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Below is the article to be submitted to Home Energy Magazine satisfying requirements for Task 1.6.2. The article focuses on a study that was conducted in Borrego Springs, CA for different types of wall systems and the impact they have on living space temperature differentials

“Battle of the Walls, Peak Reduction”  
*Written by: Steve Vang & Rob Hammon, Ph.D.*  
*For Home Energy Magazine*

According to the Energy Information Administration, heating, ventilation, and cooling make up 31 percent of the electricity consumed by U.S. households. In the cooling dominated Southwest, it is crucial to reduce residential air conditioning, which also drives summer peak demand. The added electricity to meet this summer-afternoon demand is drawn from dispatchable “peaker-plants” that are typically among the most expensive and polluting per kW generated. Reducing and/or shifting air conditioning (“AC”) to low-demand periods of the day could eliminate summer peak demand, which would reduce the need for peaker plants, reduce energy costs and pollution, simplify grid management and increase grid stability. A strategy to achieve these benefits is to flatten the peak load by both reducing cooling requirements and moving the mechanical air conditioning to night and morning hours when demand is low and compressor-based air conditioning is most efficient. Employing this strategy has the potential to both reduce both total kWh and peak kW.<sup>1</sup> This study focuses on the impacts of envelope construction, particularly walls, on implementing this AC strategy, and its impacts on annual energy use and afternoon peak demand.

Working under the U.S. Department of Energy Building America Program, the ConSol-led Building Industry Research Alliance (“BIRA”) team assisted Clarum Homes in the design and construction of three homes with identical floor plans but different envelope and mechanical systems in Borrego Springs, California. Clarum’s main objective was to find the best solution to building comfortable, and cost-effective, super energy-efficient homes with 90 percent reduced cooling requirements in the Hot-Dry climate of the American Southwest. One of the Building America objectives was to determine the impacts of the three different building-envelope systems in these homes on summer peak demand.

The Borrego Springs research project evaluated the impacts of three different wall systems on summer peak cooling demand: 2x6, 16”on-center wood-framed with Icynene foam; Structural Insulation Panels (“SIPs”); and insulated concrete mass walls<sup>2</sup>. The homes all have exposed, slab-on-grade foundations – the exposed concrete was dyed and textured, but not covered with any flooring that would reduce their thermal mass effects. The homes also had different cooling systems that are discussed in other reports<sup>3</sup>. These reports can be accessed at [www.bira.ws](http://www.bira.ws)

The experiment involved pre-cooling the homes to 72°F during night and morning off-peak hours (at least midnight until noon), then letting them “coast” through the peak hours of the afternoon when electricity is most expensive by setting up the thermostats to 80°F from noon to midnight. The “coast” period was the duration from noon (when the thermostat setpoints were set-up from the pre-cooled 72°F to 80°F) to when the indoor temperature exceeded the 80°F AC setpoint. The 80°F set-up temperature was employed as a comfortable afternoon indoor temperature when outdoor

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<sup>1</sup> Applications for Large Communities: What is Net-Zero Energy? By Robert Hammon, Ph.D, Adam Neugebauer and Faith Shimamoto.

<sup>2</sup> The specific wall structure was DOW T-Mass, which constituted factory-fabricated walls with 4” of DOW Styrofoam sandwiched between 2” of exterior concrete and 4” of interior concrete. DOW no longer provides this product, but it is available from other sources.

<sup>3</sup> Building America/DOE report, Results of Research Systems for Prototype Homes, dated Oct. 5, 2007, and Building America/DOE report, Results of Advanced Systems Research, pages 23-63, dated Feb. 15, 2008

temperatures exceed 100°F. The goal was to evaluate the performance of each home, specifically the different wall systems, by measuring the coast time each unoccupied home would take to go from the pre-cooled 72°F to a comfort-level constraint of 80°F. Of the three homes, the one with the insulated-mass wall system provided the longest coast period, with SIPs as a close second. Note that all three homes had thermal mass because the uninsulated slab floors were exposed and had no floor coverings that could insulate the mass-floor from the living space. The home with the insulated-mass wall system not only coasted for 12 hours, it experienced an indoor air temperature increase of only 3.5°F during the 12 hour test period from noon to midnight. During this time the cooling equipment was dormant due to the house and mass being pre-cooled to 72°F and the mass moderating the indoor temperature such that the cooling setpoint of 80°F was not reached during the 12 hour peak-cooling test period.

Despite the superior performance of the concrete mass walls in this experiment, Clarum Homes chose to use the SIPs wall system in future construction because, in conjunction with the mass from the floors, it produced a long coast period (almost 12 hours) and cost 48 percent less than the concrete mass walls. Detailed results including temperature and energy measurements over time, and cost-effectiveness are discussed in this report.

## Background

### Borrego Springs Location

The three houses with the same floor-plan but different wall constructions and HVAC systems are located in Borrego Springs, 90 miles northeast of San Diego, California. Figure 1 is a regional map showing the location Borrego Springs in the desert area northeast of San Diego.



Figure 1: Regional Map – Borrego Springs

## Climate

Borrego Springs is located in California Climate Zone 15 and has 1,075 Heating Degree Days (HDD) and 3,843 Cooling Degree Days (CDD), a summary of climate-descriptive data is provided in Table 1. 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. The results of this project should be applicable to other new homes that will be built in similar hot-dry climate areas in the U.S. Southwest.

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

**Table 1: Borrego Springs Climate Data**

## Home Design

Each home has 1,920 sq.ft. conditioned floor area and identical floor plans, shown in Figure 2. The homes are identified both by wall construction and by the names of the streets on which they are located. Because they are located on different streets, the fronts of the homes do not all face the same direction. Two of the homes (East Star, 2x6 wood-framed walls; and Broken Arrow, SIP walls) are front-facing 30° east of south. Country Club, the insulated mass house, faces West. The orientation plays an important role in optimizing the capabilities of the PV systems, but not on the performance of the wall systems in these homes, due to their large overhangs. The 10” thick insulated-mass wall system in Country Club consists of 4” of extruded polystyrene foam sandwiched between two layers of dense concrete material 2” on the inside and 4” on the outside,

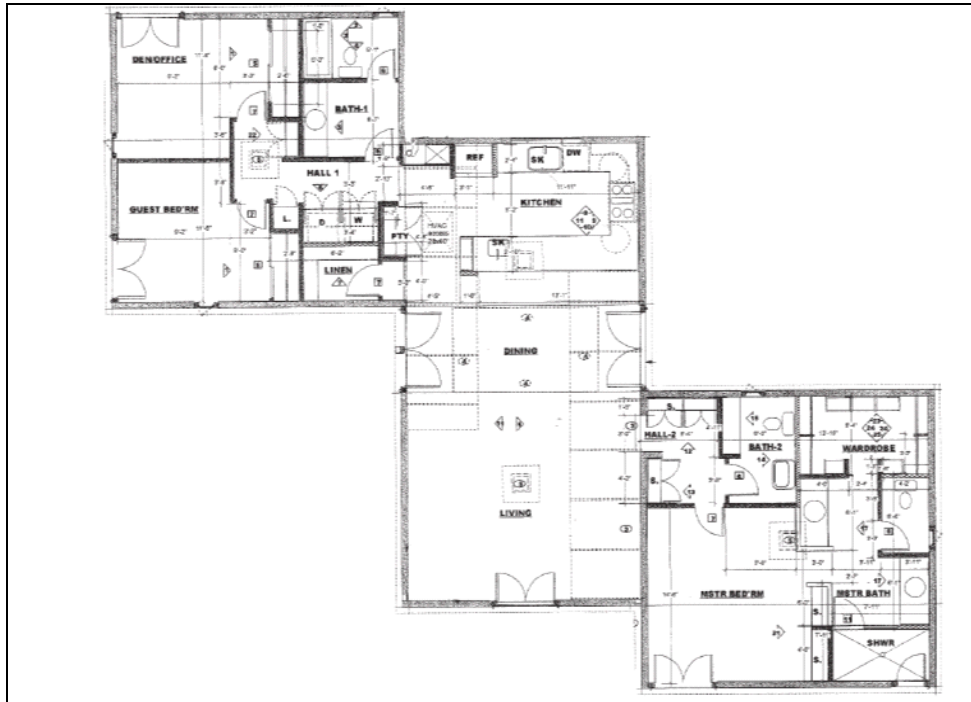


Figure 2: Home Floor Plan

In addition to having identical floor plans, the homes have the same energy features, except for the wall and HVAC systems. Table 2 lists all of the energy features for the three homes.

	Country Club	Broken Arrow	East Star
Roof	R-38 w/ radiant barrier	R-38 w/ radiant barrier	Sprayed in Icynene <sup>®</sup> R-19.8
Walls	Insulated Mass Walls (R-28 equivalent <sup>4</sup> )	6” Structural Insulated Panels (SIP) R-27	2x6 wood-framed with sprayed-in Icynene <sup>®</sup> 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)		

<sup>4</sup> TMASS (R-28 equivalent): 4” of extruded polystyrene foam sandwiched between two layers of dense concrete material 2” on the inside and 4” on the outside

Air infiltration (measured SLA)	2.9	3.3	4.0
HVAC System	OASys Evaporative Cooler + Radiant Floor Heating and Cooling	OASys Evaporative Cooler (SEER 40 equivalent) + Conventional Ducted AC for periods of high humidity (14 SEER AC)	Lennox (21 SEER rating)
Water & Space Heating	Tankless w/ Energy Factor = 0.84 & Space Heating		
Lights	CFLs throughout		

**Table 2: Summary of Energy Features**

### **Research Overview**

Over a two-year time period the Building America consortium, Building Industry Research Alliance (BIRA), led by ConSol, with the assistance of the National Renewable Energy Lab (NREL) and Davis Energy Group (DEG), conducted several experiments in the homes. BIRA's focus was to evaluate each wall system in terms of costs, buildability, energy impacts, and peak reduction. The results of all these experiments are available in the Building America report: Results of research systems for Prototype Homes, dated Oct. 5, 2007, and Results of Advanced System Research, pages 23-63, dated Feb. 15, 2008.

All three homes were instrumented for comprehensive measurement, analysis, and evaluation of the wall systems, cooling systems, electricity demand and use, and environmental conditions. Sensors were installed in the walls of all three homes in the interior, exterior, and in the middle to monitor temperatures and resulting heat flows through the walls.

This report focuses on the comparative peak-reduction impacts of the three different wall systems, by comparing AC coast-periods<sup>5</sup>, cooling energy use, and construction costs. The peak-reduction experiment conducted in August of 2006 consisted of a thermostat-control strategy as follows:

- pre-cool each home to 72°F from midnight to noon, a period that is both during utility off-peak periods (when time-of-use rates are lower) and time periods when compressor efficiencies are higher due to cooler outdoor temperatures; and
- at noon set up the indoor setpoint temperature for cooling to 80°F, a temperature deemed to be at the top of the comfort range for desert conditions with outdoor temperatures well in excess of 100°F.

<sup>5</sup> Actual electricity-peak reduction (kW) was measured but is not used here for comparison between the different wall systems because the homes also had very different cooling systems, making kW differences a composite of envelope and HVAC system impacts. Thus using kW was not a good measurement for comparative analysis of peak reduction.

The results of the peak-reduction control strategy were compared in the three homes by measuring the time each home took to go from the pre-cooled temperature of 72°F to the set-up temperature of 80°F (coast period). This provided a direct comparison of the impacts of the wall systems on reducing summer peak electricity demand (kW) due to space cooling in the homes, each of which had moderate thermal mass from the exposed-slab floor. This approach avoided complications that would have arisen due to the different HVAC systems in the three homes if actual electricity demand (kW) were used to directly determine peak reduction.

In addition to evaluating peak reduction, energy (kWh) usage was compared between the peak-reduction control strategy and a more typical thermostat control strategy of constant indoor temperature (78°F cooling setpoint). Daily kWh was used for comparison for each home between the different control strategies, but not between the three homes, because of the different cooling systems in each. This comparison of the energy use during the pre-cooling, peak-reduction days to the energy use for the constant 78°F days was done to determine whether the pre-cooling approach reduced peak at the cost of higher kWh use resulting from the pre-cooling.

### **Results of Pre-Cooling Experiment**

Three types of wall systems were studied: insulated mass walls (10" wall); structural insulated panels (8" SIP wall); and conventional 2x6 16" on-center wood framing with spray foam insulation, otherwise identified as the control home. Of these three, in terms of maintaining comfort without additional cooling through the peak-electricity period, the insulated-mass wall system performed best. Not only did the home coast for the entire 12 hour test period, the indoor air temperature changed a mere 3.5°F over the entire 12 hour coast-period from noon to midnight, during which time the cooling equipment was dormant.

The SIP wall system performed well, but not as well as the high-mass walls. During the 12 hour coast period from noon to midnight the SIPs-walls house indoor temperature went from the pre-cooled 72°F to the setpoint 80°F (8°F) in 10 hours. The stick-frame 2x6 wall home experienced the 8°F temperature rise over a 4 hour period. All three homes performed better than would most standard stick-framed homes in California – that is, they coasted for several hours during peak summer conditions with high outdoor temperatures of over 100°F) – because of the exposed mass in the floors, and the attention to detail during construction (quality insulation and air sealing).

The reason the insulated mass wall home performed the best in this experiment was due to the high thermal mass in the home. The thermal mass was charged (cooled) during the night and morning hours by cooling the indoors with the air conditioning system, then during the hottest part of the day, the electricity-peak period, the thermal mass absorbed heat, allowing the house to heat up at a much slower rate than a typical house with little or no thermal mass.

In areas with large diurnal temperature swings during the summer – cool night and hot days, such as parts of the California Central Valley – the mass could be cooled by bringing in outdoor air during the night, making the pre-cooling/coast control strategy very cost effective. While summer days in Borrego Springs are not conducive to using outside air for night cooling, this is a good approach for the swing seasons in Borrego Springs.

In terms of AC peak, the insulated mass wall and SIP homes both had zero cooling-electricity demand during time periods that exceeded the duration and included typical utility peak periods (typically mid-afternoon to early evening, such as 4 – 7 PM). These extensive zero cooling-electricity periods occurred because the AC remained dormant from the 12 PM thermostat set-up until 10 PM (for the SIPS-house: “Broken Arrow”) or midnight (insulated-concrete walls, “Country Club”). However, the 2x6 house required cooling from the AC system around 4 PM because the indoor temperature exceeded the 80°F thermostat setpoint. The pre-cooling results are detailed below in both time-temperature graphs (Figures 3-5), and kW and kWh impacts (Table 3).

This pre-cooling, peak-coasting thermostat-control approach has the added benefit that cooling is done when the outdoor temperature is at its mildest, when compressor-type cooling systems are the most efficient. To determine whether the precooling strategy saved or used more energy, another control-strategy was examined. In this experiment we compared alternative days when, rather than pre-cooling and coasting, the cooling setpoint was set at 78°F and held there for 24 hours. As shown in Table 3, the energy (total cooling load, kWh) used for the pre-cooling strategy was essentially equivalent compared to the more typical, constant-temperature thermostat control strategy (78°F setpoint for this experiment).

	SIP (“Broken Arrow”)		Mass Walls (“Country Club”)		2x6 Wood-Framed (“East Star”)	
Scenario	Pre-Cooling	78°F Setpoint	Pre-Cooling	78°F Setpoint	Pre-Cooling	78°F Setpoint
Wall System	SIP		Insulated Mass Wall		2 x 6 Wood-Framed with Icynene foam insulation	
Cooling System	OASYS + Conventional AC		OASys + Conventional Ducted AC (14 SEER equivalent)		Lennox 21-SEER AC	
Total Cooling Load (kWh)	23.3055	22.5165	30.282	33.861	23.889	23.4675
On-Peak Load (kWh)	0.00	13.269	0.00	16.083	0.7335	13.914

<b>Off-Peak Load (kWh)</b>	23.3055	9.2475	30.28	17.778	23.1555	9.5535
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**Table 3: Pre-cooling Energy Use**

The cost for these wall system types are listed in Table 4. The incremental costs incurred by Clarum for the insulated-mass walls and the SIPs walls for these homes were roughly 75 percent and 27 percent more, respectively, than that of the 2x6 frame house, all in Borrego Springs. However, we anticipate that the incremental costs for the alternative wall systems if used in volume (e.g., a subdivision or community) would be substantially lower as with virtually any construction product used in volume. There also can be cost savings due to construction time savings (and the reduced loan carrying costs); these were not measured nor estimated in this analysis.

<b>Energy Features</b>	<b>Site</b>	<b>Costs</b>	<b>Costs Compared to 2x6 Framed</b>	<b>Percent Increase</b>
<b>Insulated Exterior Mass Walls</b>	Country Club	\$99,762	\$42,520	74%
<b>SIPS Exterior Walls</b>	Broken Arrow Way	\$72,670	\$15,432	27%
<b>2x6 16”oc Wood-Framed Exterior Walls</b>	East Star	\$57,242	N/A	N/A
<b>HVAC</b>				
<b>Oasys 2-Stage Evaporative Cooler</b>	Country Club	\$17,923	\$2,077	13%
<b>Oasys w/Conventional Ducted A/C</b>	Broken Arrow Way	\$21,009	\$5,163	33%
<b>Lennox 21-SEER</b>	East Star	\$15,846	N/A	N/A

**Table 4: Builder Costs - Comparisons to East Star 2x6 Framed/21 SEER Lennox**

Figures 3, 4 and 5 are the pre-cooling results (temperature and kWh/hr vs. time) of the three wall types on a summer hot day (August 16<sup>th</sup>) where outside temperature reached 105°F. The insulated mass wall home (Figure 3) coasted with AC off for twelve hours with a temperature increase of only 3.5°F. The SIPs house (Figure 4) was able to coast for roughly ten hours from the pre-cooled condition of 72°F to 80°F when the AC turned on,. The 2x6 frame house went from 72°F to 80°F in four hours as shown in Figure 5.

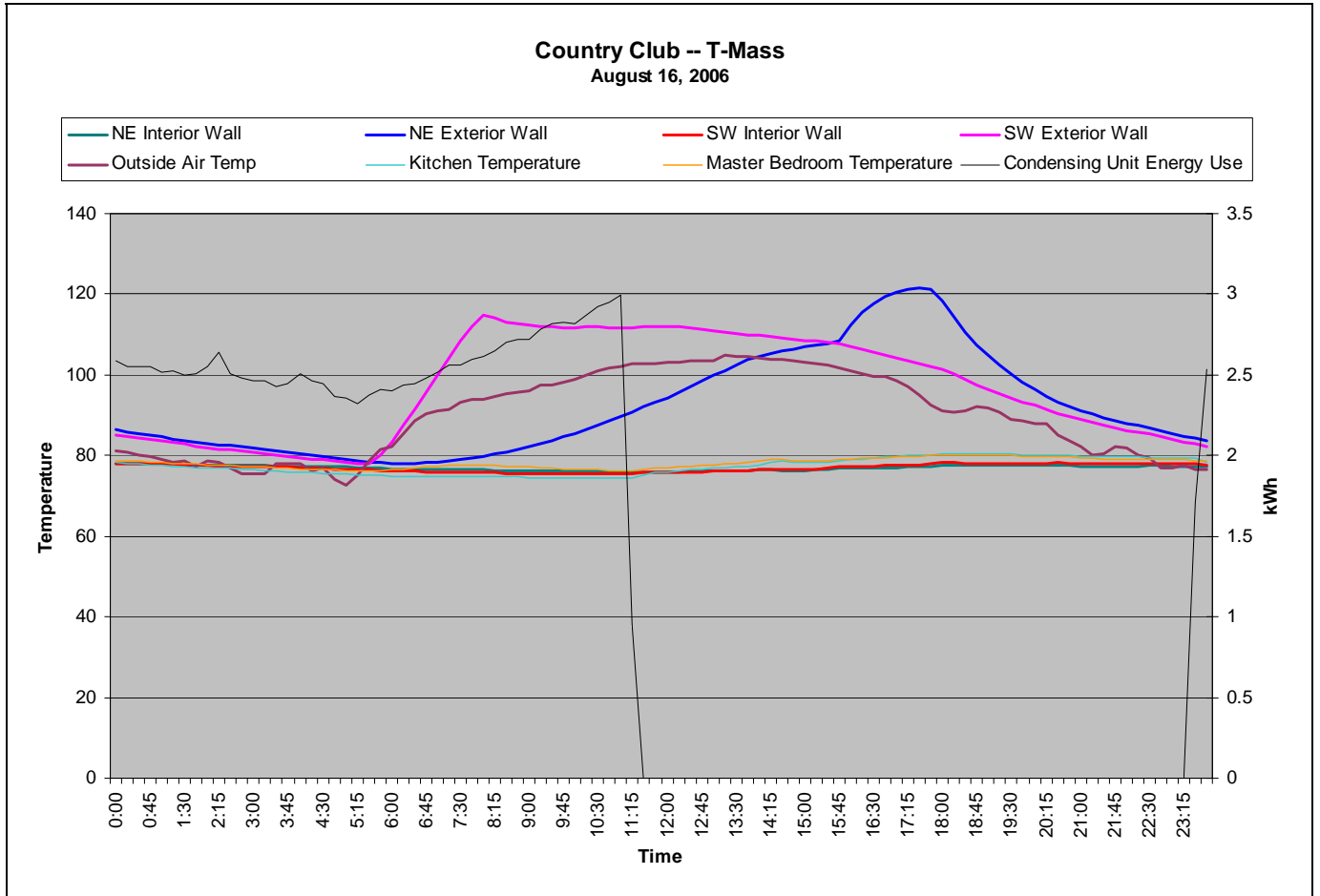


Figure 3: Pre-Cooling of Insulated Mass Home (Temp and kWh/hr vs. Time of day)

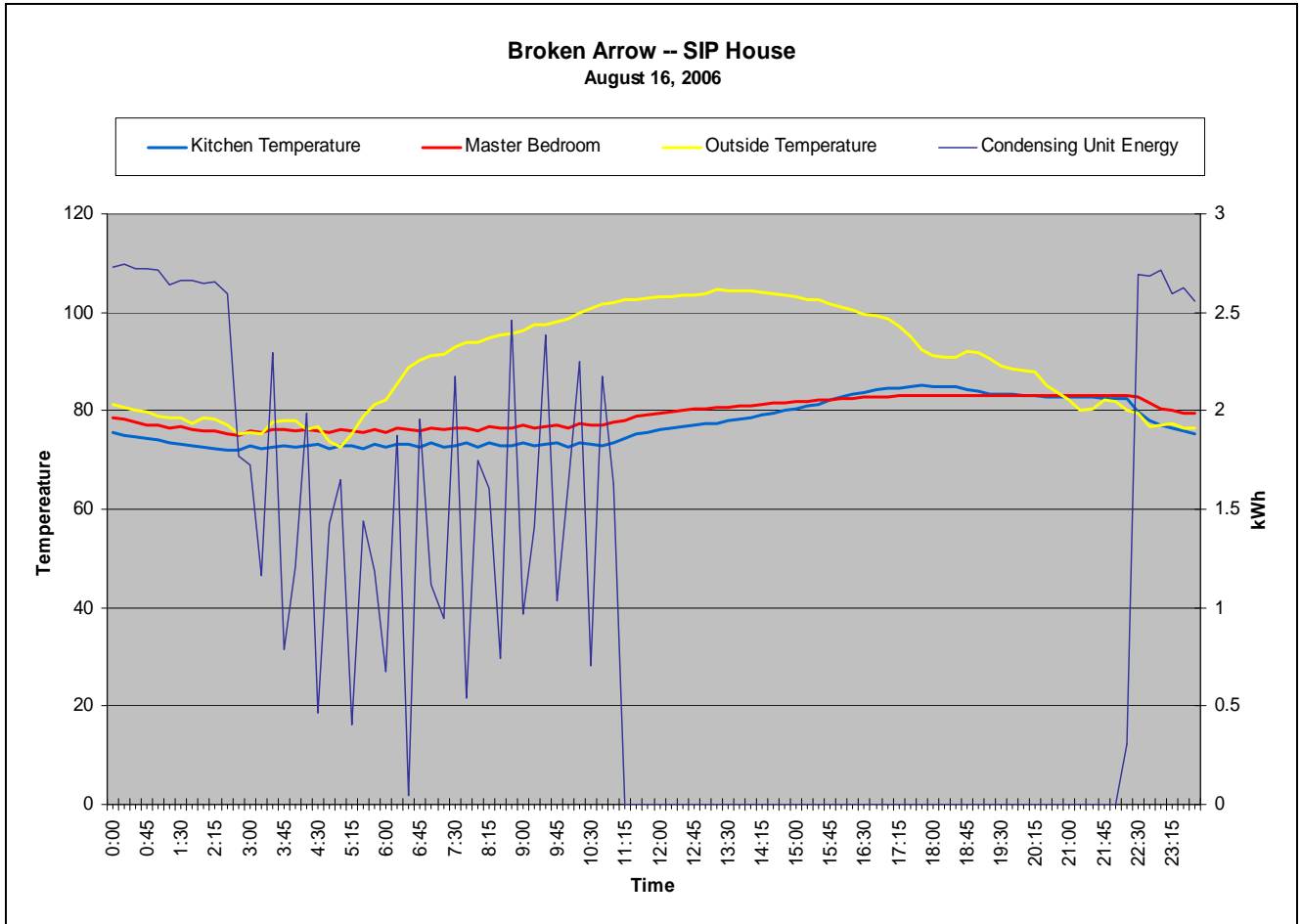
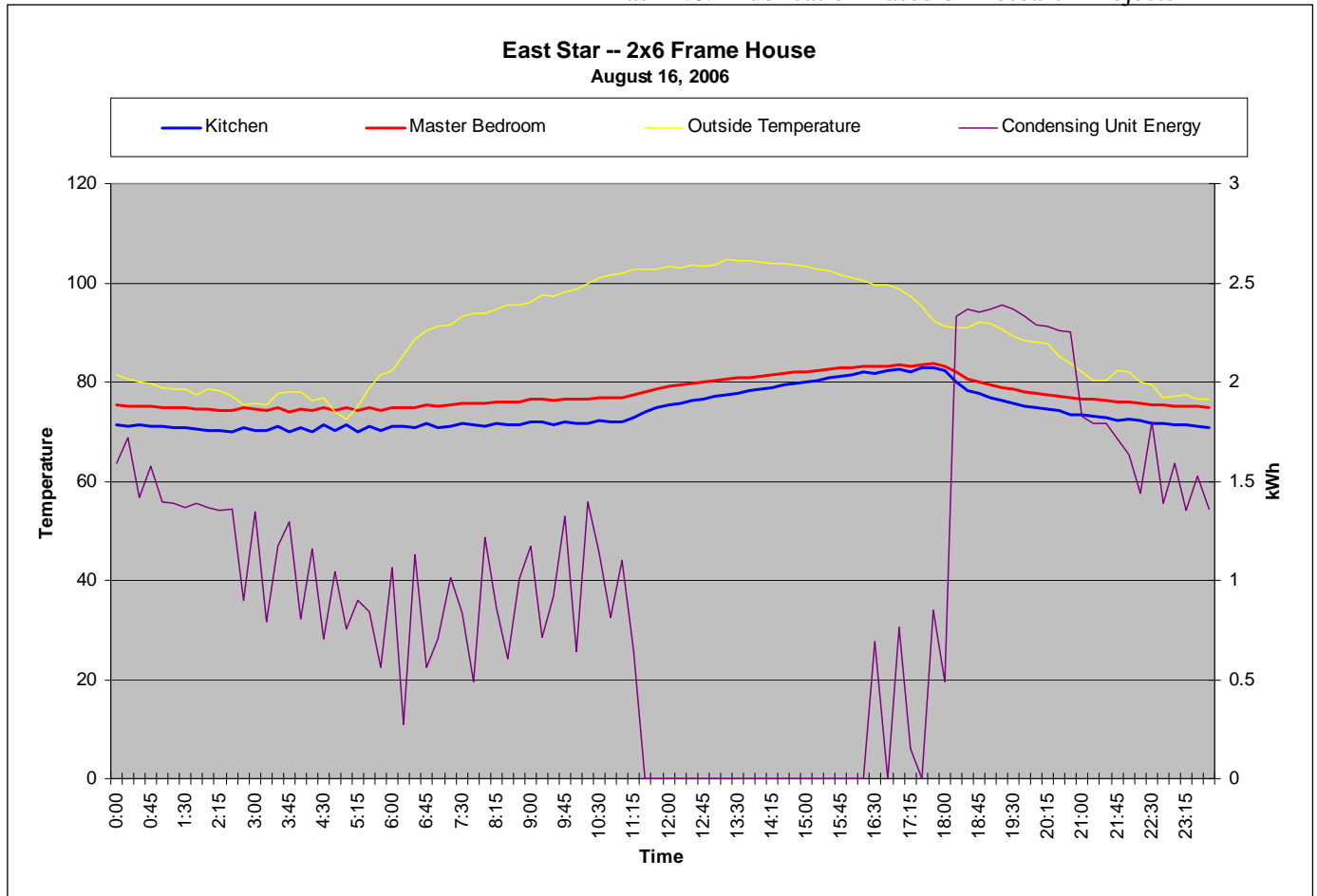


Figure 4: Pre-Cooling of SIP Home (Temp and kWh/hr vs. Time of day)



**Figure 5: Pre-Cooling of 2x6 Home (Temp and kWh/hr vs. Time of day)**

## Conclusions

Out of the three wall systems (insulated mass, SIPs, and 2x6 wood-framed with foam), the insulated-mass wall preformed the best in our peak-reduction experiment, providing a full 12 hour coast period<sup>6</sup> during which the indoor temperature increased a mere 3.5°F. The home with SIPs walls provided a nearly 12 hour coast period, with the indoor temperature covering the allowed 8°F increment (from 72°F to 80°F) in 10 hours. The home with wood-framing (2x6, 16" on center, with imperfection-free Icynene-foam insulation) fared worst, but took 4.5 hours for the indoor temperature to rise the allowed 8°F.

The results of this experiment are encouraging for management of summer electric-peak loads, which are primarily driven by residential air conditioning. However, construction costs are an issue: the insulated concrete mass wall system was the most expensive system per home, roughly 47 percent more than SIPs and 74 percent more expensive than the 2x6 stick frame. The costs of these alternative wall systems will need to come down significantly, as they should when used in volume, for them to be used by production builders.

<sup>6</sup> "Coast period: time duration from 12 noon when AC setpoint was set-up from 72°F to 80°F to when the indoor temperature exceeded 80°F, and the AC turned on. No electricity was used for cooling during the coast period.

In that regard, Clarum Homes will choose the SIPs wall system for their next foray into the Southwest, when they will be seeking a cost-effective, yet highly efficient “green building” strategy. This decision was based on SIPs’ excellent thermal performance in the experiments detailed in this report, and their lower cost compared to the high-mass walls.