# Final Report: Results of Research Systems For Prototype Homes

## Deliverable Number 15.C.1

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# 15.C.1 Final Report: Results of Research on Systems For Prototype Homes

## Executive Summary

As part of the US DOE's Building America Program (BAP), this technical report discusses results from BIRA's evaluation of systems installed in prototype homes designed to reduce overall residential building energy use by 40-50%.

- Both vented and unvented crawlspaces save about the same amount of energy and the research on both systems shows there are important cautions to take consideration of for both Marine and Cold Climates in the Pacific Northwest.
- Using actual leakage data, the results from three simulation tools examine the crawlspace alternatives in the Northern Marine climate and ducts in conditioned space above the first floor.
- The Borrego Springs Project has provided an important opportunity in the evaluation of three different wall systems in an extreme hot-dry climate. High performance and ease of construction of the SIP walls suggests that SIPS are a probable leader for energy efficient/green production home builder/developers in this climate zone.

# Task Description

BIRA shall prepare a final draft report describing the results from research on at least two advanced systems evaluated in Task A with the potential to substantially improve the overall performance of envelope systems, space conditioning systems, water heating systems, lighting systems and other energy systems in new residential buildings, with the goal of reducing residential building energy use by an average of 40-50% by 2015.

The report shall include a summary of interactions between advanced components and systems.

The report shall include a description of advanced system cost and performance tradeoffs. Tradeoff evaluations in the report shall include consideration of occupant comfort, occupant health, building and equipment durability, building and equipment reliability, and building and equipment maintainability.

The report shall include a description of design and construction strategies for integration of advanced systems into buildings including identification of simple quality control tools required to verify system performance during installation and operation, based on lessons learned from the Subcontractor’s research projects.

The report shall include a determination of whether the system meets minimum requirements for inclusion in a whole house research project with a builder partner.

The report shall identify areas where system performance or system specifications do not meet minimum requirements for inclusion in whole house research projects.

The advanced systems addressed in this report include:

- North Marine and Cold Northwest Crawlspaces
    - Conclusions about comparing vented and unvented crawlspaces and recommendations for each
    - Ducts moved to out of crawlspaces to inside space
    - Software analyzing crawlspaces
- Comparative Wall Systems for Production Builders Analyzed from Clarum Home’s Borrego Springs Project
    - 2x6 Frame Walls
    - SIP Wall System

# Crawl Space Alternatives in Northern Marine and Cold Climate in the Pacific Northwest

## *Introduction*

Team lead, Consol and BIRA partner, Washington State University (WSU) worked closely together and directly with New Traditions Homes, of Vancouver, WA, to research and compare two approaches for insulating crawlspaces in the Marine Climate of the Pacific Northwest over the last two years. With support from Energy Star, this research was expanded to also address the Northwest Cold climate on the east side of the Cascades working with Condict Homes, in Grant County in Eastern Washington.

The first of these two approaches to insulating crawlspaces is to insulate the floor with the crawlspace vented and ducts sealed and well insulated. The second approach is to insulate the perimeter walls with no vents and ducts well sealed and insulated.

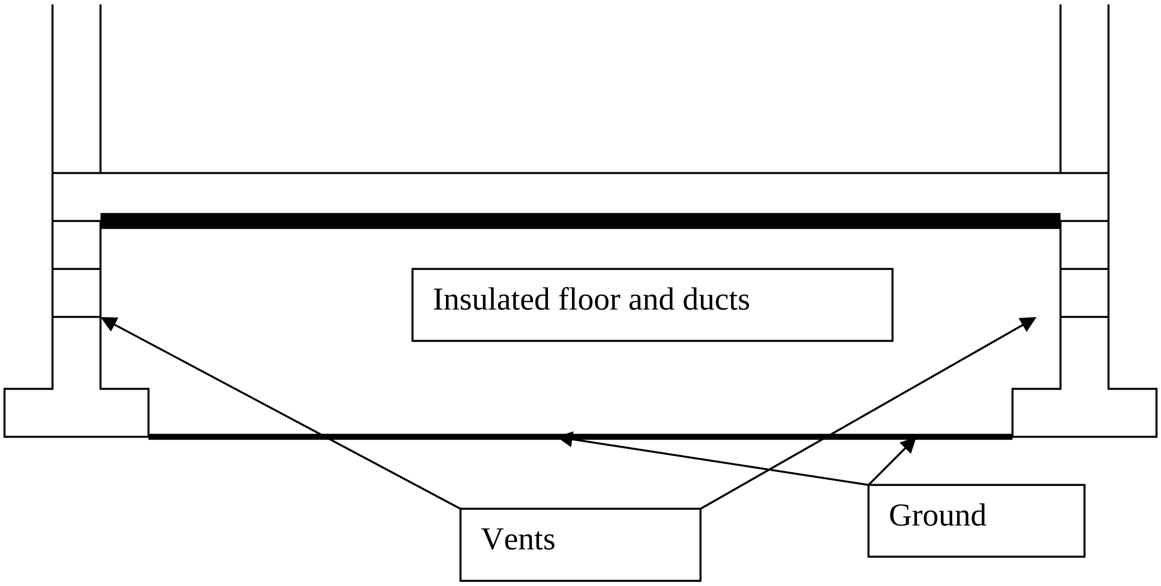


**Figure 1Crawlspace with insulated floor and ducts with perimeter wall vented.**

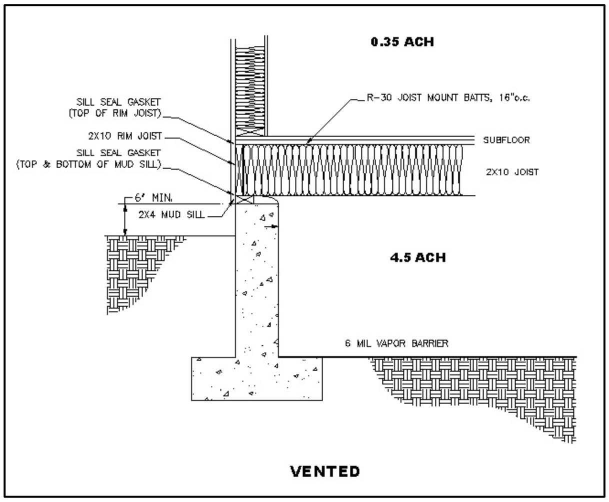


**Figure 2 Vented Crawlspace Detail**

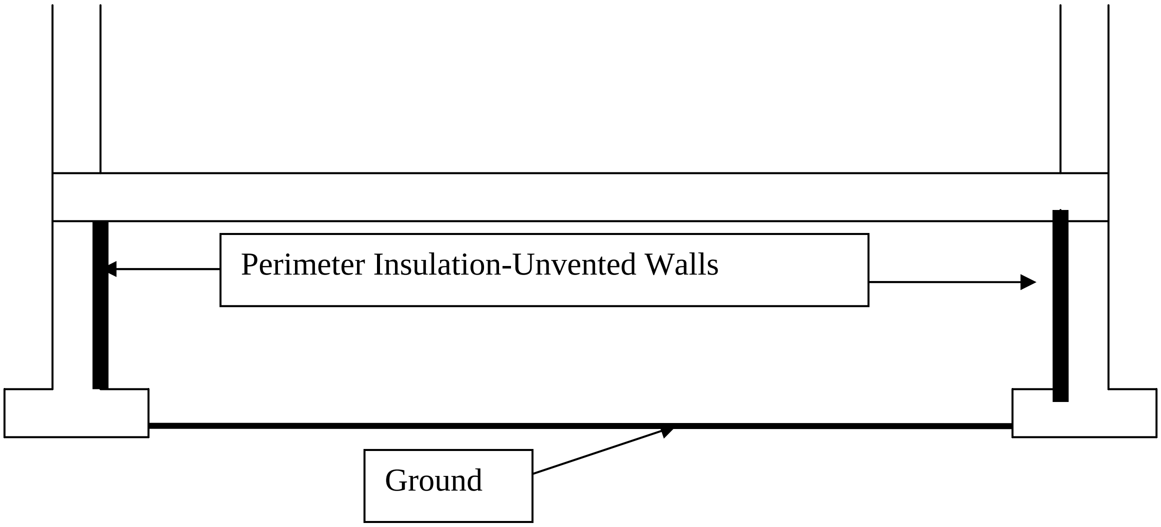
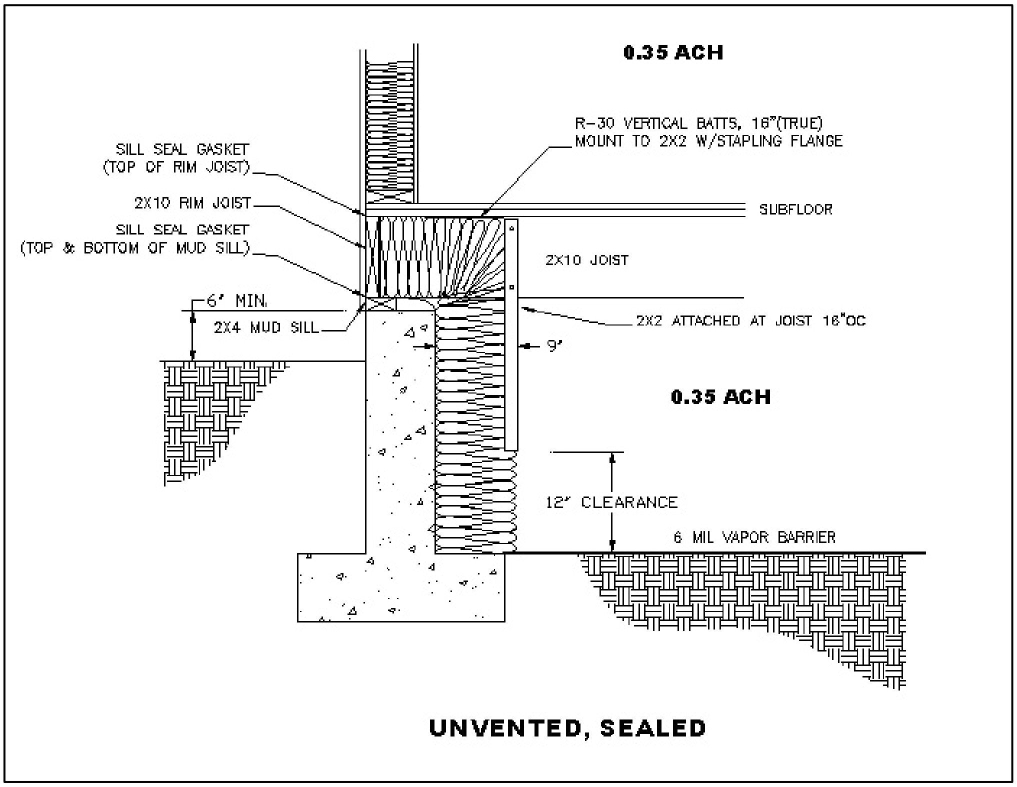


**Figure 3 Crawlspace with perimeter insulation and unvented foundation walls.**



The research comparing these two approaches to insulating crawlspaces in the North Marine Climate has been conducted for two primary reasons;

- Among various building science experts there are strong disagreements as to which approach performs better.
- Building codes, particularly in the State of Washington, conflict on the subject of these alternative approaches to insulating crawlspaces.

The original focus of this research was driven by the BAP 40% whole house savings goal in 2008 in the Marine Climate. However, the conflict of code issues and disagreement within the building science community also spilled over into the Cold Climate Zone of the Pacific Northwest.

These issues are not only a concern within BAP, Energy Star of the Northwest also lends support to WSU's efforts in concurrently supporting this research. The goal of this ENERGY STAR Homes Northwest demonstration project was to identify, package and implement leading-edge energy efficiency measures and building science techniques to help define the next generation of ENERGY STAR® Homes Northwest homes.

In addition to working with New Tradition Homes, as previously mentioned, to address the Cold Climate concerns, WSU also worked with Condict Homes, in Grant County in Eastern Washington (cold climate).

## Participating Home Builders

The builders were selected based on their willingness to participate in the research, demonstration and deployment phases of the project. The four New Traditions homes are three-bedroom, two-story 2,200 square foot (ft$^2$) homes with a roughly 15% glass-to-window-to-floor area. The Condict four homes are 1,550 ft$^2$ ranch style models, with less than 10% glazing.

**Figure 5 Moses Lake/Cold Climate (left) and Vancouver/Marine Climate Demonstration Homes**

These eight research homes represent some of the most energy efficient production housing built in Washington State in 2006. These homes:

- Exceed Washington State Energy Code (WSEC),
- Crawlspaces with vents follow WA Code using R-30 floor insulation
- Crawlspaces without vents follow IEC and use R-15 foam on the walls
- Are certified to ENERGY STAR Homes Northwest™ utility program requirements,
- Are benchmarked to USDOE Building America 30-40% whole-house savings, and
- Are evaluated for the $2000 federal energy tax credit for new homes.

The major focus of the innovations in the homes was on innovative HVAC and lighting technologies, including:

- Duct designs that move ductwork into the conditioned space or move the conditioned space around the ductwork,
- For the Condict homes, high efficiency heat pumps with high HSPF and ECM motors, commissioned according to Performance Tested Comfort Systems (PTCS) protocols (these protocols were further refined under a DOE State Technologies Assistance Collaborative (STAC) project conducted by the Northwest states),
- For the New Traditions homes, 94% AFUE gas furnaces with ECM motors, and
- For the New Traditions homes, energy efficient lighting.

Heat pump research and deployment activities were also conducted under the STAC project; this effort is ongoing.

## *Washington States Energy Code and the IRC Conflict re: Crawlspaces*

Chuck Murray, with WSU, compares and contrasts the building code issues between the two approaches to insulating and sealing and not sealing crawlspaces:

> With respect to the Washington State Energy Code (WSEC) and the Washington State Ventilation and Indoor Air Quality Code (VIAQ) the primary obstacles to implementation of unvented/perimeter insulated crawl spaces are as follows.
>
> 1. The VIAQ Chapter 5 requires all unvented crawl spaces to include a radon mitigation system similar to that described in IRC Appendix F. Vented crawl spaces only require this system in a few counties. This is not a barrier, per say, but adds to cost and time of construction.
>
> 2. When radon mitigation is required, the crawl must be sealed with respect to the interior space at the floor. This is in conflict with the 2006 IRC crawl ventilation requirements for unvented crawls. The IRC requires the crawlspaces air be open to and to communicate with the interior.
>
> 3. The WSEC only includes ventilated crawl space with floor insulation in the prescriptive path. The applicant that intends to construct a crawlspace with perimeter insulation that is unvented is required to use a UA trade off method or a systems approach to qualify buildings with the insulation included on the crawl space wall.
>
>    3a. Under the UA trade off method, the use of crawl space wall insulation will typically result in a higher UA for the building than the base case with floor insulation. The applicant will need to make up the difference by improving performance elsewhere.
>
>    3b. Under the systems approach, a method for taking credit for ducts indoors (or in the crawl) has not been included in the code. This is a grey area. The current systems approach does not easily give value to this approach. In practice, it's a “dead end”.

## *IECC Requirements Re: Crawlspaces*

Michael Lubliner, also with WSU, reports that the IECC allows R10-15 perimeter insulation in an invented crawlspace whereas WA Energy Code requires R30 floor insulation over a vented crawlspace. Heat loss analysis used in Pacific Northwest codes and utility new construction and retrofit programs and simulations using Energy Gauge USA (EGUSA) suggests that the R30 is a more energy efficient system provided that the duct system in the crawlspace is well insulated and tight.

## *Challenges to the use of conditioned crawlspaces in WA*

One of the purposes of the demonstration project was to determine the viability of the use of perimeter insulated crawlspaces on the west side of Washington State. There are a number of factors that impact the acceptability of this approach in Washington (and indeed the Northwest as a whole) and are worth their own discussion here.

- **Radon –** Washington is one of the few states in the U.S. to have adopted mandatory radon resistive construction standards. Chapter 5 of the Washington State Ventilation and Indoor Air Quality Code (VIAQ) contains these standards, which include radon vents for all homes with crawlspaces vented less than 1ft.$^2$ for each 300ft.$^2$ of crawlspace area. In high-risk radon counties (Clark, Ferry, Okanogan, Pend Oreille, Skamania, Spokane, and Stevens), additional measures are required: sub-slab gravel and sealing below-grade walls and floor.

  In addition, Washington amendments to the 2006 International Residential Code includes the following language:

  > *Unvented crawl spaces are not permitted in any high radon potential county.*

- **Rigid Foam –** For fire and smoke mitigation, the International Residential Code (IRC) requires that foams being used on the interior of a building be covered with the equivalent of ½" of gypsum. An explicit exception is for Dow's Celotex Thermax isocyanurate, where approved by the code official; this is the product used in the New Traditions homes.

- **Moisture mitigation –** One of the major concerns about the use of sealed crawlspaces is the reduced drying potential of moisture from groundwater. As such, site preparation, grading considerations and perimeter drainage are key considerations to avoiding moisture-related issues.

- **Ventilation –** The 2006 IRC requires that one of two methods of conditioning sealed crawlspaces be used. This includes either a dedicated exhaust fan integrated with a passive air pathway to the living space, or by including a supply from the HVAC system and either a passive or active return to the conditioned space. Project staff and WSEC support staff agree that the latter approach is unacceptable in Washington State, as the inclusion of ductwork in the crawlspace incurs an additional energy cost, and can potentially bring pollutants into the house. There is also evidence that the exhaust fan system will not prevent air form moving from the crawl space to the living space.

- **2006 IRC definition of conditioned crawlspace –** The IRC requires that sealed crawlspaces be connected to the house by either transfer grilles or by the inclusion of conditioned supply air to the crawlspace and a passive or active return to the living space. Project staff and WSEC support staff find neither approach acceptable for reasons identified in the previous point. WSEC support staff will propose a modification to the

IRC to remove this requirement, and are optimistic that the needed support to make the necessary changes can be garnered.

## *Moving Ducts and HVAC Within Inside Space*

It is clearly understood that moving ducts and HVAC systems within conditioned space saves energy and it is also understood that there are costs associated with these changes. It is also noted that other technical issues arise. For example, extra care must be taken with sealing rim joists if ducts are located between floors, within the floor joists of two story homes. From the perspective of investigating costs and technical issues of affecting these changes, WSU worked with both builder partners to investigate how they could move ducts from crawlspaces to locations within the insulated enclosure and to compile and analyze additional costs incurred with these changes to their standard practice.

In the Condict homes, significant challenges had to be faced in order to integrate the improvements to the HVAC system. As the Condict homes are single story, there are limited options for bringing ducts and HVAC equipment inside the heated space. In the end, dropped ceilings in hallways were used to bring ducts into the heated space, and usable living space was sacrificed to bring the air handler inside.

**Figure 6 Condict ductwork located within conditioned space, pre- and post-drywall**

Due to concerns about this non-traditional design and noise, and a serious lag time in obtaining the high-efficiency heat pump (quoted as 8-10 weeks), the existing HVAC contractor for Condict left the project. Even when a more willing HVAC contractor was brought on board, the delay in obtaining the equipment was a real concern – local distributors that listed the equipment as available couldn't procure it for 3-4 weeks (significantly less than the lag quoted by the initial contractor, but much longer than the overnight turnaround standard in the industry.)

There were no significant challenges in the New Traditions homes, other than integrating the ducts and HVAC equipment into the heated space. The loss of square footage was not an issue for New Traditions, as the homes are two-story models, with the ductwork located between floors. The air handler was included in the envelope by extending the conditioned space into the garage. The high efficiency furnace is readily available in the Vancouver-Portland market, and the HVAC contractor had no issues with any aspect of the improved HVAC system. Indeed, the only difficulty was that the builder wanted to integrate the improvements into homes already under construction, and was unable to do so, emphasizing the need to address HVAC improvements in the design rather than building phase.

**Figure 7 New Traditions Ductwork, pre- and post-drywall**

**Figure 8 Air handlers located inside the heated space for the Condict (left) and New Traditions homes.**

Table 1 identifies the incremental costs for improvements to the HVAC system.*
Note that a full listing of incremental costs is included in Appendix A.

**Table 1 – Incremental costs for HVAC improvements**

| Condict | | New Traditions | |
|---|---|---|---|
| Improvement | Cost | Improvement | Cost |
| 7.7 HSPF/13 SEER Heat Pump (Federal Std.)<br>To<br>9.1 HSPF/14 SEER Heat Pump with ECM motor | $1,610 | .80 AFUE Gas Furnace (Federal Std.)<br>To<br>.94 AFUE Gas Furnace with ECM motor | $850 |
| Moving HVAC inside heated space | $810 | Moving HVAC inside heated space | $675 |
| Total | $2,420 | Total | $1,525 |

## *Energy Use Model Savings Comparisons*

Using field testing data as inputs, three energy simulation software models were used to evaluate energy use and costs. The research compared simulation models based on foundation type, duct location (inside or outside conditioned space) and duct insulation levels. Energy use for an ENERGY STAR Homes Northwest home was also compared to a base case WSEC home. Utility savings, builder pricing and simple consumer affordability issues were derived.

The following table provides a breakdown of all modeling cases, including descriptions of HVAC location, equipment efficiency and crawlspace types. Cases 1-4 represent ENERGY STAR or better efficiency and 5, 6 represent current code practice in marine climates, where case 6 is the typical Code vented crawlspace., and 5 is a conditioned crawlspace.

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* All costs identified in this report were derived from an informal builder survey, with Washington State Energy Code assumed as the base case. Builder costs were then converted to homebuyer costs, using a markup of 35%, typical of the residential new homes market.

| Program Efficiency | AFUE - SEER<br>HSPF - SEER | Nominal R-value Roof/wall/window | Lights -% CFL WH ventilation | Crawlspace Configuration | HVAC location (Sup/Ret/AH) |
|---|---|---|---|---|---|
| 1 ENERGY STAR | 0.94 - 14.5<br>9.0 – 14.5 | R= 49<br>R= 21<br>U=.32 | 50%<br>None | Conditioned<br>R15 perimeter | crawl/attic/garage<br>“inside crawl”<br>R4 & R7 |
| 2 ENERGY STAR | 0.94 - 14.5<br>9.0 – 14.5 | R= 49<br>R= 21<br>U=.32 | 50%<br>None | Vented 1:300<br>R30 floor | crawl/attic/garage<br>“outside”<br>R4 & R7 |
| 3 ENERGY STAR + | 0.94 - 14.5<br>9.0 – 14.5 | R= 49<br>R= 21<br>U=.32 | 50%<br>None | Conditioned<br>R15 perimeter | between floors<br>“inside”<br>R4 & R7 |
| 4 ENERGY STAR + | 0.94 - 14.5<br>9.0 – 14.5 | R= 49<br>R= 21<br>U=.32 | 50%<br>None | Vented 1:300<br>R30 floor | between floors<br>“inside”<br>R4 & R7 |
| 5 WSEC | 0.8 - 13<br>8.0 – 13 | R= 38<br>R= 21<br>U=.35 | 50%<br>None | Conditioned<br>R15 perimeter | between floors<br>“inside crawl”<br>R4 & R7 |
| 6 WSEC | 0.8 - 13<br>8.0 – 13 | R= 38<br>R= 21<br>U=.35 | 50%<br>None | Vented 1:300<br>R30 floor | crawl/attic/garage<br>“outside”<br>R4 & R7 |

**Table 2: Case Descriptions**

**Table 3: Envelope Leakage, HVAC Leakage Results From Field and Used in Modeling**

| Case | Tested Blower Door ACH50 | Tested Duct Leak CFM50 Out | Tested HVAC Flow Rate (**) | Model Used CFM50 Out (EG & REM) | Model Used ACH (fixed) (SEEM) | Model Duct Leak CFM25 Out (EG&REM) | Model Duct Leak CFM25 Out/CFM AH flow (SEEM) | Tons AC + HP | Model HVAC Flow (CFM) |
|---|---|---|---|---|---|---|---|---|---|
| 1 marine* | 4.7 | 130 | 880 | 2135 | 0.35 | 77 | 0.11 | 2 | 700 |
| 2 marine | 3.4 | 95 | 788 | 2135 | 0.35 | 77 | 0.11 | 2 | 700 |
| 3 marine | 3.3 | 32 | 910 | 2135 | 0.35 | 0 | 0.0 | 2 | 700 |
| 4 marine | 3.7 | 45 | 925 | 2135 | 0.35 | 0 | 0.0 | 2 | 700 |
| 5 marine | n/a | n/a | n/a | 2460 | 0.4 | 192.5 | 0.22 | 2.5 | 875 |
| 6 Marine | n/a | n/a | n/a | 2460 | 0.4 | 192.5 | 0.22 | 2.5 | 875 |
| 1 Cold | 3.7 | 25 | 725 | 1880 | 0.35 | 96.3 | 0.11 | 2.5 | 875 |
| 2 Cold | 3.7 | 65 | 731 | 1880 | 0.35 | 96.3 | 0.11 | 2.5 | 875 |
| 3 Cold* | 4.3 | 25 | 798 | 1880 | 0.35 | 0 | 0 | 2.5 | 875 |
| 4 Cold* | 4.6 | 25 | DH | 1880 | 0.35 | 0 | 0 | 2.5 | 875 |
| 5 Cold | n/a | n/a | n/a | 2150 | 0.4 | 264 | 0.22 | 3 | 1200 |
| 6 Cold | n/a | n/a | n/a | 2150 | 0.4 | 264 | 0.22 | 3 | 1200 |

(*) first homes prior to ENERGY STAR QC
(**) Flow for cases 1-4 (ENERGY STAR) is on high speed setting for ECM motor

# Research Results

The research findings and recommendations from the BIRA/Washington State study are presented in the two following sub-sections.

## Findings

### Energy Use Modeling

- Of significant concern to the Energy Star Homes Northwest program is the inability of the three approved software tools, REMRate, Micropas and Energy Gauge, to qualify any of these homes modeled with a heat pump for the federal tax credit for new homes. This has been identified as an issue with the RESNET standards, and doesn't allow what many in the PNW believe is proper credit to be applied to a home with a properly commissioned heat pump.

### Comparative Crawlspace Systems: Vented vs. Unvented

- In research to date, perimeter insulation conditioned crawlspaces do not save energy over vented floor insulated crawlspaces in heating dominated PNW climates, not in Marine nor Cold.
- All 8 homes in this study were occupied for most of the time when data was being collected making it difficult to discern small differences.
- Either approach can be used with appropriate precautions to achieve the 40% Energy Savings BAP goal. BIRA/WSU recommend insulating the floor and venting the crawlspaces.
- Moving ducts inside appears to be a very cost effective energy saving measure.
- If ducts are in a crawlspace, with either vents or no-vents, ducts must be well sealed and insulated.
- Moving both ducts from crawlspace and air handler from garage to house reduces crawlspace and garage pollutants from entering the home.
- The use of site moisture & IAQ management practice are needed regardless of the crawlspace design.

## Next Steps

- Analyze and report additional data as it becomes available.
- Test the crawlspaces of at least four of the homes with tracer gas and report the results.
- Working closely with BIRA, WSEC support staff will propose a modification to the IRC to remove the requirement that sealed crawlspaces be connected to the house, and are optimistic that the needed support to make the necessary changes can be garnered.

# Summary of Wall Systems Research in Borrego Springs

## *Introduction*

In 2005 BIRA Partner Clarum homes set the goal to find the best solutions to building homes in an extreme Hot-Dry Climate that reduce cooling energy by at least 90%. Clarum homes built four prototype homes to test different cooling systems, and wall systems, as well as evaluate detailed and overall costs and construction strategies. Many lessons have been learned from this project including the challenges of building in a remote desert location as well as how to monitor and evaluate performance in this climate as well as hard to reach site. This report will reference almost two years of research and analyzed data. Based on this research recommendations of which of the three wall systems being researched could substantially improve the overall performance of the home and be considered to move from Stage Gate 3 to SG4 is provided. The recommendation will be based on :

- Interaction between advanced systems and components
- Advanced system cost and performance tradeoffs
- Integration of advanced systems into the building

## *Background*

### Borrego Springs Location

The pre-production houses are located in Borrego Springs, 90 miles northeast of San Diego, CA. Figure 9 is a regional map of the Borrego Springs area.

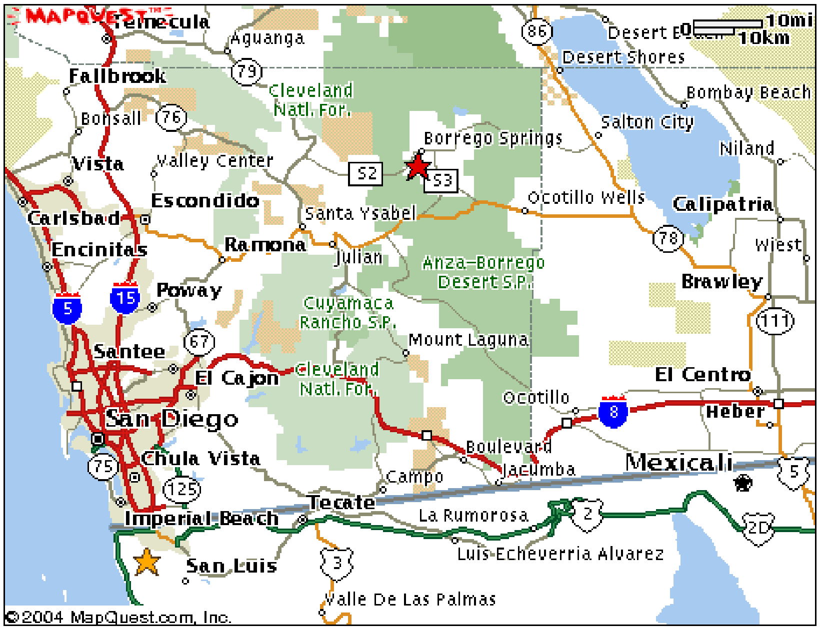

Figure 9: Regional Map – Borrego Springs

Figure 10 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 10: 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. These monitoring project findings 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 4: Borrego Springs Climate Data**

## Home Design

Construction began in 2005 on the high efficiency prototype homes. Each home is 1,920 sq.ft. with identical floor plans, shown in Figure 11. Three of the homes (East Star, Broken Arrow and Di Giorgio) are front facing 30° east of south while the fourth home (Country Club) faces west due to site constraints. The orientation plays an important role in optimizing the capabilities of the PV systems.

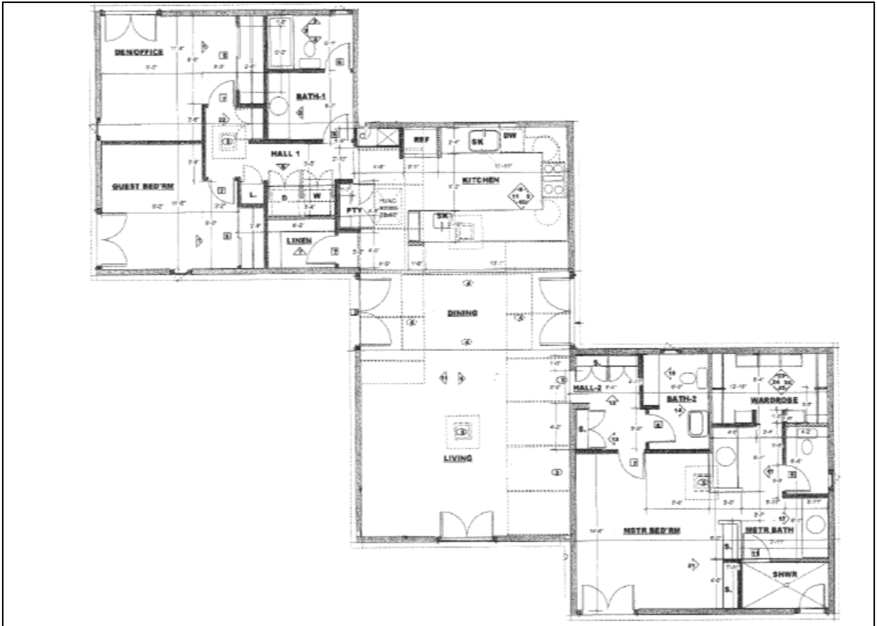

**Figure 11: Home Floor Plan**

Apart from having identical floor plans, the homes have the same energy features, excluding the wall and HVAC systems. Table 2 summarizes the energy features, HVAC systems and wall system of the four homes.

| | **Di Giorgio** | **Country Club** | **Broken Arrow** | **East Star** |
|---|---|---|---|---|
| Roof | R-38 w/ radiant barrier | R-38 w/ radiant barrier | R-38 w/ radiant barrier | Sprayed in Icynene® R-19.8 |
| Walls | T-MASS (R-28 equivalent) | T-MASS (R-28 equivalent) | 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<br>SL (U=0.35, SHGC = 0.35)<br>FX (U=0.35, SHGC - 0,35)<br>Patio Dr (U = 0.35, SHGC = 0.35) | | | |
| Air infiltration (SLA) | 3.3 | 2.9 | 3.3 | 4.0 |
| HVAC System | Freus w/ Ducts and Floor Pre-cooling + NightBreeze | OASys Evaporative Cooler + Radiant Floor Heating and Cooling | OASys Evaporative Cooler + Conventional Ducted AC for periods of high humidity (14 SEER equivalent) | Lennox (21 SEER equivalent) |
| Water & Space Heating | Tankless w/ Energy Factor = 0.84 & Space Heating | | | |
| Lights | CFL's throughout | | | |

**Table 5: Summary of Energy Features**

| 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 6: Builder Costs- Comparisons to East Star 2x6 Frame/Lennox**

## *Research Overview*

Over a two year time period BIRA with the assistance of NREL and DEG conducted three short term experiments to evaluate each wall system. The first experiment conducted in August of 2006 was to super cool each home at night during off peak to evaluate the impact of the wall systems in maintaining comfort through the peak of the day without using additional energy and document the impact of Building America homes in reducing peak demand. The second experiment examined the benefit of cooling each home using evaporative cooling[a]. The third experiment focused on how the homes performed during the heating season. The focus of each experiment was in how each of the prototype homes were able to maintain comfort conditions during the cooling and heating season and how they could reduce peak demand.

All four homes have been instrumented for comprehensive evaluation and analysis of the walls, cooling systems, electric load, and environmental conditions. Sensors have been installed in the walls of all four homes in the interior ,exterior, and in the middle to monitor different temperatures and resulting heat flows. Ground sensors were also installed in the slab and buried in the ground for evaluation of the impact of ground coupling on each home. Unfortunately due to construction and environmental conditions most of the sensors in the ground have been deemed inoperable. Among the many lessons learned on this project is what materials not to use below grade for monitoring.

## *Research Results*

All research findings are a result of the various experiments and analysis of monitored data. Some of the findings have been documented in previous reports. All previous reports referenced in this document will be referenced in Appendix B.

# T-MASS®™Wall System

BIRA has welcomed the opportunity to evaluate different wall systems side-by-side to include a system with high thermal mass that was expected to perform well regarding comfort and to have other advantages. These thermal advantages are dependent on carefully managing the time of day of energy uses and the optimal employment of accessing outside night cooling and passive solar heating both when appropriate. Introducing mass into a home has shown value during extensive overheated periods of the year at times of day for peak cooling hours while also maintaining a lower mean radiant temperature in the home than would normally be experienced in light frame homes. The capacitive effect of mass with proper management can be very comfortable, energy efficient and can produce cost savings with time of use rates (TUR).

**Figure 12: T-MASS®™Home**

# Findings

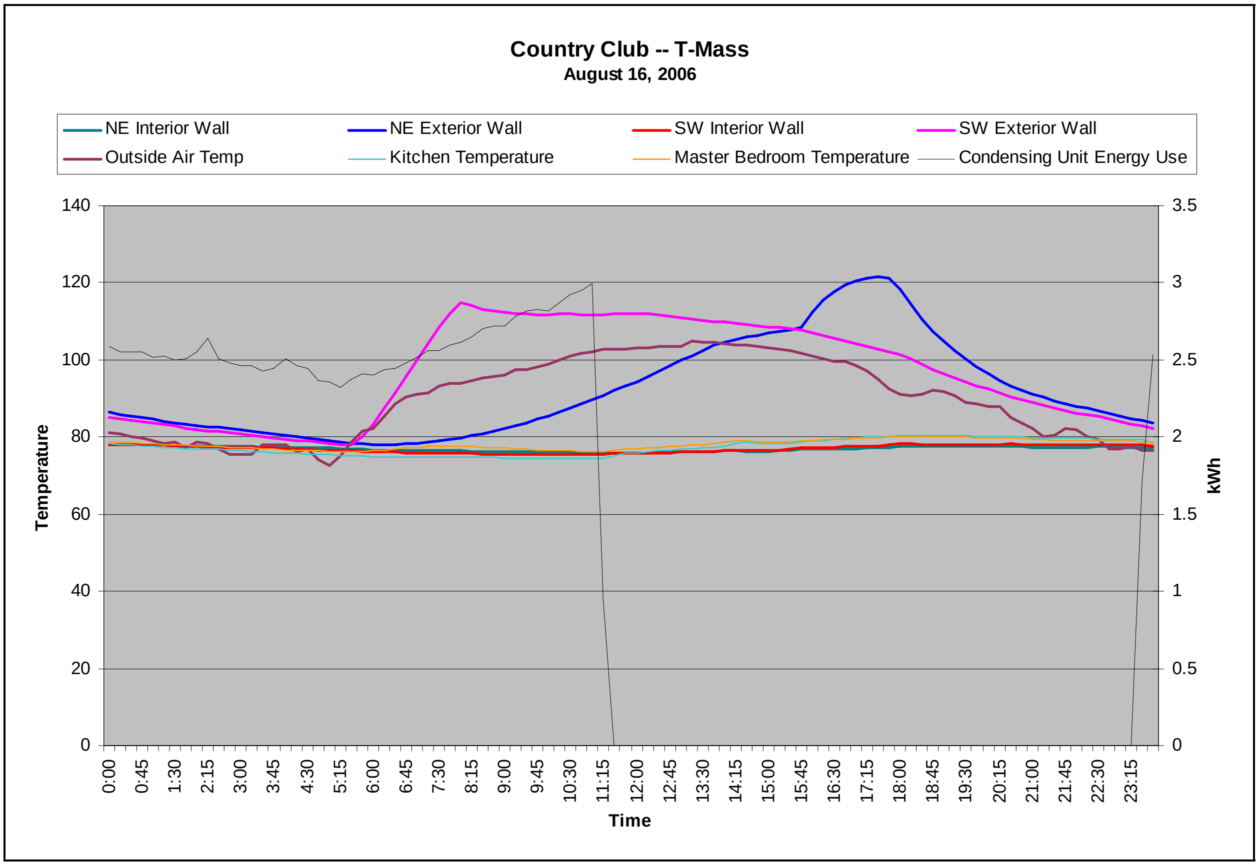

**Figure 13: Pre-Cooling Experiment- T-MASS®™**

- The high mass construction was the best at maintaining indoor comfort.

  During both pre cooling experiments the T-MASS®™construction varied the least in temperature while cooling equipment was not in use. Figure 13 above shows in the almost 12 hour period with outside conditions o 105 degrees and the cooling equipment off the T-MASS®™home only varied in temperature by 3.5 degrees.[b]

- The 2” exterior layer of the T-MASS®™ wall did not demonstrate to be of any value from an energy perspective. Comparing the heat flow through the stucco and the 2” layer both conducted the heat at very similar rates .
- The Plan to Manufacturing to Construction process appeared to have a few problems. Figure 14 shows panels not connecting as originally designed.

**Figure 14: T-MASS®™ Wall Mistakes**

- Plans indicating weld plates location were difficult to understand. resulting in weld plates having to be epoxyed in instead of buried in the concrete. Figure 16 shows weld plates in T-MASS®™walls.

Figure 15: T-MASS®™Weld plate on floor

**Figure 16: Incorrect Weld Plate Placement**

- Three of the four homes were unoccupied during the coldest time in Borrego Springs. Figure 17 below indicates how well each home was able to maintain indoor temperature without any heating. Note how the T-MASS®™home performs just as it did in the summer by maintaining indoor temperature throughout the day . To homes evidence the value of utilizing advanced wall systems and in some instances the conventionally framed 2x6 house preformed reasonably well, but not as originally designed and intended.

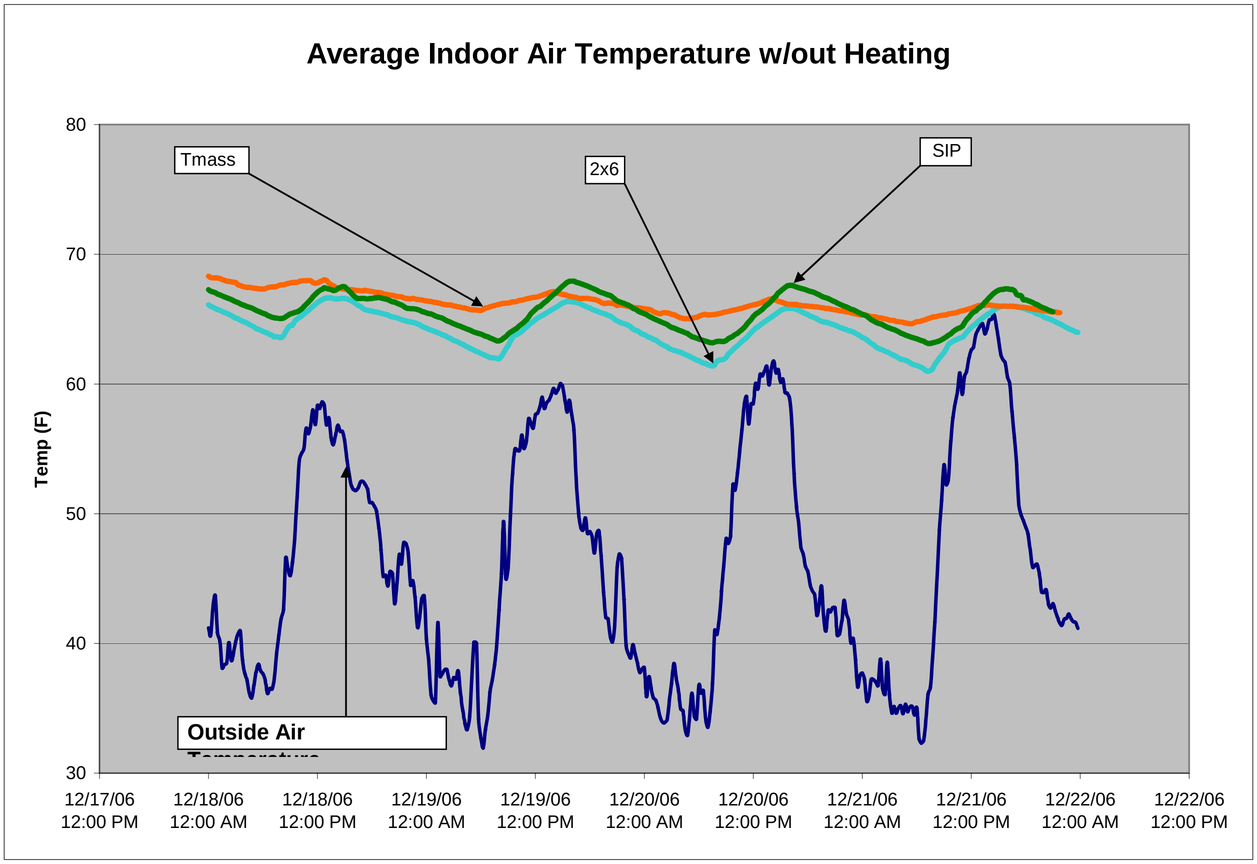

Figure 17: Average Indoor Air Temperature With No Heating

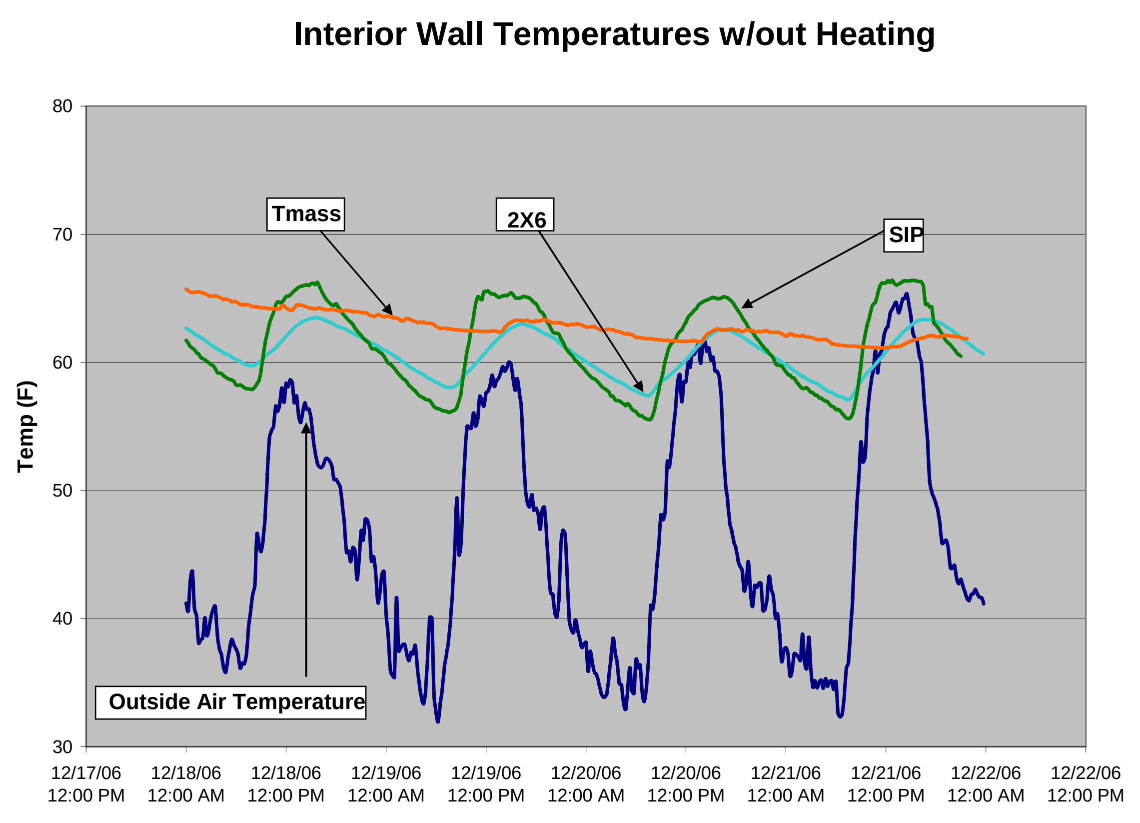

Figure 18: Interior Wall temperatures For All Three Homes

## Builder Feedback

The following is a list of issues and suggestions collected by the builder for T-Mass:

- Inconsistency with panel colors.
- Cosmetic surface cracking of wall panels
- Application of wood trim, cabinets and bath hardware into concrete.
- Inadequate provisions for electrical wiring.
- Difficulty providing adequate flashing at window and doors
- “Wet-set” electrical boxes not level or plumb.
- Costly and time consuming to ship, handle and erect.
- Difficult to match color and texture when patching wall

## Recommendations

The T-MASS®™wall system in terms of energy efficiency performed the best. Unfortunately in this experiment it proved to be the most costly. Compared to the 2x6 home the T-MASS®™wall system cost over 75% more from cost provided by the builder as shown on Table 4. During this experiment the two factories on the west coast that could supply this product decided not to manufacture T-MASS®™wall system any longer. Assuming supply and cost were not an issue for the T-MASS®™product, to be production worthy some very significant changes would need to be made. Those changes would need to be reflected in the design, and manufacturing process in order to deal with some of the findings of our research , and the issues the builder evidenced. Therefore at this time the T-MASS®™wall system cannot be considered for stage gate advancement.

### *Wall system: 2x6 wood frame with Spray foam insulation*

This home as might be predicted came in a clear third place in this project regarding air tightness and energy efficiency. This home was originally intended to use Optimum Value Engineering (OVE) framing system With 2x6's 24 inches on center, but due to an over anxious construction superintendent was framed 16 inches on center using much more wood than the structural engineer intended. Since this home has been constructed with walls most similar to conventional construction it has become the reference, or control, home regarding comparisons. This home provided many lessons learned as well as interesting challenges due to air leakage. This home had the possibility of being the tightest and wound up being the leakiest of the four homes in this project.

Figure 19: 2x6 Frame House

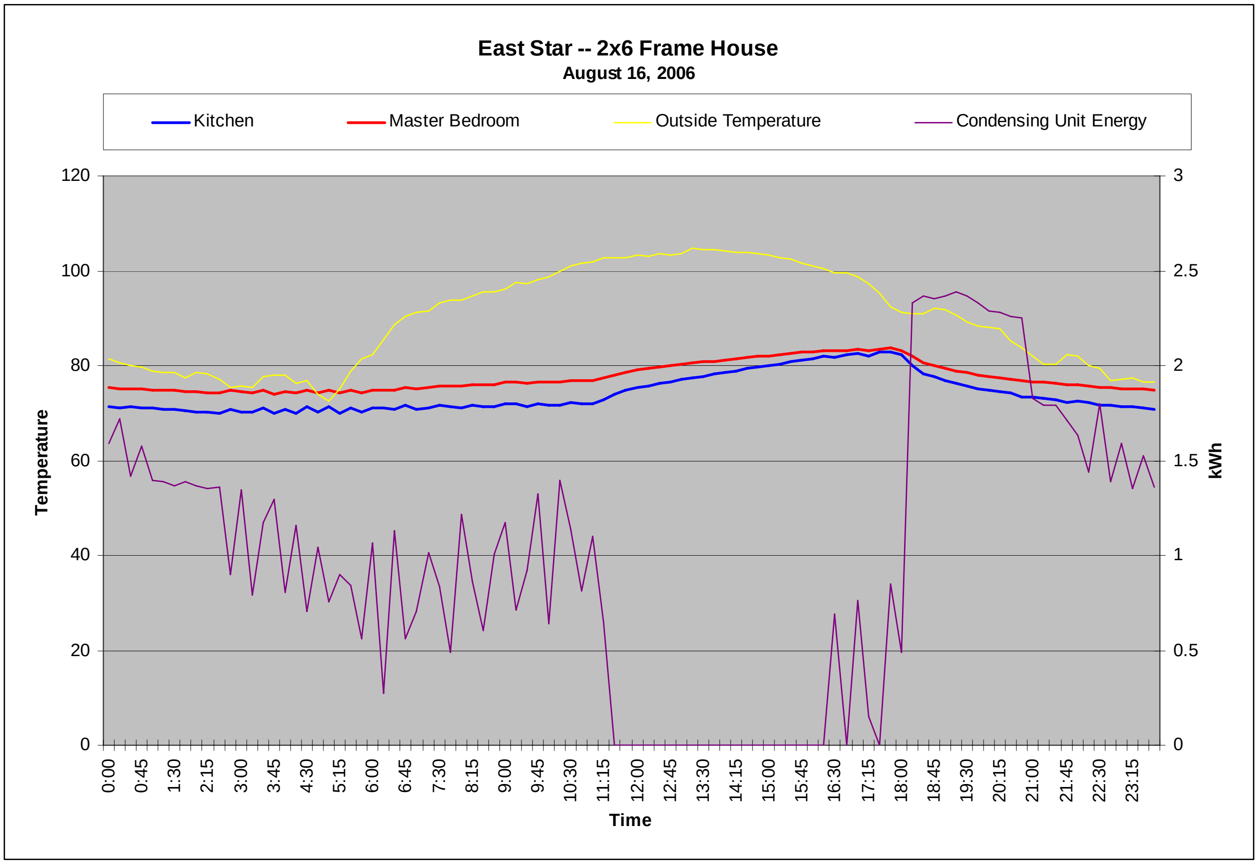

**Figure 20:: Pre Cooling Experiment -2x6 House**

## Findings

- This home after a few communication issues went from a test house to a control house in this our research. Past research has shown that this home was a good control home. This home was the only one that did not coast during the pre-cooling experiment as shown in figure 20.
- This home used radiant barrier roof sheathing which was not needed since spray foam insulation was to be installed under roof sheathing.
- When introducing a new building practice value engineering becomes very critical. This home was supposed to be OVE however the construction superintendent was under pressure to speed up construction and fell back to framing practices that he was familiar with ignoring the engineered drawings that were provided and built the home using standard framing practices.

## Recommendations

This home proved to be an example of the importance of communications throughout the entire process from design to construction and the need for close supervision and teaching anytime new practices are introduced, until they become the new routine.

## *Wall system: SIP*

The SIP wall system of the three homes did not perform as well as the T-MASS®™but if all of the principles of cost and transition to production were weighed, the SIP system was a clear winner. Findings will show the value of the SIP system not only in energy performance as well as in the delivery and construction process. From this project and lessons learned in the process from design to construction . Clarum homes has decided to utilize SIPS in future projects.

**Figure 21: SIP Home**

## Findings

- Figure 22 below shows how well the SIP wall system performed in August 2006 experiment with pre cooling. Like the T-MASS®™system the AC system never reached set point during the experiment and was able to coast over the twelve hour period. The temperature difference was greater than T-MASS®™ with a difference of 8.3 degrees.
- Overall in the heating season for this climate as shown in figure 10 above, SIPs were able to maintain a level of comfort and with minimal heating could achieve comfort levels with less energy. This project did not produce as tight of homes as BIRA had hoped based on general industry experience, however, past experience with SIPS has shown that this system with proper installation can result in a home with very low air infiltration.
- BIRA interviewed building partners who have used this system in the past. Comments below are findings that these interviewed builders concurred on:.

Pros:

- Once contractors were trained in standing and joining wall sections, process time to put up buildings was cut in half compared to conventional wall framing.
- A trained crew of 4 to 5 people could put up a SIP home, whereas it would take a larger crew with more extensive experience for typical wood frame.
- Shear strengths, and insulation requirements exceed structural and energy requirements
- Stiffer energy code requirements (IECC, California Title 24) are making it difficult to meet the demands with typical wood construction and alternatives systems need to be pursued.
- It is a simpler, faster way to achieve high energy performance homes.

Cons:

- Finding superintendents willing to try new construction methods and not charge too much to learn in the process.
- Foundations need to be level, for easy and proper panel installation
- There are inadequate provisions for electrical wiring.
- Panels cannot easily accommodate mechanical or plumbing.

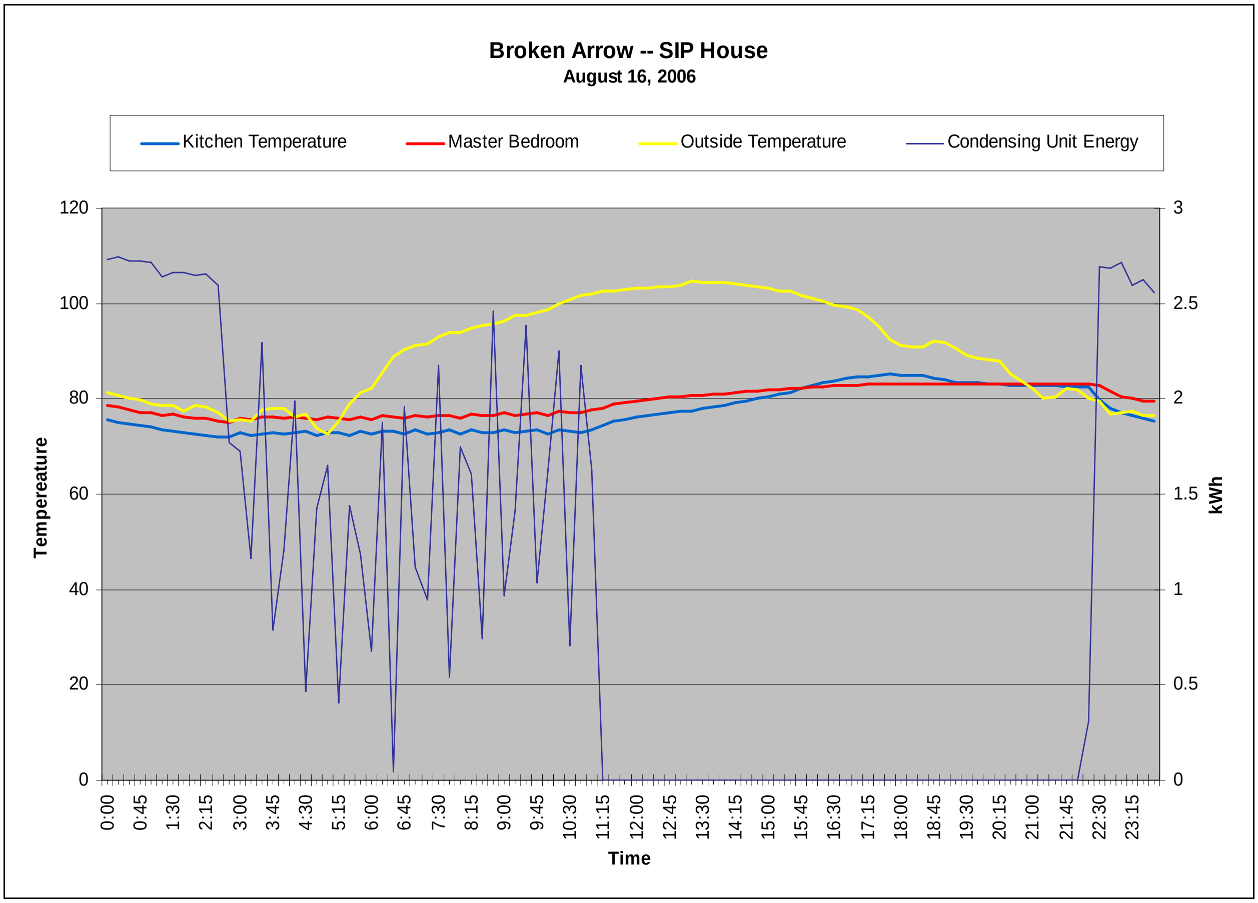

**Figure 22: Pre Cooling Test: SIP House**

## Recommendations

Most of the of the above "Cons" are issues relating to training and the understanding that SIP systems, although in the marketplace for many years, are still new to production home builders. Therefore, much if not all of these issues can be addressed as the SIP market penetrates into the production market as more innovative builder developers go through the learning curve of their early experiences of utilizing this more advanced wall system.

A transition from typical wood frame construction to SIPS will need to be looked at from the design stage to accommodate the plumbing and electrical issues. Builders will need to look at changes needed to accommodate the use of SIPS.

The value to the builder with relation to cost, design change, industry training needs be documented for this wall system to move from prototype to large production scale. BIRA will work with BA building partners to better qualify and quantify the savings to a builder using SIPS on larger scales.

# Conclusion

This final research report discusses results from BIRA's evaluation of systems installed in prototype homes designed to reduce overall residential building energy use by 40-50%.

Earlier reports examined the Borrego Springs projects' wall performance using nighttime pre-cooling. Results from the Las Vegas Vinings ZEH and standard 2x6 framed homes confirms the performance benefits of high-mass wall performance and nighttime pre-cooling strategies seen at Borrego Springs.

For the Hot/Mixed Dry climate, the introduction of mass has proven to be ideal but as stated prior the T-MASS®™alternative is to costly and not widely available. The ideal sandwich would be a hybrid of both SIPS and T-MASS®™. BIRA is currently in the prototype phase of using Concrete SIPS (CSIPs) in Fresno, California. From research findings in Borrego Springs a natural progression to a solution in this climate is the use of CSIPs. BIRA will be working with BA building partner Alvis Projects in the evaluation of TCLEAR's Protec® CSIP wall system. BIRA will test the value of less mass and monitoring this value in both heating and cooling in Fresno. The prototype home is scheduled for completion middle of the first quarter in 2008.

In summary, BIRA has moved forward from results from the Borrego Spring project ,and is proud to work with BA building partner Alvis Projects and industry partner TClear in the evaluation of there Protek® CSIP wall system. Alvis Projects will be incorporating the Protek® panel system in Citihouse II of the Fresno Green project combined with a concrete cap on the wood framed floor, double drywall on interior walls and a clerestory window to provide passive solar heating into the north side of the home in winter. The Fresno Green project is sponsored by the City of Fresno's Housing and Community Development Department. The goal of this project is to show the local building community that Green building could be affordable . This is one of three homes being built using a different wall system and incorporating different energy savings features. Citihouse II will also be evaluating NREL/DEG SunCache solar thermal system.

# APPENDIX A – Incremental Cost Tables

**Table 7– Incremental Costs – Marine Climate Homes**

| | Vented Crawlspace | | Sealed Crawlspace | |
|---|---|---|---|---|
| Component | Measure | Cost | Measure | Cost |
| Crawlspace | R-30 floor insulation | $1,279 | R-15 Perimeter insulation | $1,364 |
| | | | Additional "rat slab" with drain | $675 |
| | | | Additional crawlspace exhaust fan and grill<br>Or<br>Two Supply Ducts to crawlspace | $250<br>$30 |
| | | | Radon pipe from crawlspace | $405 |
| | | | Exterior Drain pipe/rock | $300 |
| Total Crawlspace | $1,279 | | $2,774-$2,994 | |
| HVAC | AFUE 80% to 94% with ECM (60K) | $850 | AFUE 80% to 94% with ECM (60K) | $850 |
| | Moving HVAC inside | $675 | Moving HVAC inside | $675 |
| Total HVAC | $1,525 | | $1,525 | |
| ENERGY STAR Homes Northwest | Duct Sealing with Mastic and testing | $850 | Duct Sealing with Mastic and testing | $850 |
| | Duct Testing and 3rd party verification | $400 | Duct Testing and 3rd party verification | $400 |
| | Envelope air sealing to beyond-code practice | $100 | Envelope air sealing to beyond-code practice | $100 |
| | Hot water heater upgrade – EF .58 to .61 | $150 | Hot water heater upgrade – EF .58 to .61 | $150 |
| | Attic insulation upgrade – R38 to R49 | $320 | Attic insulation upgrade – R38 to R49 | $320 |
| | 50% CFL Lighting | $120 | 50% CFL Lighting | $120 |
| Total ENERGY STAR | $1,290 | | $1,290 | |
| Incremental Cost – all upgrades | $4,094 | | $5,589 - $5,809 | |

## Table 8 – Incremental Costs – Cold Climate Homes

| | Vented Crawlspace | | Sealed Crawlspace | |
|---|---|---|---|---|
| Component | Measure | Cost | Measure | Cost |
| Crawlspace | R-30 floor insulation | $1,432 | R-19 batt insulation | $713 |
| HVAC | 9.1 HSPF/14 SEER Heat Pump with ECM – 2 ton | $1,620 | 9.1 HSPF/14 SEER Heat Pump with ECM – 2 ton | $1,620 |
| | Moving HVAC inside | $810 | Moving HVAC inside | $810 |
| Total HVAC | | $2,430 | | $2,430 |
| ENERGY STAR Homes Northwest | Duct Sealing with Mastic and testing | $270 | Duct Sealing with Mastic and testing | $270 |
| | Duct Testing and 3rd party verification | $203* | Duct Testing and 3rd party verification | $203* |
| | Envelope air sealing to beyond-code practice | $608 | Envelope air sealing to beyond-code practice | $608 |
| | Electric Hot water heater upgrade – EF .88 to .94 | $113 | Electric Hot water heater upgrade – EF .88 to .94 | $113 |
| | 50% CFL Lighting | $216 | 50% CFL Lighting | $216 |
| Total ENERGY STAR | | $1,410 | | $1,410 |
| Incremental Cost – all upgrades | | $5,272 | | $4,553 |

# Appendix B

## Reference Documents

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[a] Cubano, Abe; Shimamoto,Faith (2007) Results From Performance Evaluations in Preproduction Prototypes; Preprint 42pp; Building America Deliverable Number 16.B.2

[b] Shimamoto, Faith , Cubano, Abe(2006)Completion of Performance Evaluations of Preproduction Prototypes
; Preprint. 38 pp.; Building America Deliverable Number 12.C.2