sealed
FAU Mfr: Speakman	FAU Seams	Y N
Model: CR5 OASYS	FAU Door	Y N
AFUE: ___ Output BTU: ___	Coil Seams	Y N
AC Mfr:	Duct Collars	Y N
Model:	Dry Wall	Y N
SEER: ___ Tons: ___	Can Seams	Y N
Coil Mfr:	M. Dampers	Y N
Model:	P-Trap	Y N
Equipment Sizing Matches Design: Y N	TXV	Y N
Air Conditioner on: Y N	Sheetmetal Insulated	Y N

Supply & Re measured: BEFORE or AFTER coil
Supply vs. Attic:
Return vs. Attic:
Supply vs. Return:
Static Pressure (IWC):

Room by Room Air Flow

System: 1 2 3 Upstairs / Downstairs

Room	Design CFM	Actual CFM
Kit		392
Den		304
Liv		459

Return	Design CFM	Actual CFM

Duct Blaster

Total, Supply & Return

System: 1 2 3 Upstairs / Downstairs

Ring: 0 1 2 3 | 0 1 2 3
At 25 Pascals
Duct Pressure: 25
Fan Pressure:
Flow (CFM): 12
Leakage %: 6%
Target leaks per below 6%
Target CFM at 6%:
Tonnage: 3
Floor Area:
BTU:
Fan Flow:
Pass Fail

Ring: 0 1 2 3 | 0 1 2 3
At 50 Pascals
Duct Pressure: 50
Fan Pressure:
Flow (CFM):
Leakage %:
Notes:

Ceiling Insulation

Batt Blown in Fiberglass Cellulose
Target Insulation R-
Observed R-Value
Depth (blown in):
Using Radiant Barrier Y N
Uniform depth Y N
Pass Fail

Duct Insulation

Target R-
Observed R-
Pass Fail

Water Heater

Target Size: Observed Size:
Blanket required: Yes No
Blanket present: Yes No
Target Energy Factor: EF ___ Observed: EF ___
Target Recovery Efficiency: RE ___ Observed: RE ___
W. H. Mfr: Model:
Pass Fail
Recirculation System Y N If so, Type
Solar Water Heating Y N If so, Temperature Gauge Present: Y N
Hot Water Main Pipe Insulation Verified at rough Y N

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Di Giorgio

Aug 14 06 04:16p Rob Starr 9097950252 p.1

Test Data Collection Form

Rater Name: ROB STARR Date: 8-14-06

Builder: CLARUM Plan:

Project: BORREGO SPRINGS Phase: Lot: Square Feet: 2040

Address: 742 DI GIORGIO Number of Floors: 1

Stage of Construction (circle one): ROUGH (FINAL) House faces: N (S) E W

Blower Door Depressurize Target: 50 pascals Target Infiltration (SLA): 1.5 - 3.8 Pass Fail

Small Fan, ring size: (0) 1 2 3 House Pressure: 34 True Fan Flow (CFM): 1342 Carpet Y (N) Y (N) Holes

Large Fan, ring size: 0 A B C Fan Pressure: Measured Infiltration (SLA): 3.2 Weather-strip (Y) N # 1 F.place

Mechanical Ventilation off (Y) N open (closed)

Static Pressure System: 1 2 3 Sealed

F.A.U. Mfr: NEGATREEEZE		FAU Seams	Y N
Model: NB10-Z-120A		FAU Door	Y N
AFUE:	Output BTU:	Coil Seams	Y N
AC Mfr: FOCUS		Duct Collars	Y N
Model: 10MO7-36		Dry Wall	Y N
SEER:	Tons:	Can Seams	Y N
Coil Mfr: AMANA		M. Dampers	Y N
Model: CHF-60T		P-Trap	Y N
Equipment Sizing Matches Design: Y N		TXV	Y N
Air Conditioner on: Y N		Sheetmetal Insulated	Y N

Supply side measured: BEFORE or AFTER coil

Supply vs. Attic:

Return vs. Attic:

Supply vs. Return:

Static Pressure (IWC):

Room by Room Air Flow

System: 1 2 3 Upstairs / Downstairs

Room	Design CFM	Actual CFM
KIT		296
DIN		346
LIV		454
M BED		116
½ BATH		122
MWC		57
MBA		62
BED 1		54
OFF / BED 2		168
		183

Return	Design CFM	Actual CFM
A		1412

Duct Blaster Total, Supply & Return

System: 1 2 3 Upstairs / Downstairs

Ring:	0 1 2 (3)	0 1 2 3	Target CFM at 6%:
At 25 Pascals			Tonage: 3
Duct Pressure:	25		Floor Area:
Fan Pressure:			BTU:
Flow (CFM):	54		Fan Flow:
Leakage %:	4.5		
Target leakage below 6%			(Pass) Fail
Ring:	0 1 2 3	0 1 2 3	Notes:
At 50 Pascals			
Duct Pressure:	50		
Fan Pressure:			
Flow (CFM):			
Leakage %:			

Ceiling Insulation Batt Blown-in Fiberglass Cellulose Using Radiant Barrier Y N

Target Insulation R- Observed R-Value Depth (blown in): Uniform depth Y N Pass Fail

Duct Insulation Target R- Observed R- Pass Fail

Water Heater Target Size: Observed Size: Blanket required: Yes No Blanket present: Yes No

Target Energy Factor: EF Observed: EF Target Recovery Efficiency: RE Observed: RE

W. H. Mfr: Model: Pass Fail

Recirculation System Y N If so, Type Hot Water Main Pipe Insulation Verified at rough Y N

Solar Water Heating Y N If so, Temperature Gauge Present: Y N

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East Star Road

Aug 14 06 04:17p Rob Starr 9037950252 p.2

Test Data Collection Form

Rater Name: Rob Starr — Date: 8-14-06
Builder: Clarum — Plan:
Project: Berkeley Springs — Phase: — Lot: 322 — Square Feet: 2000
Address: 3224 East Star Road — Number of Floors: 1
Stage of Construction (circle one): ROUGH FINAL — House faces: N S E W

Blower Door — Depressurize Target: 50 pascals — Target Infiltration (SLA): 1.5 - 3.8 — Pass Fail
Small Fan, ring size: 0 1 2 3 — House Pressure: 26 — True Fan Flow (CFM): 1381 — Carpet Y N / Y N Holes
Large Fan, ring size: 0 A B C — Fan Pressure: — Measured Infiltration (SLA): 4.0 — Weather-strip Y N # 1 F.place
Mechanical Ventilation off Y N open closed

Static Pressure — System: 1 2 3

		Sealed
F.A.U Mfr: Lennox	FAU Seams	Y N
Model: CBX32MV-036	FAU Door	Y N
AFUE: Output BTU:	Coil Seams	Y N
AC Mfr: Lennox	Duct Collars	Y N
Model: XC21-036	Dry Wall	Y N
SEER: Tons:	Can Seams	Y N
Coil Mfr:	M. Dampers	Y N
Model:	P-Trap	Y N
Equipment Sizing Matches Design: Y N	TXV	Y N
Air Conditioner on: Y N	Sheetmetal Insulated	Y N

Supply side measured: BEFORE or AFTER coil
Supply vs. Attic:
Return vs. Attic:
Supply vs. Return:
Static Pressure (IWC):

Duct Blaster — Total, Supply & Return
System: 1 2 3 — Upstairs / Downstairs

Ring:	0 1 2 3	0 1 2 3	Target CFM at 6%:
At 25 Pascals			Tonage: 3
Duct Pressure:	25		Floor Area:
Fan Pressure:			BTU:
Flow (CFM):	24		Fan Flow:
Leakage %:	2%		

Target leakage: below 6% — Pass Fail

Ring:	0 1 2 3	0 1 2 3	Notes:
At 50 Pascals			
Duct Pressure:	50		
Fan Pressure:			
Flow (CFM):			
Leakage %:			

Room by Room Air Flow

System: 1 2 3 — Upstairs / Downstairs

Room	Design CFM	Actual CFM
MBA		90
MBED		105
1/2 BA		43
LIV		267
DIN		335
KIT		143
LAV		67
BA 2		94
BED 1		295
BED 2		226

Return	Design CFM	Actual CFM
A		1276

Ceiling Insulation — Batt Blown-in Fiberglass Cellulose — Using Radiant Barrier Y N
Target Insulation R- — Observed R-Value — Depth blown in): — Uniform depth Y N — Pass Fail

Duct Insulation — Target R- — Observed R- — Pass Fail

Water Heater — Target Size: — Observed Size: — Blanket required: Yes No — Blanket present: Yes No
Target Energy Factor: EF — Observed: EF — Target Recovery Efficiency: RE — Observed: RE — Pass Fail
W. H. Mfr — Model:
Recirculation System Y N — If so, Type — Hot Water Main Pipe Insulation Verified at rough Y N
Solar Water Heating Y N — If so, Temperature Gauge Present: Y N

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Broken Arrow Road

Aug 14 06 04:17p Rob Starr 9097950252 p.3

Test Data Collection Form

Rater Name: ROB STARR — Date: 8-14-06

Builder: CLARUM — Plan:

Project: BORREGO SPRINGS — Phase: — Lot: 73 — Square Feet: 1940

Address: 3234 BROKEN ARROW RD — Number of Floors: 1

Stage of Construction (circle one): ROUGH FINAL — House faces: N S E W

Blower Door — Depressurize Target: 50 pascals — Target Infiltration (SLA): 1.5 - 3.8 — Pass Fail

Small Fan, ring size: 0 1 2 3 — House Pressure: 33 — True Fan Flow (CFM): 1351 — Carpet Y N / Y N Holes

Large Fan, ring size: 0 A B C — Fan Pressure: — Measured Infiltration (SLA): 3.4 — Weather-strip Y N / # 1 F.place

Mechanical Ventilation off Y N open closed

Static Pressure — System: 1 2 3

F.A.U. Mfr: CARRIER

Model: 58STXA036-30

AFUE: — Output BTU:

AC Mfr: CARRIER FC4R-036

Model:

SEER: — Tons:

Coil Mfr:

Model:

Equipment Sizing Matches Design: Y N

Air Conditioner on: Y N

	Sealed
FAU Seams	Y N
FAU Door	Y N
Coil Seams	Y N
Duct Collars	Y N
Dry Wall	Y N
Can Seams	Y N
M. Dampers	Y N
P-Trap	Y N
TXV	Y N
Sheetmetal Insulated	Y N

Supply side measured: BEFORE or AFTER coil

Supply vs. Attic:

Return vs. Attic:

Supply vs. Return:

Static Pressure (IWC):

Room by Room Air Flow

System: 1 2 3 — Upstairs / Downstairs

Room	Design CFM	Actual CFM
MBA		123
MBED		138
1/2 BA		76
LIV		274
DIN 1		339
2		320
BA		83
WC		80
BED 2		214
BED 1		345

Return	Design CFM	Actual CFM
A		1371

Duct Blaster — Total, Supply & Return

System: 1 2 3 — Upstairs / Downstairs

Ring: 0 1 2 3 | 0 1 2 3 — Target CFM at 6%:

At 25 Pascals — Tonnage: 3

Duct Pressure: 25 — Floor Area:

Fan Pressure: — BTU:

Flow (CFM): 54 — Fan Flow:

Leakage %: 4.5

Target leakage: below 6% — Pass Fail

Ring: 0 1 2 3 | 0 1 2 3 — Notes:

At 50 Pascals

Duct Pressure: 50

Fan Pressure:

Flow (CFM):

Leakage %:

Ceiling Insulation — Batt Blown-in Fiberglass Cellulose — Using Radiant Barrier Y N

Target Insulation R- — Observed R-Value — Depth (blown in): — Uniform depth Y N — Pass Fail

Duct Insulation — Target R- — Observed R- — Pass Fail

Water Heater — Target Size: — Observed Size: — Blanket required: Yes No — Blanket present: Yes No

Target Energy Factor: EF — Observed: EF — Target Recovery Efficiency: RE — Observed: RE

W. H. Mfr: — Model: — Pass Fail

Recirculation System Y N — If so, Type — Hot Water Main Pipe Insulation Verified at rough Y N

Solar Water Heating Y N — If so, Temperature Gauge Present: Y N

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Appendix B: Energy Analysis

(Note: the estimated costs included in the preliminary analyses in Appendix A do not include HVAC system costs.)

Broken Arrow – SIP

Clarum Homes
Borrego Springs — **SIP Panels**
Floor Area = **1,920** **Sqft**
Borrego Springs, CA - CZ 15

Energy and Cost Analysis for Base Case and BA Prototype Houses

	Base Case / BA Benchmark House (kBtu/sf-yr)	Base Case / BA Benchmark House (kBtu/yr)	Prototype House - Energy Savings Features (kBtu/sf-yr)	Prototype House - Energy Savings Features (kBtu/yr)	Reduction in Energy Use (kBtu/yr)
Heating	1.63	3,130	1.48	2,842	
Cooling	62.49	119,981	23.25	44,640	
Water Heating	12.99	24,941	7.96	15,283	
Total	77.11	**148051**	32.69	**62765**	**57.6%**
Lighting		23,969		7,191	
Total (Heat, Cool, WH and Lighting)		**172,021**		**69,956**	**59%**
Other Uses		59,213		58,643	
Total (Heat, Cool, WH, Lighting & Other Uses)		**231,234**		**128,598**	**44%**
Site Generation (2.4kW PV)				(38,703)	
Overall Total Energy Savings		**231,234**		**89,895**	**61%**
ENVELOPE: (Insulation U-Values or R-Values)					
Roof (attic)	R-30		**R-38 (U-value = 0.025)**		
Roof (at furnace)	R-30		**R-19 (U-value = 0.047)**		
Wall (Exterior)	U-value = 0.085		**R-27**		
Wall (Kneewall)	U-value = 0.085		**R-13**		
Floor (above garage)	N/A		N/A		
Floor (cantilever)	N/A		N/A		
Attic Radiant Barrier	No		**Yes**		
Low Air Infiltration	No		**Yes**		
GLAZING:					
			Dual Pane Vinyl Frame Windows w/ Spectrally Selective Glass		
U-Factor					
Slider (horz)*	0.877		**0.35**		
Fixed*	0.877		**0.35**		
Patio*	0.877		**0.35**		
SHGC					
Slider (horz)*	0.581		**0.35**		
Fixed*	0.581		**0.35**		
Patio*	0.581		**0.35**		
HVAC SYSTEM: (Oasys Evap Cooler by Davis Energy Group)					
Furnace: AFUE	0.78		**0.84 equivalent**		
A/C: SEER	10 SEER		**14.0**		
Duct Insulation / Location	5.0/Attic		**R-4.2 buried in insulation**		
Duct Testing	No		**Yes**		
ACCA Manual D	No		**Yes**		
	No				
WATER HEATING:					
Water Heater Size	40 gal		**Tankless System**		
Energy Factor	0.54		**0.80**		
Distribution Type	Standard		**Pipe Insulation**		
External Wrap	R-12		**None**		
3rd Party Inspections and Testing (In ComfortWise Program)	No		**Yes**		
Gas dryer stub	No		**Yes**		

Comparison of Total Energy Use 3 Bedrooms

OVE Wall System	Base Case / BA Benchmark House			BA Prototype House - Energy Savings (Upgraded Features, Fluorescent, Gas Dryer Stub, and Tankless Hot Water)		
	\		Dollars	Energy Use		Dollars
	Therms	kWh	$	Therms	kWh	$
Energy Code Related						
Space Heating	31		$ 31.30	28		$ 28.42
Space Cooling		11,718	$ 1,523.34		4,360	$ 566.77
Water Heating	249		$ 249.41	153		$ 152.83
Other Uses						
cooking	78		$ 78.00	78		$ 78.00
clothes washer		105	$ 13.65		105	$ 13.65
dishwasher		206	$ 26.77		206	$ 26.77
electric or gas dryer		835	$ 108.55	72	76	$ 81.89
refrigerator		669	$ 86.97		669	$ 86.97
Miscellaneous (Appliances + Plug)		3,206	$ 416.83		3,206	$ 416.83
Lighting		2,341	$ 304.33		702	$ 91.30
reduce kWh by solar contribution		n/a	n/a		(3,780)	$ (491.40)
Total use	359	19,080	$ 2,839.15	331	5,545	1,052.03
Total Annual Energy Use		231,234	kBtu/yr		89,895	kBtu/yr
Reduction in Energy Use				8%	71%	63%
Total for Column in kBtu/yr	35,870	195,363		33,125	56,770	

Total kBtu/yr for BA Benchmark House	231,234	kBtu/yr
Total kBtu/yr for Prototype House	89,895	kBtu/yr
Percent End Use Energy Savings	**61%**	

	Base Case	Prototype
Estimated Montly Energy Bill	$ 236.60 /mo	$ 87.67 /mo
Reduction in Energy Cost		37%

price of gas/therm	$1.00
price of electricity/kWh	$0.13000

East Star – 2x6 Frame

Clarum Homes
Borrego Springs **OVE House**
Floor Area = **1,920 Sqft**
Borrego Springs, CA - CZ 15

Energy and Cost Analysis for Base Case and BA Prototype Houses

	Base Case / BA Benchmark House (kBtu/sf-yr)	Base Case / BA Benchmark House (kBtu/yr)	Prototype House - Energy Savings Features (kBtu/sf-yr)	Prototype House - Energy Savings Features (kBtu/yr)	Reduction in Energy Use (kBtu/yr)
Heating	7.94	15,245	1.89	3,629	
Cooling	80.85	155,232	25.75	49,440	
Water Heating	12.99	24,941	7.96	15,283	
Total	101.78	**195418**	35.60	**68352**	**65.0%**
Lighting		23,969		7,191	
Total (Heat, Cool, WH and Lighting)		**219,387**		**75,543**	**66%**
Other Uses		59,213		58,643	
Total (Heat, Cool, WH, Lighting & Other Uses)		**278,600**		**134,186**	**52%**
Site Generation (2.4kW PV)				(38,703)	
Overall Total Energy Savings		**278,600**		**95,482**	**66%**

	Base Case	Prototype
ENVELOPE: (Insulation U-Values or R-Values)		
Roof (attic)	R-30	**R-38 (U-value = 0.025)**
Roof (at furnace)	R-30	**R-19 (U-value = 0.047)**
Wall (Exterior)	U-value = 0.085	**R-21+1" Foam (R-5.0) / U-value = 0.047**
Wall (Kneewall)	U-value = 0.085	**R-13**
Floor (above garage)	N/A	N/A
Floor (cantilever)	N/A	N/A
Attic Radiant Barrier	No	**Yes**
Low Air Infiltration	No	**Yes**
GLAZING:		**Dual Pane Vinyl Frame Windows w/ Spectrally Selective Glass**
U-Factor		
Slider (horz)*	0.877	**0.35**
Fixed*	0.877	**0.35**
Patio*	0.877	**0.35**
SHGC		
Slider (horz)*	0.581	**0.35**
Fixed*	0.581	**0.35**
Patio*	0.581	**0.35**
HVAC SYSTEM:		
Furnace: AFUE	0.78	**0.84 equivalent**
A/C: SEER	10 SEER	**Lennox 19 SEER**
Duct Insulation / Location	5.0/Attic	**R-4.2 buried in insulation**
Duct Testing	No	**Yes**
ACCA Manual D	No	**Yes**
	No	
WATER HEATING:		
Water Heater Size	40 gal	**Tankless System**
Energy Factor	0.54	**0.80**
Distribution Type	Standard	**Pipe Insulation**
External Wrap	R-12	**None**
3rd Party Inspections and Testing (In ComfortWise Program)	No	**Yes**
Gas dryer stub	No	**Yes**

Comparison of Total Energy Use 3 Bedrooms

OVE Wall System	**Base Case / BA Benchmark House**			**BA Prototype House** - Energy Savings (Upgraded Features, Fluorescent, Gas Dryer Stub, and Tankless Hot Water)		
	\		Dollars	Energy Use		Dollars
	Therms	kWh	$	Therms	kWh	$
Energy Code Related						
Space Heating	152		$ 152.45	36		$ 36.29
Space Cooling		15,161	$ 1,970.91		4,829	$ 627.72
Water Heating	249		$ 249.41	153		$ 152.83
Other Uses						
cooking	78		$ 78.00	78		$ 78.00
clothes washer		105	$ 13.65		105	$ 13.65
dishwasher		206	$ 26.77		206	$ 26.77
electric or gas dryer		835	$ 108.55	72	76	$ 81.89
refrigerator		669	$ 86.97		669	$ 86.97
Miscellaneous (Appliances + Plug)		3,206	$ 416.83		3,206	$ 416.83
Lighting		2,341	$ 304.33		702	$ 91.30
reduce kWh by solar contribution		n/a	n/a		(3,780)	$ (491.40)
Total use	480	22,523	$ 3,407.87	339	6,013	1,120.85

Total Annual Energy Use		278,600	kBtu/yr		95,482	kBtu/yr
Reduction in Energy Use				29%	73%	67%
Total for Column in kBtu/yr	47,986	230,615		33,912	61,570	

Total kBtu/yr for BA Benchmark House	278,600	kBtu/yr
Total kBtu/yr for Prototype House	95,482	kBtu/yr
Percent End Use Energy Savings	**66%**	

Estimated Montly Energy Bill	$ 283.99 /mo	$ 93.40 /mo
Reduction in Energy Cost		33%

price of gas/therm $1.00
price of electricity/kWh $0.13000