Whole House Research Performance Results

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T-Mass Wall Performance and Utility Impact

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Introduction

During the past year, the BIRA team has completed two sets of experimental homes using DOW Chemical Company's 10" T-MASS®™ wall systems. The first set, located in Las Vegas, NV, were built by Pinnacle Homes. The second set, located in Borrego Springs, CA, were built by Clarum Homes. This paper presents an evaluation of the comparative wall performance for the two Las Vegas homes and their impacts on utilities.

Background

Pinnacle Homes constructed two side-by-side homes, one with conventional 2x4 wood frame construction and the other with DOW Chemical Company's 8" T-MASS®™ wall systems and other added energy efficient features with a large 5.0 kW DC PV system. (See Appendix C for a comparison of energy features.) BIRA partners are monitoring these side-by-side homes along with the University of Nevada at Las Vegas (UNLV), and Paragon Consulting (PC).

Appendix A contains a detail description of the T-Mass and conventional wall system construction.

Location

The two prototype homes are located on adjacent lots in The Vinings Pinnacle Homes project in Las Vegas, Nevada. The Las Vegas regional map and site locations are shown in the figures below.

Figure 1: The Vinings Pinnacle Homes Site -- Las Vegas, Nevada

Figure 2: The Vinings Lot Locations

Solar Orientation

The homes are perfectly oriented for solar. They both face north with living areas on the back of the homes and the PV system on the T-Mass house facing south for maximum annual production.

Figure 3 Wood frame house on the left and T-Mass on the right.

Climate

The climate (TMY2 data) for Las Vegas, Nevada is shown in Table 1, below:

Heating Degree Days	2,499 HDD
Cooling Degree Days	3,201 CDD
Average Maximum Temperature	82.4ºF
Average Temperature	62.7ºF
Average Minimum Temperature	43.0ºF
Summer Outside Design Temperature	110ºF
Winter Outside Design Temperature	30ºF

Table 1: Las Vegas, Nevada Climate Data

Research objectives

The wall systems of both houses have sensors to monitor the wall temperatures on the outer surface, the inner surface and on both sides of the insulation. Additional monitor points are also available in both houses (See Appendix B for a complete list). For this study, the thermal performance of the two wall systems will be analyzed and compared to see which house performs better under the extreme hot-dry climate in Las Vegas.

Another research objective is to assess the benefits of utilizing the large heat capacity and energy conductivity of the interior width of the concrete wall systems (in comparison to conventional home construction) to store heat in winter and coolness in summer. These thermal mass characteristics of concrete walls have the potential to play a significant role in reducing energy bills using a Time-of-Use rate structure. In summer, the cool outside air and/or air conditioning during off peak times can be used to cool the house through the night when electricity is less expensive. During the day, data will be collected to determine if the cooled concrete walls will absorb enough heat to enable reasonable comfort to be maintained in the house with minimal, or no, use of air conditioning during peak hours when electricity is most expensive.

The wall systems will be evaluated to determine their effectiveness in reducing summer peak loads in these very hot climates. The potential savings of the walls in summer is considerably more valuable to homeowners and beneficial to utilities.

Preliminary studies

A high thermal mass (exterior walls and floor) coupled with nighttime cooling to discharge (cool) the mass, can result in significant energy and cost savings in homes that can benefit both the home owner and utility. The thermal mass benefits 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.

In the Las Vegas area, air conditioning costs represent a majority of the overall energy costs in a residential home. The T-Mass home with PV (Near PV) is designed to reduce those air conditioning costs by reducing the overall cooling load on the house and by feedback electricity to the utility. One such load reducing strategy chosen is to replace the standard frame wall with a more massive Dow T-Mass concrete wall. Simulation shows that there is a significant reduction in the amount of heat that is transferred through the walls of the T-Mass house when compared to the house with a normal wall construction.

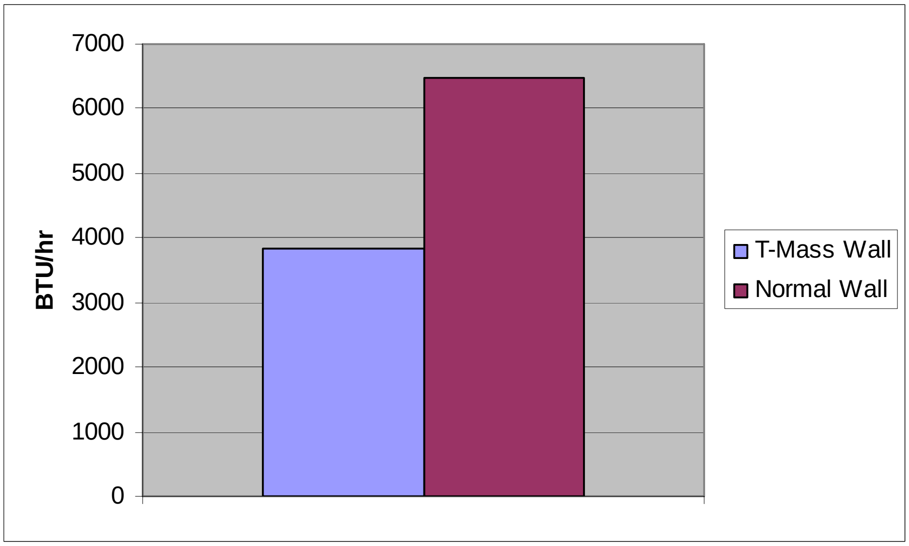


Figure 4: Average Wall Loads

Figure 4 shows that there is an average reduction in the load from the walls of approximately 40 percent, even though the actual R-value of the two walls is nearly the same at R-12. This indicates that the mass of the wall does help to reduce the heat transferred to the inside of the home. For a normal stick frame home to accomplish this, the overall R-value of the home would have to be at least R-18. This overall R-value includes both the framing, insulation and inner and outer layer of the wall. Since framing reduces the effectiveness of the insulation that is placed in the cavities, the R-value of the insulation would have to be significantly higher. To achieve that overall value of R-18 the insulation, assuming it is blanket and batt, would have to be rated as an R-30 to 35. This could also be accomplished by placing a foam board insulation on the exterior in conjunction with blanket and batt insulation. Examining the total peak load in the house, which includes all loads due to roofs, windows, etc, which is shown in Figure 5, there is a reduction of 10 percent between the house with the normal walls and the T-Mass house.

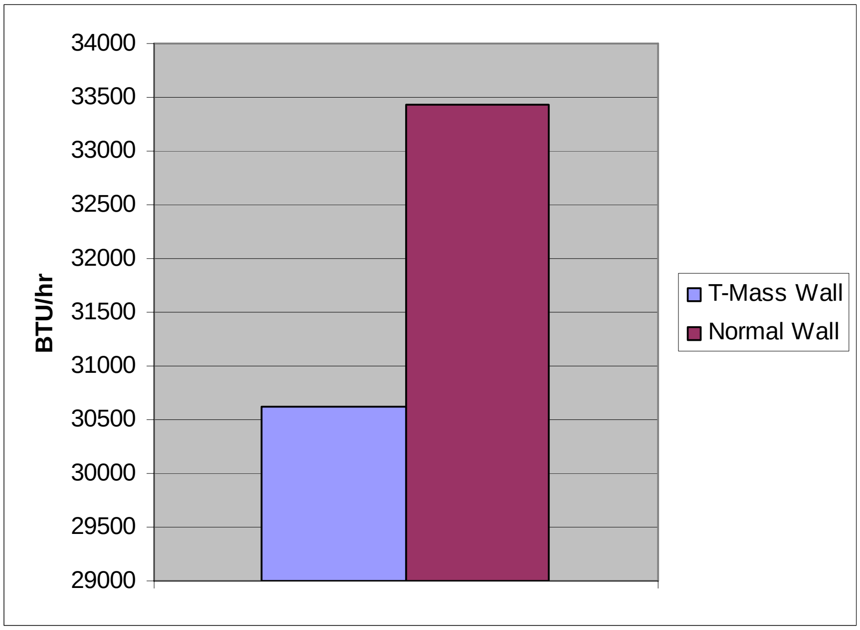


Figure 5: Total Peak Loads

This reduction can lead to potential upfront savings from the fact that the home with the T-Mass walls could be conditioned with a unit that is 0.5 tons smaller than the conventional home. The T-Mass home is also able to shift the peak loads to later times in the day. It has been shown in short term testing of another T-Mass house that the T-Mass home can be pre-cooled and coast, or use not air conditioning through the peak demand period. Depending on how much utility companies charge for electricity usage during on peak hours this shift in peak loads has the ability to lead to substantial savings, in addition to the reduction of overall air conditioning usage. The other benefit of T-Mass in homes is that if cooled the mass will provide a lower mean radiant temperature and enhance comfort in summer. In winter, T-Mass warmed by winter sun during the day will provide higher mean radiant temperatures and enhance comfort under the winter circumstances of comfort too.

Research Methodology

The research will monitor the wall systems to compare their performance against each other and to determine their contribution with respect to the whole house energy savings. The wall systems will also be compared against each other with the house being pre-cooled at night and being allowed to coast through the day.

Results

Wall Performance

Figure 6 and 7shows data from the interior and exterior thermocouples embedded in the south walls of the Near ZEH and Baseline House (respectively) for a 24-hour period on August 11, 2006. The ambient outdoor temperature is also plotted on these graphs. The graph on the right

(Baseline) shows the exterior thermocouple (pink) goes from 80° F to a maximum of over 120° F. As the heat flows through the wall several hours later, the interior wall temperature (green) goes from 78° F to96° F. Comparing that to the graph on the left (Near ZEH), the interior wall temperature has very little variation as the exterior wall temperature ranges from 83° F to 102° F. Concrete has high conductivity and high thermal mass, so sunlight and heat absorbed at the surface is conducted laterally and into the interior and absorbed with the high heat capacity, moderating the temperature fluctuations. Between the helpful rolls of both the exterior 2" of concrete and the interior 4" of concrete significant reductions to peak cooling requirements can be achieved.

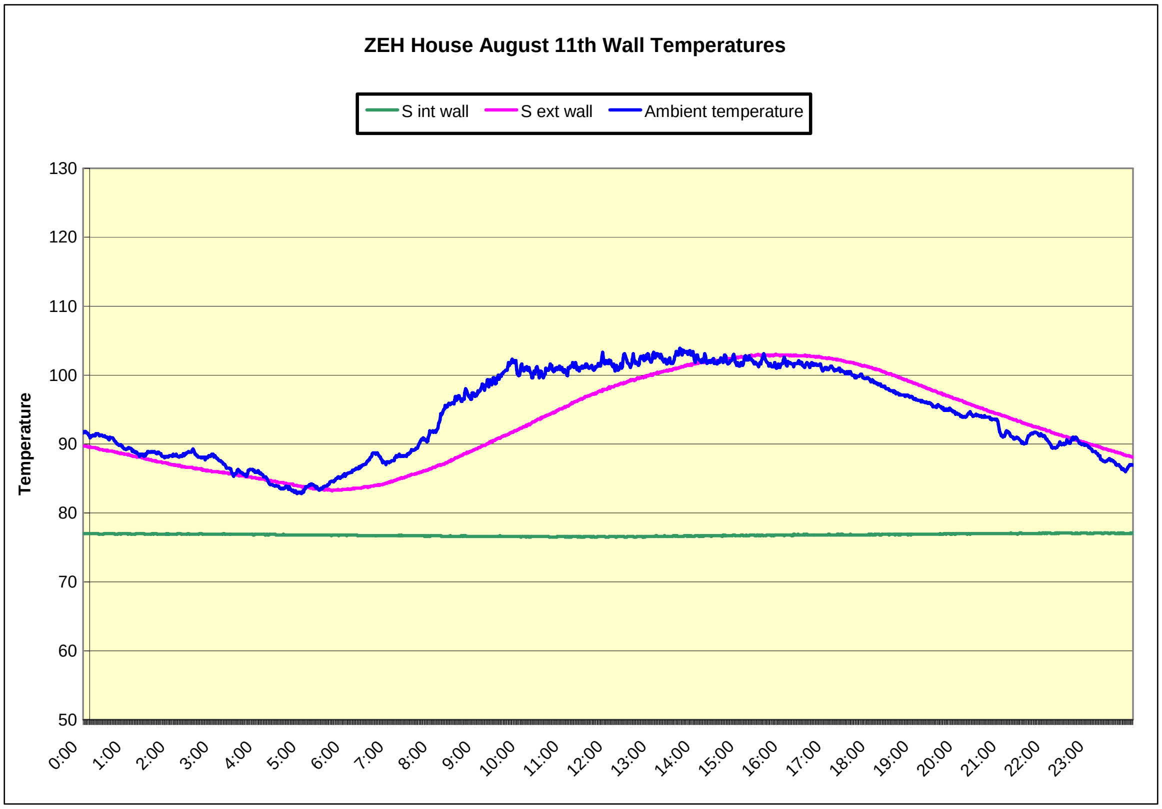


Figure 6: Exterior and Interior Wall Temperatures of the Near ZEH August 21, 2006

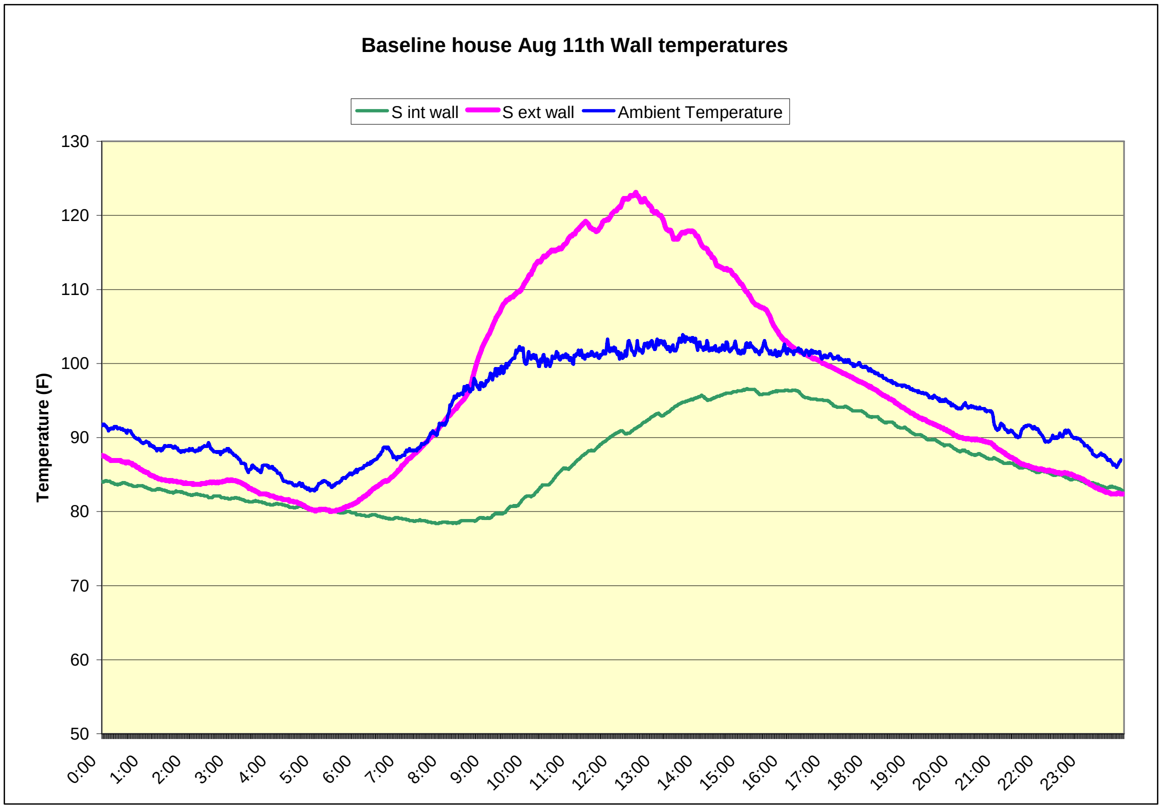


Figure 7: Exterior and Interior Wall Temperatures of the Baseline
August 21, 2006

Figure 5 and 6 also confirms that the T-Mass walls are not as affected by the large temperature swing of outdoor air temperature. The temperature of the indoor wall remains almost constant no matter how the temperature on the outside of the wall changes during the day. The constant temperature of the interior of the wall will helps to maintain the indoor ambient temperature stable and more comfortable.

Another indicator of wall performance is the temperature difference between the interior and exterior of the walls. Table 2 shows the average temperature fluctuation the interior surfaces of the north and west walls of both houses experiences over a day during the winter months of October 2005 to February 2006. The Near ZEH walls vary only by a degree or two where as the Baseline walls vary from three degrees up to 7.45 degrees. This shows that the walls are functioning well during the winter months.

Average Daily Temperature Range (°F)	Zero Energy Home		Baseline Home	
	North	West	North	West
October	2.09	2.25	7.27	5.38
November	1.51	1.76	7.32	5.65
December	1.06	1.03	5.17	3.18
January	1.16	1.20	6.02	4.01
February	0.99	1.33	7.45	5.35

Table 2: Monthly Average Daily Temperature Range

Figure 8 compares real usage data for the AC power use for both the Near ZEH and Baseline homes. The Near ZEH home, with its concrete T-Mass walls, has the ability to reduce total power use and shift the peak cooling loads to later in the day when electricity costs are reduced.

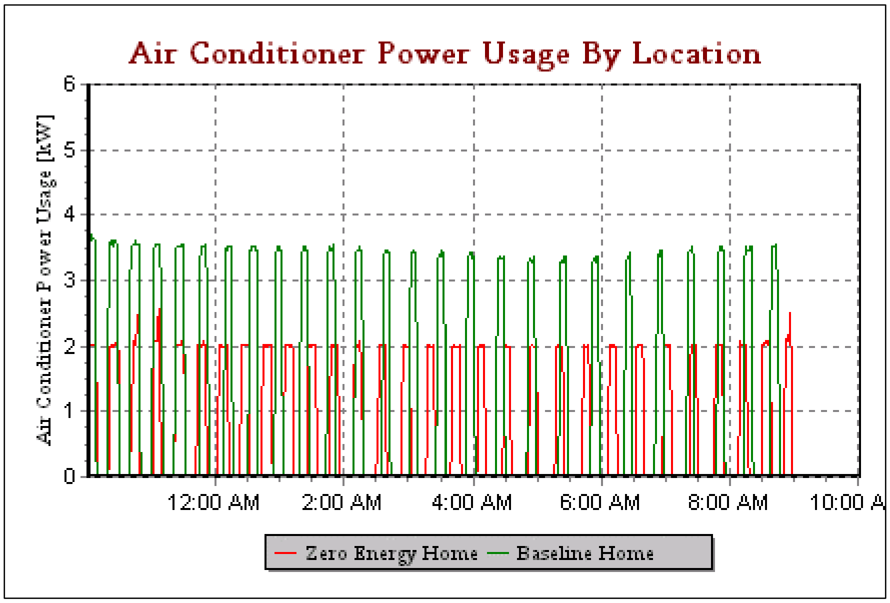


Figure 8: Near ZEH vs. Baseline House AC Power Usage

Power Rates

The Near Zero Energy Home is serviced by Nevada Power and is subject to its rate structure. For single family homes, Nevada Power offers two types of rate structures; the Normal Residential Single-Family Rate, shown below, and the Time-of-Use Residential Rate. If selected, the Normal Single-Family Rate remains in effect all year.

Residential Single Family Rate	
Customer Charge, per KWH	$0.08763
Deferred Energy Accounting Adjustment All KWH, per KWH	$0.00578
Customer Charge, per meter (per month)	$6.00

Table 3: Normal Residential Single Family Rate

Nevada Power's Time-of-Use Rates are shown in the table below. Summer rates are in effect from June through August. The on-peak hours are 1pm to 7pm. This rate structure is designed for those who are not home during the day, as the use of electrical devices including the HVAC system will be significantly reduced. In addition to evaluating how well the Near ZEH home can offset loads when compared to the baseline home, the effect of the two different rate structures are compared.

Time Rate of Use Residential Rate	
Summer On Peak, per KWH	$0.16030
Summer off Peak, per KWH	$0.06617
Winter all periods	$0.07139
Deferred Energy Accounting Adjustment All KWH, per KWH	$0.00578
Customer Charge, per meter (per month)	$7.30

Table 4: Rate of Use Residential Rate

Since Nevada Power only charges for Peak kWh in the summer, the Peak kWh were only calculated from June-August. This simulation was done with the cooling system in operation at all times maintaining an indoor temperature of 75° F.

Figure 9 shows the Peak and Non-Peak kWh for both the Near ZEH and Baseline home. As shown, the Zero Energy Home does a good job of shifting the load to off-peak hours, especially in the months of July and August. Note that in June, the Baseline home uses less Peak kWh than the Near ZEH. In total, the Near ZEH home uses about 14.5 percent less energy for cooling during the summer months than the Baseline home.

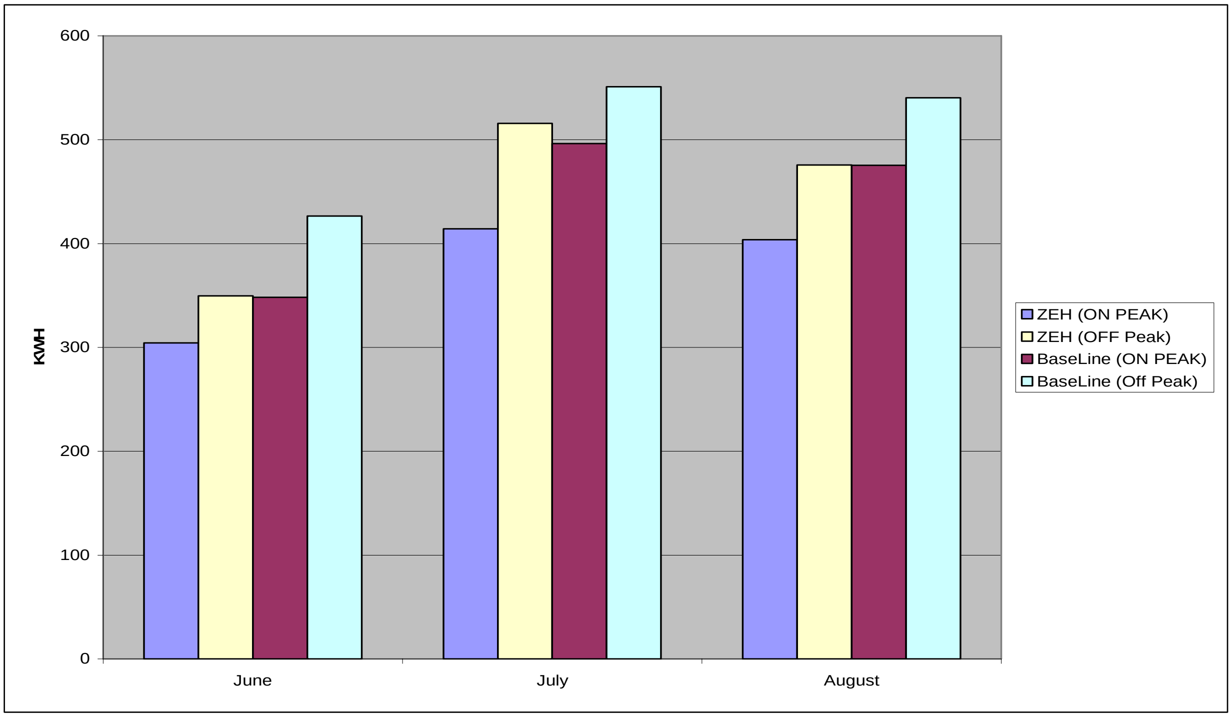


Figure 9: Peak Vs Non-Peak kWh Used

To evaluate what this energy use costs in actual dollars, both the Normal Residential Rate and the Time-of-Use Rate were applied. These results, shown in Figure 10, indicate that using the Time-of-Use rate structure actually results in higher monthly costs than using the Normal Residential Rate for both homes. Although the Near ZEH does a better job of offsetting the peak charges, it is not enough to overcome the cost of using the Time-of-Use structure. Since the Time-of-Use structure was devised for those who completely shut down or lower their cooling system and overall electrical usage, this is not unexpected.

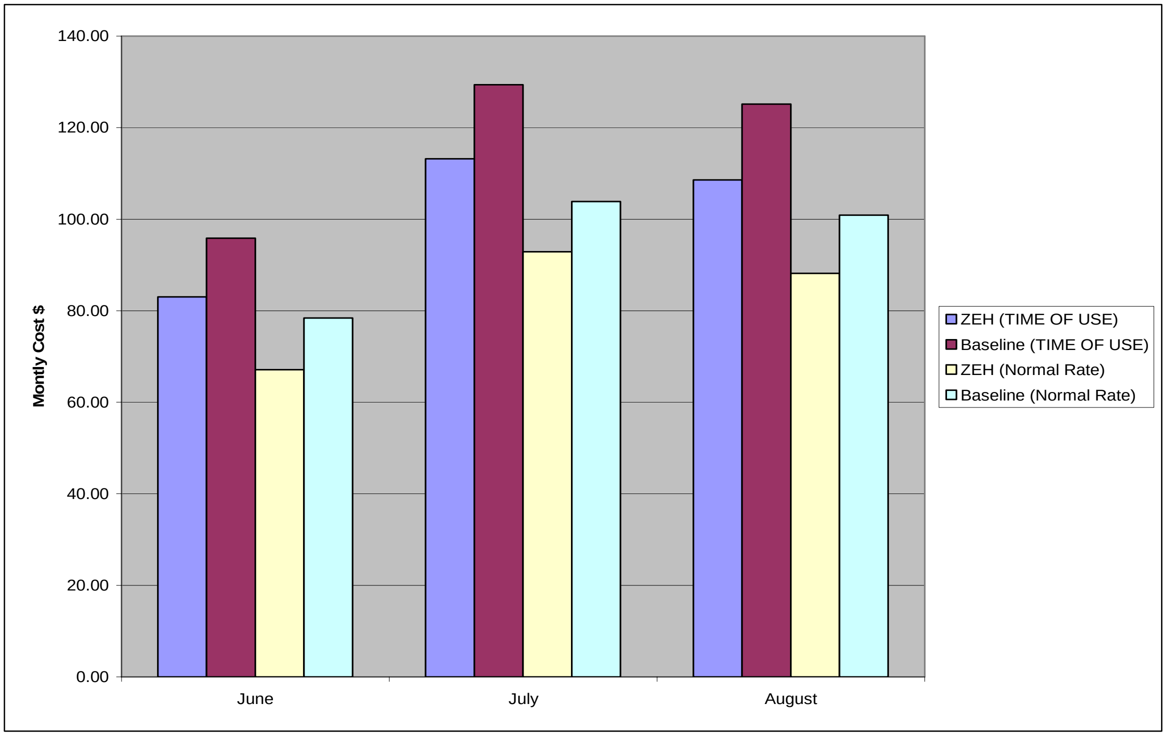


Figure 10: Energy Rate Comparison

Since these rate structures are in effect for the entire year, with the Time-of-Use having a lower rate for the winter, it is important to look at the energy costs for the entire year. Figure 11 shows the total kWh used for cooling for both homes over an entire year.

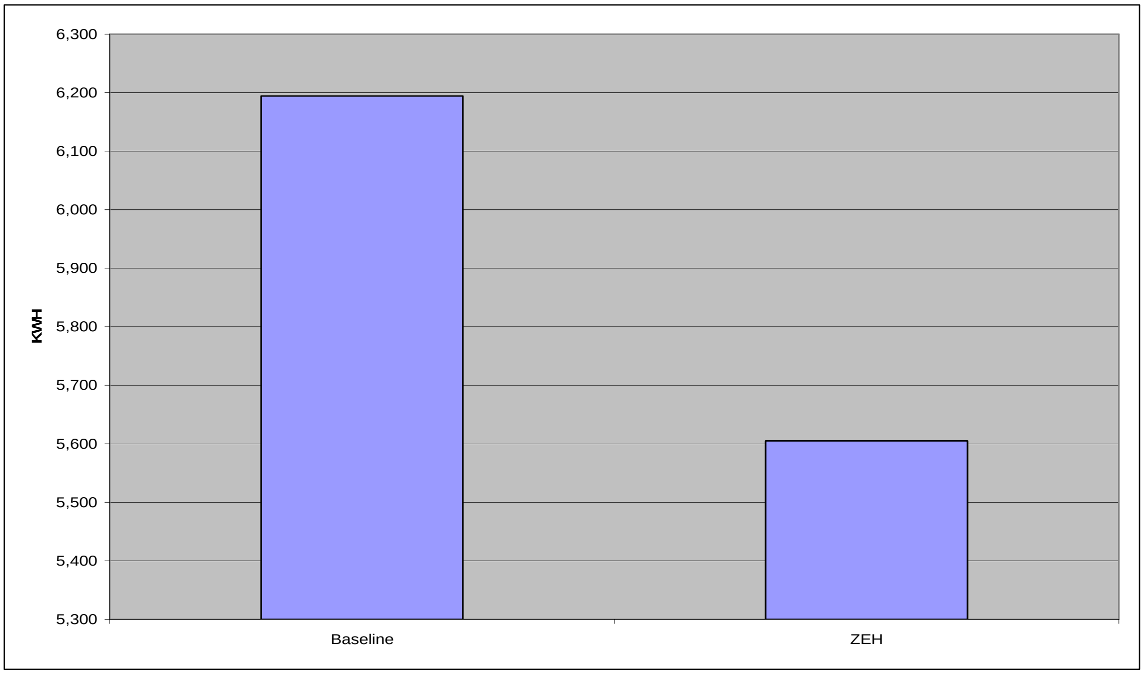


Figure 11: Annual Cooling Energy Use

Table 5 shows the cost impact of applying the two rate structures for the entire year. This indicates that the Time-of-Use Rate costs more for either home on an annual basis than the Normal Single Family Residential Rate. However, the Near ZEH cost is only 1 dollar more per year. If the Near ZEH home were put on a cooling schedule, for example shutting down or lowering the cooling system from 1 to 4 PM during the summer, there would be a greater savings than if the same schedule were applied to the baseline home. If the Nevada Power fee of $1.30 per month for the Time-of-Use Rate were discontinued, this cost structure would be less for the entire year, even with the air conditioning system running at all hours.

	Normal Single Family Rate	**Time Of Use Rate**
Near ZEH	$530	$531
BaseLine	$585	$593

Table 5: Annual Cooling Energy Cost

Conclusions

Real AC power usage data for both the Near ZEH and Baseline homes indicate that the Near ZEH home, with its concrete T-Mass walls, has the ability to reduce total power use and shift the peak cooling loads to later in the day when electricity costs are reduced. Monitored wall performance also confirms that the T-Mass interior walls remain more stable, providing a more stable indoor ambient temperature and cooler mean radiant temperature, enhancing comfort.

In addition to reduced total power use and peak shifting, properly managed energy conservation (e.g. setback thermostats) can multiply the benefit of the rate structure. TOU rates while slightly more expensive under Nevada Power’s current rate program, can be made an effective energy conservation tool when combined with a consumer program that includes setback thermostats and reduced program fees.

When a strategy of shifting to off peak power is considered in combination with PV production, the economic benefits to the home owner and utility and be greatly enhanced, particularly in the case of this prototype home with its 5.0 kW DC PV system.

Appendix A: Wall Construction

T-Mass Wall construction

The main feature of the T-Mass wall is its ability to effectively use the high thermal heat capacity of concrete to shift timing of the cooling loads to off peak hours when power rates are lower in summer. The T-Mass wall's high thermal heat capacity also serves well to store heat from sun shining in windows on winter days for warmth provided back to occupants through the night. The large heat capacity of the concrete allows the wall to absorb and store more heat than a frame wall and then radiate it back to the inside when the inside temperature drops in the evening. In the summer, cooling the mass at night with outside ventilation air or off peak cooling with AC enables the T-Mass to act as a "heat sink" absorbing heat during the heat of summer days and providing a lower mean radiant temperature than a wood frame home with drywall. The Styrofoam insulation shown in Figure 12 in between the two layers of concrete (4" inside and 2" outside) helps to minimize between inside and outside.

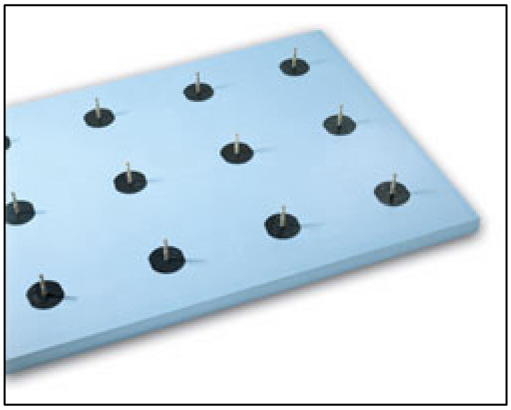


Figure 12: Styrofoam insulation

The Styrofoam is connected to the concrete with connectors made up c of 76% glass fibers and 24% vinyl ester polymer, The connectors have a low thermal conductivity and do not cause thermal bridges or energy/vapor leaks, and are effective in eliminating thermal loss through the wall. The T-Mass wall is designed to work well in an area such as Las Vegas where there are large temperature swings between night and day. This can in lead to a substantially larger equivalent performance R-value when compared to the actual R-value based upon the material properties.

Figure 13 shows a cross section of the wall with the insulation between the two layers of concrete.

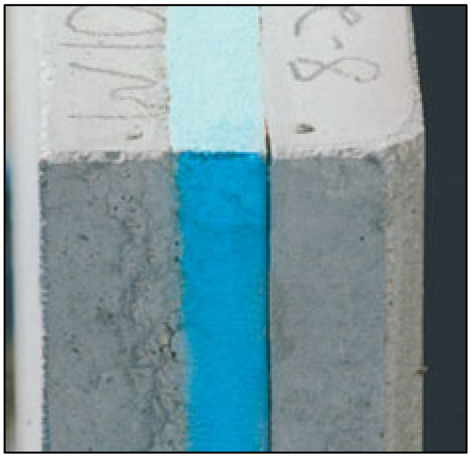


Figure 13: T-Mass Wall cross-section

The concrete used in this wall is taken to have a density of 130 lb/ft3 and a conductivity of 1.04 Btu/hr-ft2-F per inch. The specific heat is taken to be 0.22 Btu/lb*F. The outer wall has 2inches of concrete while the inner wall is composed of 4 inches of concrete. The interior insulation is composed of 2 inches of STYROFOAM extruded polystyrene and polyisocyanurate rigid board insulations. The insulation is rated to have an R-value of 5 hr-ft2-F/BTU per inch, and a specific heat of 0.27 Btu/lb*F. The wall was also modeled to have standard 0.5 inch dry wall on the interior and 1 inch of stucco on the exterior. Including interior and exterior film coefficients the overall R-value of the T-Mass Wall was found to be 12.15 hr-ft2-F/Btu. The overall weight of this wall was found to be 77 lb/ft2.

Standard Wall

The standard wall construction is based on frame construction, 2 X 4ft 16 in on center. The insulation installed between the framing is R-13 Blanket and Batt insulation. As with the T-Mass wall, the exterior is covered by stucco and the interior by dry wall. With the same interior and exterior film coefficients as well and taking into account the loss due to the effect of framing the R-value for this normal wall was found to be 12.22 hr-ft2-F/BTU. The overall weight of this wall is found to be 14.6 lb/ft2.

Appendix B: Floor Plan and Sensor Schedule

Floor Plan with Sensor Locations

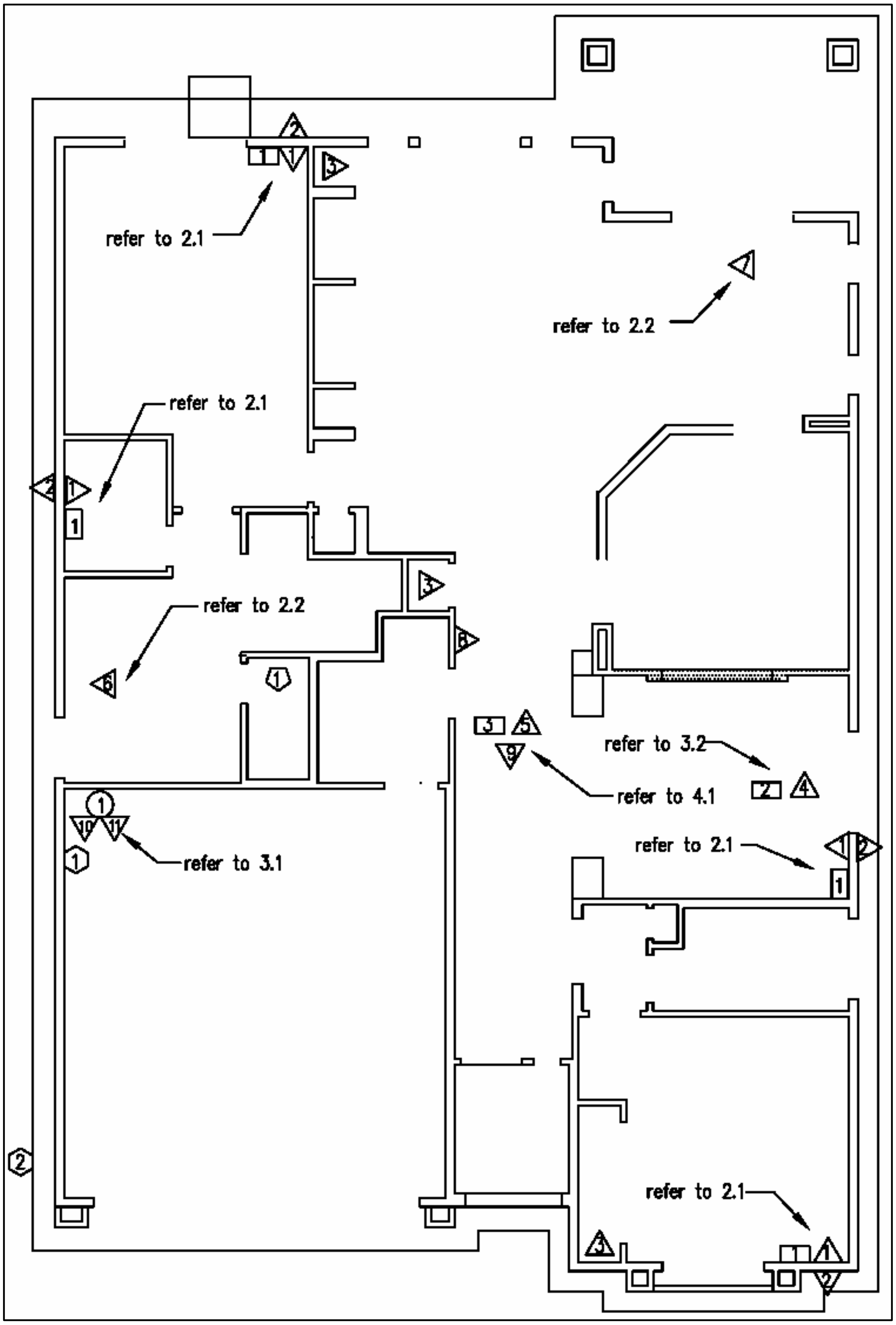
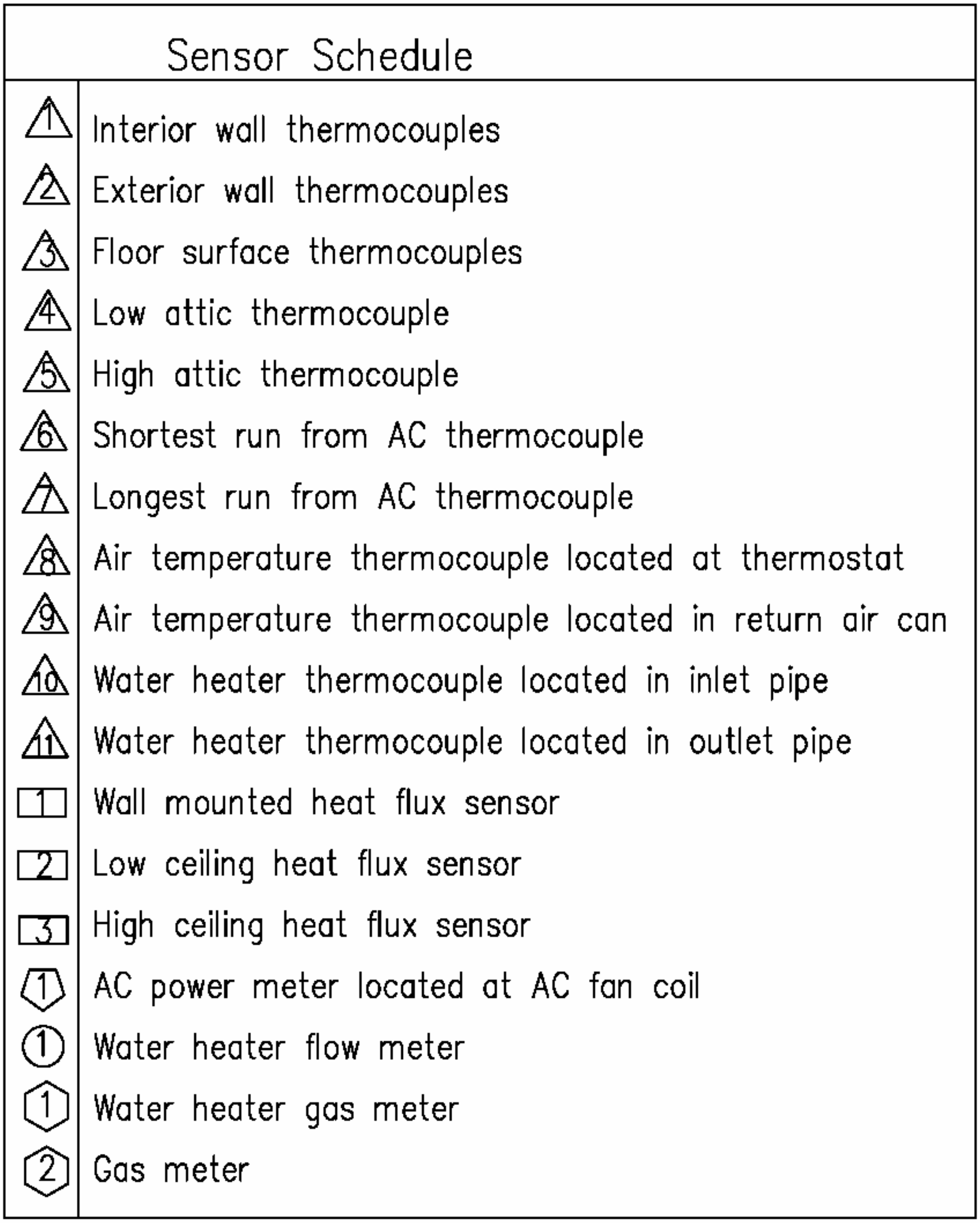


Figure 14: Plan view of the Vinings baseline house -- The Near ZEH is the mirror image

Sensor Schedule

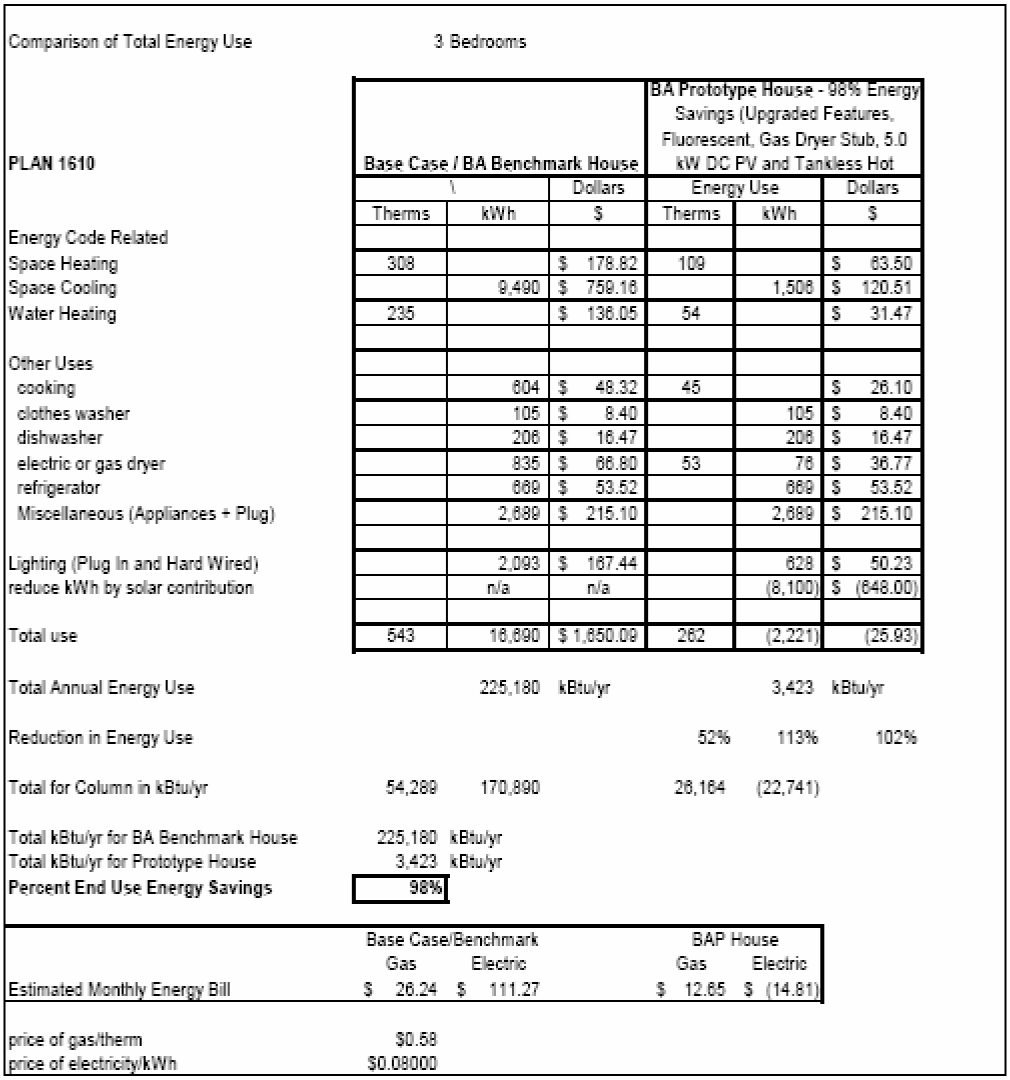


	Sensor Schedule
△1	Interior wall thermocouples
△2	Exterior wall thermocouples
△3	Floor surface thermocouples
△4	Low attic thermocouple
△5	High attic thermocouple
△6	Shortest run from AC thermocouple
△7	Longest run from AC thermocouple
△8	Air temperature thermocouple located at thermostat
△9	Air temperature thermocouple located in return air can
△10	Water heater thermocouple located in inlet pipe
△11	Water heater thermocouple located in outlet pipe
□1	Wall mounted heat flux sensor
□2	Low ceiling heat flux sensor
□3	High ceiling heat flux sensor
⬠1	AC power meter located at AC fan coil
○1	Water heater flow meter
⬡1	Water heater gas meter
⬡2	Gas meter

Table 6: Key to Instrumentation Notation

Appendix C: Energy Features

Pinnacle Homes, Las Vegas		
	Baseline House	**BAP House**
Roof	R-30	R-38 w/ radiant barrier
Walls	R-13+1”Foam (R-4.2)	DOW’s T-Mass Wall (outside to inside is 4” concrete, 2” polystyrene, 2” concrete, 0.9” stucco)
Windows	Dual pane vinyl frame windows with spectrally selective glass. SL (U = 0.35, SHGC = 0.30), FX (U=0.33, SHGC = 0.32) Patio Dr (U = 0.35, SHGC = 0.28)	Dual pane vinyl frame windows with spectrally selective glass. SL (U = 0.35, SHGC = 0.30), FX (U=0.33, SHGC = 0.32) Patio Dr (U = 0.35, SHGC = 0.28)
Air Infiltration	3.1 SLA	2.9 SLA
HVAC System	80% AFUE / 10.0 SEER	82% AFUE / 19 Equivalent SEER (Freus A/C with Hydronic heating with solar hot water heating backup).
Duct Insulation	R-4.2 in attic	R-4.2 in conditioned space
Water Heater	40 Gal, EF = 0.53	Tankless, EF = 0.82
Lights	Incandescent	CFL
Appliances	Energy Star	Energy Star
Photovoltaic	None	5.0 kW DC



Comparison of Total Energy Use 3 Bedrooms

PLAN 1610	Base Case / BA Benchmark House			BA Prototype House - 98% Energy Savings (Upgraded Features, Fluorescent, Gas Dryer Stub, 5.0 kW DC PV and Tankless Hot		
	\		Dollars	Energy Use		Dollars
	Therms	kWh	$	Therms	kWh	$
Energy Code Related						
Space Heating	308		$ 178.82	109		$ 63.50
Space Cooling		9,490	$ 759.16		1,506	$ 120.51
Water Heating	235		$ 136.05	54		$ 31.47
Other Uses						
cooking		604	$ 48.32	45		$ 26.10
clothes washer		105	$ 8.40		105	$ 8.40
dishwasher		206	$ 16.47		206	$ 16.47
electric or gas dryer		835	$ 66.80	53	76	$ 36.77
refrigerator		669	$ 53.52		669	$ 53.52
Miscellaneous (Appliances + Plug)		2,689	$ 215.10		2,689	$ 215.10
Lighting (Plug In and Hard Wired)		2,093	$ 167.44		628	$ 50.23
reduce kWh by solar contribution		n/a	n/a		(8,100)	$ (648.00)
Total use	543	16,890	$ 1,650.09	262	(2,221)	(25.93)
Total Annual Energy Use		225,180	kBtu/yr		3,423	kBtu/yr
Reduction in Energy Use				52%	113%	102%
Total for Column in kBtu/yr	54,289	170,890		26,164	(22,741)	
Total kBtu/yr for BA Benchmark House	225,180	kBtu/yr				
Total kBtu/yr for Prototype House	3,423	kBtu/yr				
Percent End Use Energy Savings	98%					

	Base Case/Benchmark		BAP House	
	Gas	Electric	Gas	Electric
Estimated Monthly Energy Bill	$ 26.24	$ 111.27	$ 12.65	$ (14.81)

price of gas/therm	$0.58
price of electricity/kWh	$0.08000

Figure 15: Calculated Total Energy Savings