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Formsulate Project Final Technical Report

Development and Demonstration of a Leave-in-Place Slab Edge Insulating Form System

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1. Executive Summary

Project Background

Concrete slabs represent the primary foundation type in residential buildings in the fast-growing markets throughout the southern and southwestern United States. Nearly 75% of the 2005 U.S. population growth occurred in these southern tier states. Virtually all of these homes have uninsulated slab perimeters that transfer a small, but steady, flow of heat from conditioned space to outdoors during the heating season. It is estimated that new home foundations[1] constructed each year add 0.016 quads ***annually*** to U.S. national energy consumption; we project that roughly one quarter of this amount can be attributed to heat loss through the slab edge and the remaining three quarters to deep ground transfers, depending upon climate. With rising concern over national energy use and the impact of greenhouse gas emissions, it is becoming increasingly imperative that all cost-effective efforts to improve building energy efficiency be implemented. Unlike other building envelope components that have experienced efficiency improvements over the years, slab edge heat loss has largely been overlooked. From our vantage point, a marketable slab edge insulation system would offer significant benefits to homeowners, builders, and the society as a whole.

Conventional slab forming involves the process of digging foundation trenches and setting forms prior to the concrete pour. Conventional wood form boards (usually 2 x 10's) are supported by vertical stakes on the outer form board surface, and by supporting "kickers" driven diagonally from the top of the form board into soil outside the trench. Typically, 2 x 10's can be used only twice before they become waste material, contributing to an additional 400 pounds of construction waste per house. Removal of the form boards and stakes also requires a follow-up trip to the jobsite by the concrete subcontractor and handling (storage/disposal) of the used boards.

In the rare cases where the slab is insulated (typically custom homes with radiant floor heating), the most practical insulation strategy is to secure rigid foam insulation, such as Dow Styrofoam™, to the inside of the wooden slab edge forms. An alternative is to clad insulation to the perimeter of the slab after the slab has been poured and cured. In either case, the foam must have a "termite strip" that prevents termites from creating hidden tunnels through or behind the foam on their way to the wall framing above. Frequently this termite strip is a piece of sheet metal that must be fabricated for each project. The above-grade portion of the insulation also needs to be coated for appearance and to prevent damage from construction and UV degradation. All these steps add time, complexity, and expense to the insulating process.

[1] An estimated 868,000 slab foundations in 2005

The Opportunity

Builders currently have the opportunity to install slab edge insulation on new homes, but as a rule they choose not to. Added cost, installation difficulties, construction slowdown, appearance, and termite issues (in some parts of the country), are all factors that affect their decision. A cost-effective, installer-friendly system could have huge market appeal. California, our target market for introduction of a slab edge insulation system, offers additional leverage to the situation. The statewide Title 24 residential energy code, the most aggressive in the nation, offers credits for perimeter slab insulation. Since the three year Title 24 update cycle has essentially harvested all of the low hanging (energy efficiency) opportunities, a cost-effective slab edge insulation system may well offer more bang for the buck than competing measures. These market forces should drive acceptance of a well-engineered, easy to install slab edge insulation product.

Formsulate Concept

The Formsulate concept developed in this project replaces conventional wood form boards with a PVC profile extrusion that is filled with rigid insulation treated with termiticide. The product includes linear couplers and interior and exterior corners to provide a professional looking product and to help streamline the installation process. The goal of this development project was to design and demonstrate an improved product and processes that save construction time compared to current slab edge forming practices, while providing insulation that substantially improves energy performance, offers value to builders, and reduces greenhouse gas emissions. The Formsulate system is shown in Figure 1 and Figure 2.

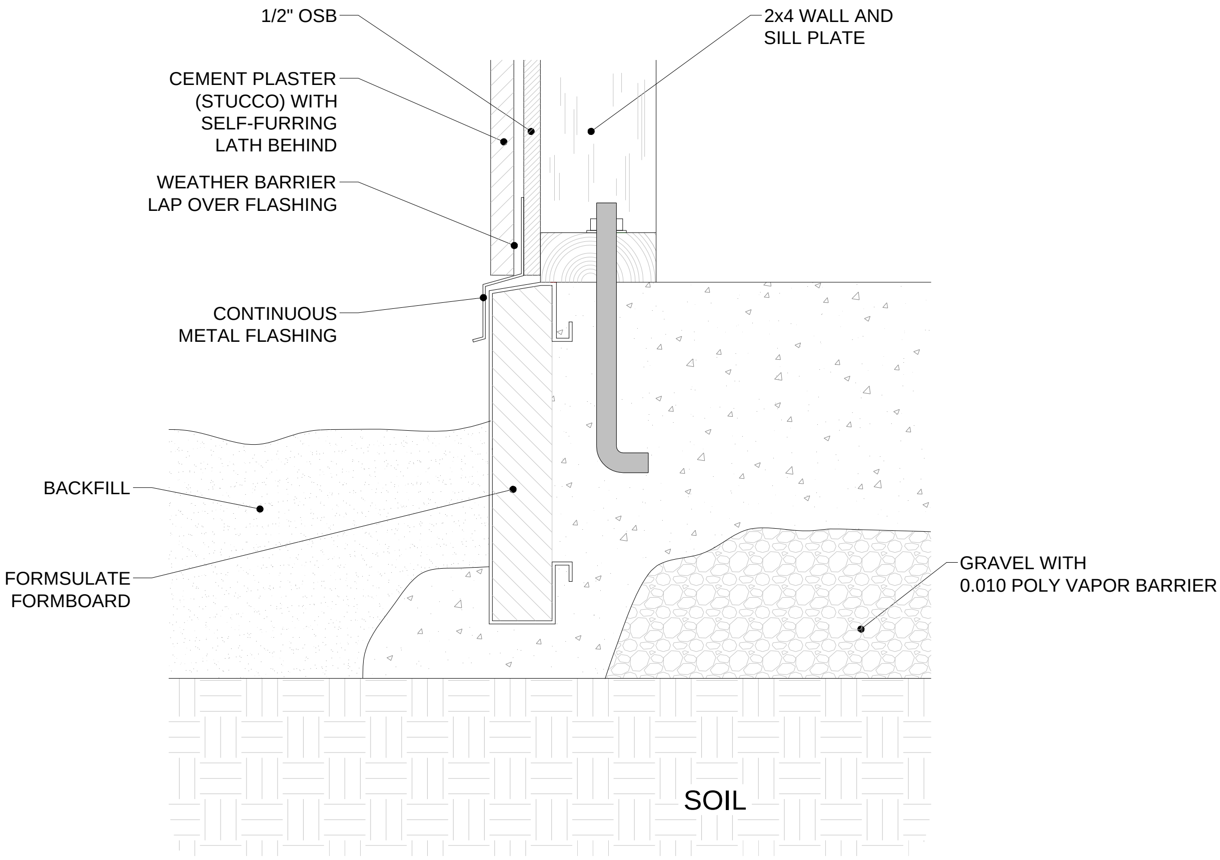


Figure 1: Formsulate Schematic

Figure 2: Formsulate Components

Project Objectives

The key project objective was to successfully commercialize a slab edge insulation form ("Formsulate") systems that has benefits for the builder (favorable costs offset with value from energy credits), operating cost savings for the homeowner, and societal benefits for all by reducing heating energy consumption and the associated environmental impacts. To successfully penetrate the production home construction market, the Formsulate system should provide the following benefits:

- Favorable builder economics
- Easy to install
- Proven termite mitigation
- Provide long-term durability

During the course of the project the popularity of post-tensioned slab construction in many regions of the country became evident. A project reach goal was added to design and demonstrate a Formsulate system that could accommodate both post-tensioned and conventional two-pour slabs.

Project Results and Accomplishments

This project spanned two NETL funding Phases. The first Phase ran from May 2005 through October 2006. Favorable Phase I progress and overall findings resulted in NETL extending funding for Phase II efforts. Phase II work, focused on finalizing the design and developing a market ready product, ran from October 2006 through August 2009. Key accomplishments by Phase are listed below.

Phase I

Task 1: Market Research. We completed a review of code issues and current slab construction practice with input from builders, concrete subcontractors, post-tension contractors, building officials, and other parties that influence the selection and specification of construction materials. We developed a detailed cost model based on two production scenarios, and a nationwide market analysis based on U.S. Census Bureau data for four different commercialization strategies.
Task 2: Insulation Optimization. A highly regarded TRNSYS three-dimensional finite difference model was used to evaluate potential Formsulate savings in five U.S. climates with three different insulation levels (R-5, R-10, and R-15). Reasonable national savings estimate for a typically sized new home with a central gas furnace is on the order of 60 therms per year for the R-10 case.
Task 3: Design Options and Details. We evaluated various design alternatives in terms of cost, ease of installation, durability, construction industry acceptance, and structural performance using Finite Element Analysis. We developed designs for the staking system, linear and corner joints, and evaluated each design for thermal expansion, termite resistance, weatherability and other issues. Together with Dow Chemical, we evaluated foam material options.

Task 4: Prototype Development. We selected an extrusion vendor and procured a die for the PVC profile. We installed both Styrofoam and foam-in-place polyurethane into profiles to create sample forms which then underwent strength testing. An interior staking system was prototyped and installation evaluated in a variety of soil conditions.

Phase II

Task 4b: Prototype Development. Based on our improved understanding of slab construction practice in much of California and other growth areas of the country, we directed project resources to designing a post-tensioned slab (PT) compatible Formsulate system. An initial design was completed, but projected tooling costs in addition to the conventional Formsulate design costs could not be accommodated within the existing project budget. Additional funding is needed to fully develop, refine, and demonstrate a PT Formsulate product.

Task 5: Mockup & Prototype Testing. A 10’ x 20’ slab was built with a heated structure above. The slab separated into two 10’ x 10’ halves by R-10 rigid insulation, had one side with uninsulated slab edge and the other side with Formsulate. Monitoring was completed in both forced air and radiant floor heating modes of operation. Results demonstrate the benefits of the insulated slab edge, as well as the higher edge losses during the floor heating mode of operation. Monitoring results were compared to TRNSED slab edge heat loss simulation results and found to be in good agreement.

Task 6: Field Testing. The goal of the field testing task was to install Formsulate in both custom and production homes. Given the housing market slowdown, finding and securing production home builders proved to be difficult. In the end, three custom home projects, ranging in size from 1,400 to 3,800 ft^2, were secured. Unfortunately the third site (3,800 ft^2) converted to a PT design at the last minute and dropped out. Installer and builder feedback from the remaining two sites was uniformly positive.

Task 7: Evaluation, Reporting, and Technology Transfer. As the Formsulate design process was moving towards completion, we engaged vendors, suppliers, and industry professionals to develop a product that was geared towards low-cost and meeting the needs of the foundation contractor. Builders were contacted both in one-on-one sessions and through venues such as the Pacific Coast Builders Conference. This project final report represents the culmination of this development project.

Market Viability

The potential market for a viable slab on grade insulation system is considerable. U.S. Census Bureau data indicate that 868,000 slab foundations were constructed nationally in 2005. The housing downturn has certainly tempered short term market projections, but construction should return to this level within five years. At this point, projected Formsulate costs appear to be competitive, especially in the current custom home market where slab edge insulation is typically installed with radiant floor heating systems. In the more cost-competitive production home market, Formsulate incremental costs present a marketing challenge. However in states with aggressive energy codes such as California, Formsulate cost effectiveness is likely considerably more favorable than competing measures that provide incremental efficiency improvements. The Formsulate cost structure and payback analysis are shown in Table 1. Projected savings are based on the detailed modeling completed in this study. Average assumed natural gas rate of

$1.50/therm is higher than current short-term rates, but reflects our estimate of costs in a few years when market demand increases and carbon taxes come into play.

Table 1: Formsulate Cost Model

Scenario	Low-Volume (Start-up)	Medium-Volume
# of Houses/Production Batch	50	1,000
Materials Subtotal per House	$895	$753
Markup	100%	50%
Wholesale Price per House	$1,790	$1,130
Annual Projected Savings	$90/year (60 therms/year)	
IRR (4% utility rate escalation)	8.5%	15.0%

Extensive communications with construction industry experts during 2005 and 2006 indicated a shift away from standard two-pour slab construction to a monolithic post-tensioned (“PT”) process in many areas where slab on grade construction is common. The PT process involves installation of steel tendons prior to the pour, with cable tensioning occurring after the pour. The significant market share of PT slabs strongly suggests that the Formsulate product should ultimately be made compatible with this construction process.

Termites represent a key code issue that must be successfully addressed for code acceptance in many jurisdictions. Formsulate has been designed to provide a continuous termite barrier and uses insulating materials that are treated with approved chemicals to resist termites from tunneling through the foam insulation.

Projected Formsulate National Energy Impacts

Based on the market analysis completed in Phase I, we estimate that 56,000 Formsulate homes will be built nationwide in the third year of product commercialization after the housing market returns to the construction rates of the early 2000’s. Based on estimated 60 therm/year national average estimated savings, we project the first-year energy savings of these homes will be 3.4 million therms. With a 20% annual growth rate in installations, cumulative Formsulate energy savings will total 214 million therms in the first 10 years after market introduction. In Califrona, sales should be positively influence by the latest Title 24 revision (takes effect January 2010), as builders search for the most cost-effective compliance options. Greenhouse gas reduction goals and other climate change initiatives will further spur conservation efforts resulting in greater demand of easy to implement products such as Formsulate.

Steps to Commercialization

We feel that the potential for a slab edge insulation product is significant and the market is primed for introduction of a viable product. In Phase I, we made significant progress in understanding the market, assessing potential savings, and developing a prototype design. Phase II funding allowed our team to refine the Phase I design, improve system cost, complete production tooling for the non-PT design, monitor Formsulate performance, and demonstrate the system in the field. The technology is now ready for marketing to the preferred radiant floor heating market. Additional funding is needed to fully develop a PT-compatible design suitable for commercialization. In August 2009, a proposal was submitted in response to NETL's American Recovery and Reinvestment Act's "Advanced Energy Efficient Building Technology" solicitation to complete PT development and demonstration and to perform market transformation activities.

2. Introduction

2.1. Background

Concrete slab-on-grade construction is the predominant foundation type for new low-rise homes in fast-growing residential markets throughout the southern and southwestern U.S. According to the National Association of Home Builders, over 2 million homes were built in 2005 (1.7 million single-family and 350,000 multi-family). U.S. Census data indicates that the six states with the greatest population increase from 2004 to 2005 (Florida, Texas, Georgia, California, Arizona, and North Carolina)[2] are all located in the southern tier where slab-on-grade construction is the predominant foundation construction technique. Improving the energy efficiency of production home slabs could have a noticeable impact on new home heating energy use. Since most "envelope" components in new buildings have evolved to fairly high levels of energy efficiency, the uninsulated slab edge stands out as one of the few building features that have not improved over the past fifty years. It is estimated that new home foundations add 0.016 quads annually to U.S. energy consumption; we estimate that ~25% of this is due to uninsulated slab edges.

Slab edge insulation is used on a small number of new homes, most commonly on custom homes with radiant floor heating. The current process is cumbersome, time-consuming, and costly. With typical slab-on-grade construction, the most practical insulation strategy is to secure rigid foam insulation (typically extruded polystyrene such as Dow Styrofoam™) to the inside of the wooden slab edge forms. An alternative is to attach insulation to the perimeter of the slab after the slab has been poured and cured. In either case, the rigid foam must have a "termite strip" (often a sheet metal piece) that prevents termites from creating hidden tunnels through the foam on their way to the wall framing above. In addition, high termite infestation areas require that below grade insulation have ICC approval for termite effectiveness. The above-grade portion of the insulation should also be protected both to prevent damage from construction, ultraviolet degradation, and "weekend warrior" shovels, as well as for appearance. For applications other than radiant floor heating, the high cost for slab edge insulation typically deters its use.

California is an ideal market for introduction of a slab edge insulation system, because the state's stringent Title 24 residential energy code forces builders to adopt increasingly costly measures to demonstrate compliance and also offers credits for perimeter slab insulation. Since a builder must invest in a variety of energy efficiency measures to demonstrate Title 24 compliance, the viability of a slab edge insulation product is further enhanced if it is more cost-effective than competing measures. Since the first increment of insulation is always the most cost-effective, the economics of slab edge insulation should be highly favorable. Title 24 also requires that all radiant-heated slabs have slab edge insulation. This represents a natural niche market for Formsulate since construction cost pressures are typically lower and the radiant heating market has struggled over the years to find the right insulation solution.

[2] Representing 57% of the total U.S. population growth in the year 2005.

2.2. Project Partners

The project team is comprised of Davis Energy Group, Dow Chemical, and Amaro Construction. Additional tooling and production support was provided by Dennis Hart, Profile Plastics, and Magic Plastics.

Davis Energy Group (DEG) has provided energy consulting and product development services geared toward energy efficient construction over the past 25 years. One product development involved a cooperative effort between DEG and the Certainteed Corporation. In 1993 Davis Energy Group (DEG) and Certainteed agreed to co-develop an advanced slab edge insulated form system. Certainteed extrudes unique plastic shapes for the construction industry. The two firms invested more than $50,000 over a two-year period before a management change at Certainteed ended the project. The effort resulted in completion of a substantial market analysis, development and refinement of a range of design concepts, and the completion of several initial prototype efforts.

Dow Chemical is a leader in science and technology, providing innovative chemical, plastic, building materials, and agricultural products to many essential consumer markets. Dow's strong connection to the building products industry and its key market position in both rigid polystyrene and spray urethane foams make it an ideal project partner.

Amaro Construction serves the California construction industry with Home Energy Rating Services for new and retrofit residential housing. Their connection to the building industry and experience with construction practices supported the market data collection and field demonstration portions of the project.

In addition to the formal members of the team, DEG cultivated relationships with builders, concrete subcontractors, post-tension contractors, and building officials to further the design and market acceptance of the slab edge insulation system developed in this project.

2.3. Objectives

The key project objective was to successfully commercialize a slab edge insulation form ("Formsulate") system that offers benefits for the builder (favorable first costs and potential energy credits), homeowner operating cost savings, and general societal benefits by reducing heating energy consumption and reducing wood waste, both of which offer associated environmental impacts. The insulated Formsulate form board takes the place of conventional wood forms, but remains in place to provide permanent slab edge insulation.

To penetrate the production home construction market, a successful slab edge insulation system should provide the following benefits:

- <u>Favorable builder economics.</u> By replacing the wood used in conventional forms, additional material costs can be minimized, and the concerns over form storage and disposal are eliminated. A conventional form board staking system provides a familiar solution to concrete subcontractors. Energy savings enhance marketability and elimination of wood form boards offers additional environmental benefits.

- Structurally sound and easy to install. Acceptance with concrete contractors depends on providing a product with adequate strength and ease of installation. The light weight of the Formsulate product and lack of need for storing and disposal (conventional wood forms) are clear product benefits.
- Accommodate post-tension process. Prior to the 2008 housing downturn, post-tensioned concrete slabs had developed a strong market position in the production home market in the Sunbelt states. The ability of the form system to accommodate the post-tensioning process is important for future broad market success. A description of the post-tensioning process can be found in Appendix A.
- Proven termite mitigation. Most of the residential slab construction market is in areas of heavy termite risk. To comply with building codes the form system cannot allow termites to reach the wood structure undetected, and should be made of termite-resistant materials.
- Long-term durability. As a permanent building product, the form materials must have a lifetime of 50 years or more. However, durability is most related to cosmetic appearance because the form is structurally loaded only during the concrete pour. Weatherability factors such as UV- and corrosion-resistance have the greatest impacts.

2.4. Phase I Accomplishments

The goal of Phase I was to update market research, analyze insulation performance, develop the Formsulate design including all accessory details, and fabricate prototypes of the basic form system. The Phase I work was divided into the following tasks:

Task 1: Market Research. We completed a review of code issues and current slab construction practice with input from builders, concrete subcontractors, post-tension contractors, building officials, and other parties that influence the selection and specification of construction materials. We developed a detailed cost model based on two production scenarios, and a nationwide market analysis based on U.S. Census Bureau data for four different commercialization strategies.

Task 2: Insulation Optimization. A sophisticated finite difference model was needed to understand the heat transfer processes between house and the ground in a variety of climates. We investigated available tools, selected a preferred model, and completed simulations to determine optimal insulation thickness in a variety of climates. Projected "typical" average national savings of 60 therms per year are estimated for an R-10 insulated 2000 – 2500 ft^2 new home with a central gas furnace.

Task 3: Design Options and Details. We evaluated various design alternatives in terms of cost, structural and thermal performance, ease of installation, durability, and construction industry acceptance. To optimize the extrusion design, we used Finite Element Analysis (FEA) and coordinated closely with the extrusion vendor. We developed designs for the staking system, linear and corner joints, and evaluated each design for thermal expansion, termite resistance, weatherability and other issues. Together with Dow Chemical, we evaluated foam material options.

Task 4: Prototype Development. We selected an extrusion vendor and procured a die for the PVC profile. The vendor developed the die and produced an initial run of 1000' of the profile.

Both DEG and Dow installed Styrofoam and foam-in-place polyurethane into profiles to create sample forms for strength testing. An interior staking system was prototyped and installation evaluated in a variety of soil conditions.

The Phase I final report can be found in Appendix B.

2.5. Phase II Accomplishments

The goal of Phase II was to finalize all aspects of the Formsulate system in anticipation of product commercialization, including:

- Finalizing extrusion design
- Procurement of all production tooling
- Development and fabrication of linear couplers, interior, and exterior corners
- Field thermal testing of Formsulate slab vs. conventional slab
- Field demonstrations at several new home construction sites
- Project management and reporting

Phase II accomplishments by task included:

Task 4b: Prototype Development*.* Based on our improved understanding of slab construction practice in much of California and other growth areas of the country, we directed project resources to designing a post-tensioned (PT) slab compatible Formsulate system. An initial design was completed, but projected tooling costs in addition to the conventional Formsulate design costs could not be accommodated within the existing project budget. Additional funding is needed to fully develop, refine, and demonstrate a PT Formsulate product.

Task 5: Mockup & Prototype Testing. A 10' x 20' slab was built with a heated structure above. The slab separated into two 10' x 10' halves by R-10 rigid insulation, had one side with uninsulated slab edge and the other side with Formsulate. Monitoring was completed in both forced air and radiant floor heating modes of operation. Results demonstrate the benefits of the insulated slab edge, as well as the higher edge losses during the floor heating mode of operation. Monitoring results were compared to TRNSED slab edge heat loss simulation results and found to be in good agreement.

Task 6: Field Testing*.* The goal of the field testing task was to install Formsulate in both custom and production homes. Given the housing market slowdown, finding and securing production home builders proved to be difficult. In the end, three custom home projects, ranging in size from 1,400 to 3,800 ft^2, were secured. Unfortunately the third site (3,800 ft^2) converted to a PT design at the last minute and dropped out. Installer and builder feedback from the remaining two sites was uniformly positive.

Task 7: Evaluation, Reporting, and Technology Transfer*.* As the Formsulate design process was moving towards completion, we engaged vendors, suppliers, and industry professionals to develop a product that was geared towards low-cost and meeting the needs of the foundation contractor. Builders were contacted both in one-on-one sessions and through venues such as the Pacific Coast Builders Conference. This project final report represents the culmination of this development project.

3. Design Development and Prototype Fabrication

3.1. Phase I

During Phase I of the project, three iterations of the Formsulate design were developed. (The design approaches and details are fully presented in the Phase I report.) The first design was completed immediately after the start of the project. Intended for use with conventional two-pour slabs, the design featured a PVC profile extrusion at the top edge for strength in the horizontal direction, but relied on extruded polystyrene insulation to provide strength from the top edge to the bottom stake connection point. The first Phase I design shown in Figure 3. includes an interior staking concept that eliminates any post-pour additional labor for stake and form removal.

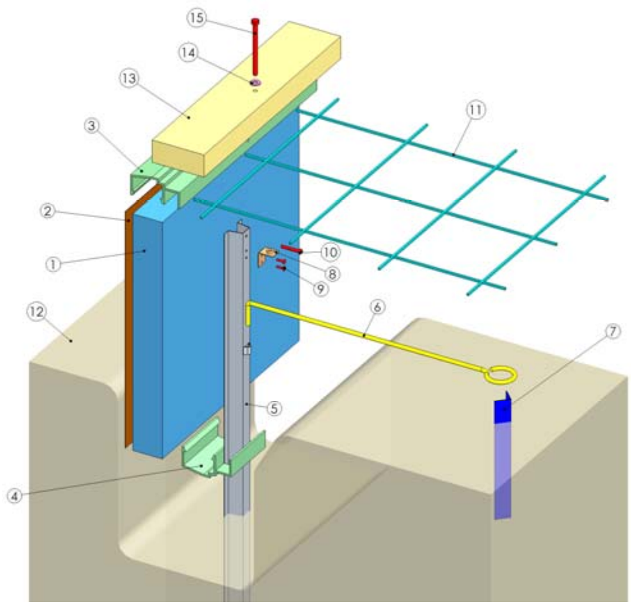


Figure 3: First Phase I Formsulate Design

After market research indicated that the majority of production homes were being built with post-tensioned slabs, the design was revised to accommodate post-tension cables and to be compatible with both a uniform thickness "monolithic" slab (trenchless) and a waffle slab (with perimeter and interior trenches). In contrast to the original design in which the PVC extrusion was used only at the top, Finite Element Analysis (FEA) indicated that a bottom extrusion was also needed to provide additional strength. The second Phase I design is shown in Figure 4. Holes would need to be drilled in the field to accommodate the post-tension cables.

FEA computer simulations reduced design cycle time relative to physical prototypes and optimize designs more accurately than would otherwise be possible without fabricating a large number of prototypes. FEA is particularly well suited to tooling-intensive production processes and homogenous materials such as plastics. Significant detail on the FEA design activities can be found in the Phase I final report.

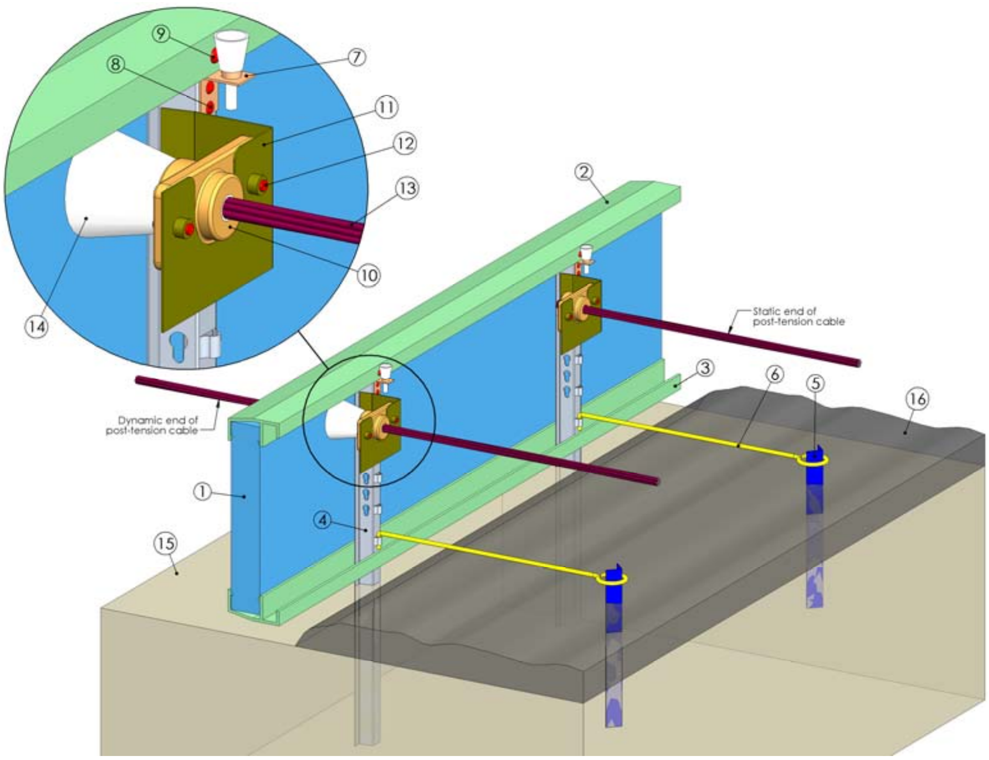


Figure 4: Second Phase I Formsulate Design

After learning more about weatherability and termite issues, we revised the design to use a closed PVC profile. FEA was used on both the extrusion and stakes to ensure sufficient deflection resistance. To reduce overall Formsulate costs, labor steps, and a potential tripping hazard associated with the prior interior staking system, we designed a staking system relying on only a diagonal stake just below the base of the extrusion. With these changes, we arrived at the final Phase 1 Formsulate design, shown in Figure 5.

The staking system was revised completely to use a diagonal stake just below the bottom of the extrusion, and the post-tension anchors were moved from the stake to decouple the PT anchor/cable spacing from the stake spacing. (PT cable spacing varies from 18” to 5’, with typical spacing of 24 to 30 inches. The stake spacing is nominally 3’, depending upon soil conditions and slab thickness.) This also eliminated the potential corrosion path through the stakes to the PT anchors and cables. A cross-section detail of the final Phase 1 Formsulate design is shown in Figure 6.

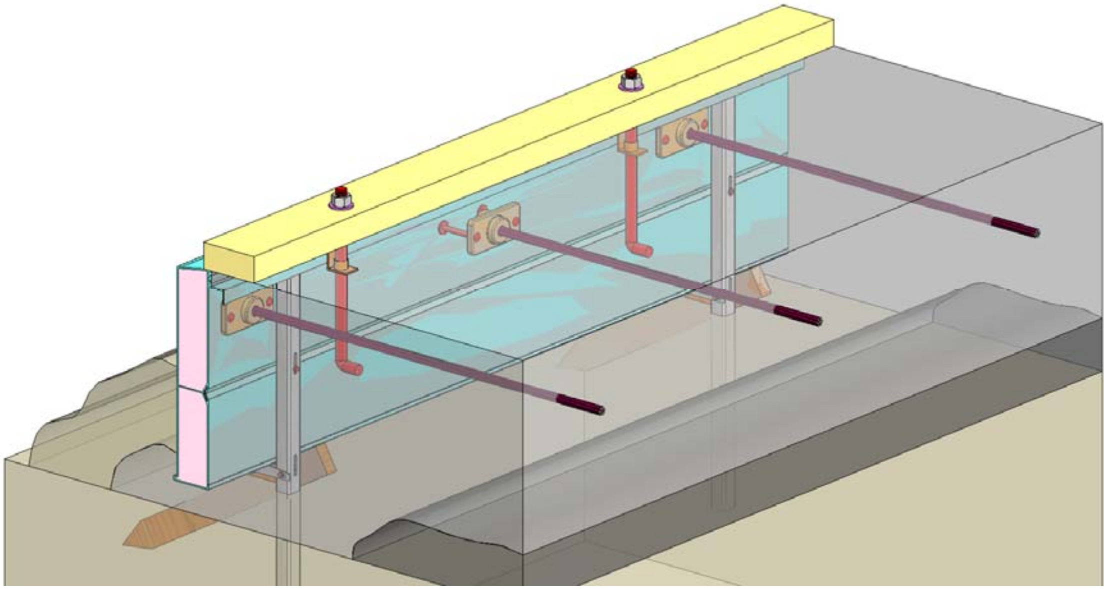


Figure 5: Final Phase I Formsulate Design

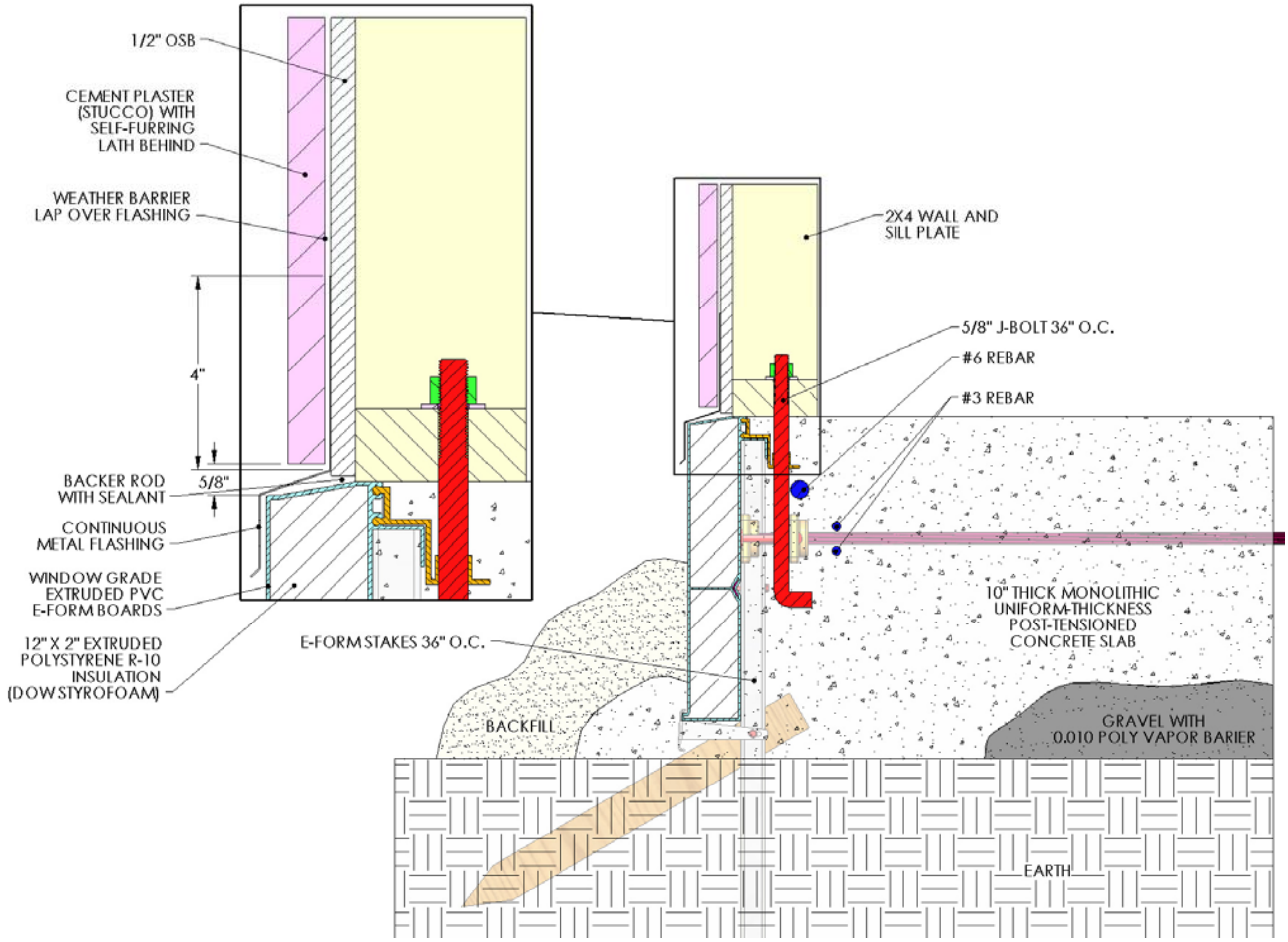


Figure 6: Cross-Section Construction Detail of Final Phase 1 Formsulate Design

At the conclusion of Phase I, the team investigated several corner and linear couplers and chose a strategy of fabricated corners with a simple H shaped extrusion for linear joints, as shown in Figure 7.

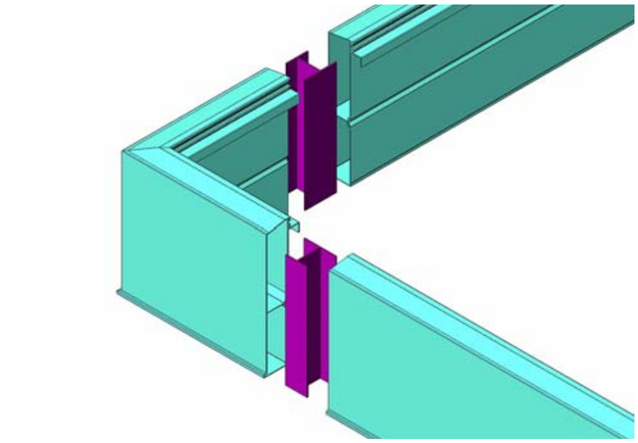


Figure 7: Corner and Linear Joiner Concept at End of Phase I

As part of Task 4, the team ordered extrusion tooling from Profile Plastics and 1000' of extrusion for Phase II activities. As with all Phase I designs, the final design used internal stakes. A sheet metal supplier fabricated 100 prototype stakes. A mockup of the final Phase I design is shown in Figure 8.

Key design elements include:

- PVC Extrusion. A rigid, closed design PVC profile provided the strength necessary to resist the static and dynamic loads of a concrete pour. The 12" tall profile included details for attaching an internal staking system and structural hold-downs, and includes a continuous horizontal strip that embeds in the concrete to prevent termites from passing between the form and slab. The profile had two hollows to accommodate 2" wide foam insulation.
- Foam Insulation. In Phase I we identified two leading candidates for foam insulation: extruded polystyrene foam (Styrofoam™) and polyurethane foam. Both foam materials have R-5 per inch insulative performance. At the time of completion of Phase I, Dow Chemical was preparing to begin production of Blueguard Styrofoam, a new termite-resistant insulation approved by ICC-ES for below grade use in heavy termite risk areas. The polyurethane foaming approach provides for greater form board strength, but does not resist termites.
- Stake system. All stake materials were originally designed to be installed inside the form board, eliminating the need for the concrete contractor to return to the site. The team attempted to develop a low cost system that can be quickly and accurately installed in a range of soil types, but was unable to develop a stake that could be driven into the hard summertime soils found in California.
- Structural hold-downs. A proposed track system at the top of the PVC profile would accommodate all popular structural hold-down products.

Figure 8: Mockup at Conclusion of Phase I

3.2. Phase II

Task 5 began with the first Formsulate installations, one for thermal testing at DEG's shop facility and another at a custom home project in Davis, California.

One of the main challenges encountered in Task 4 of Phase I was installation of foam in the PVC extrusion. Polyurethane pour-foam was used with some success, but required forms and careful control to prevent it from deforming the rigid PVC extrusion. At the start of Phase II, the team switched to using Dow BlueGuard Styrofoam extruded polystyrene insulation, which had recently received IBC listing in compliance with termite resistance. However, using the rigid BlueGuard meant that two different shaped foam inserts needed to be cut to fill each 8' length of extrusion. (BlueGuard availability is limited to 4 x 8 sheets, so four pieces would be required to fill a 12' length.)

Another major departure for the team was abandoning of the interior staking concept used throughout Phase I. Because internal stakes are encased within the concrete, the original Formsulate concept eliminated the need to return to the site to strip formboards or recover stakes. However, most homes include some portions that do not require insulation, such as garage stem walls. These use conventional forms and stakes, making it necessary to return to the site anyway. In addition feedback from concrete subcontractors questioned the benefit of an interior staking design both from an installation perspective and from a total system cost perspective. At the time, steel prices were skyrocketing as part of the bubble in commodity prices and prices are still high enough to preclude the viability of disposable stakes.

The team also had difficulty fabricating corner pieces for the Phase I design. Waviness in the extrusion made it impossible to precisely match surfaces for solvent joining. Available PVC solvent cement products require interference fit instead of a butt joint, so the team was forced to fabricate and rivet joiners from straight pieces of extrusion, as shown in Figure 9.

Figure 9: First Task 6 Installation (Davis, CA)

The standard Simpson® forming tool for suspending structural hold-downs (shown in blue) worked well screwed directly in to the PVC form. The holes were sealed afterwards and covered by a sheet metal flashing. As a result, the team chose to use these for future designs to take advantage of the low cost and wide availability of the Simpson product, rather than develop a custom injection-molded part that would use the track integral to the extrusion.

After these early installation experiences, the team concluded that the Phase I extrusion design needed redesign in response to the following issues:

- Double-hollow shape required excessive cutting and fitting of the foam
- High per-foot material content resulted in high costs
- Lower exterior lip interfered with stakes

Despite these shortcomings the Phase I extrusion *did* demonstrate that the basic concept was valid. The concrete bonded well to the PVC, and both the team and the concrete contractor felt that the extrusion was stiff enough to be used with similar stake spacings as wood formboards.

In addition to developing a new extrusion, the team also concluded that injection molded linear and corner couplers would be necessary. During Phase I, the team had hoped to be able to use Phase 2 resources to develop the ancillary parts needed to make Formsulate compatible with the slab post-tensioning process, despite the fact that this effort was not part of the original project scope. However, development and tooling costs for the new extrusion and couplers would consume a substantial portion of the remaining project budget. This meant that the team would have to minimize costs associated with field testing (Task 6) and severely curtail technology transfer activities (Task 7). Despite this, the team felt strongly that a revised Formsulate design would take advantage of the important lessons learned from the first extrusion, resulting in a higher quality product with a greater chance of widespread market success.

The primary departure from the Phase I design is that the Phase II extrusion design is an open **C**-channel shape. A single piece of rigid foam is used, and because of the great consistency in the Phase 2 design, the foam can be cut in bulk ahead of time. Four ½" wide pressure-sensitive adhesive (PSA) strips are strategically applied to keep the foam from moving during handling and to create a composite beam. As a result of these changes, both material and labor costs were substantially less than in the Phase I extrusion. The Phase II Formsulate design is shown in Figure 10.

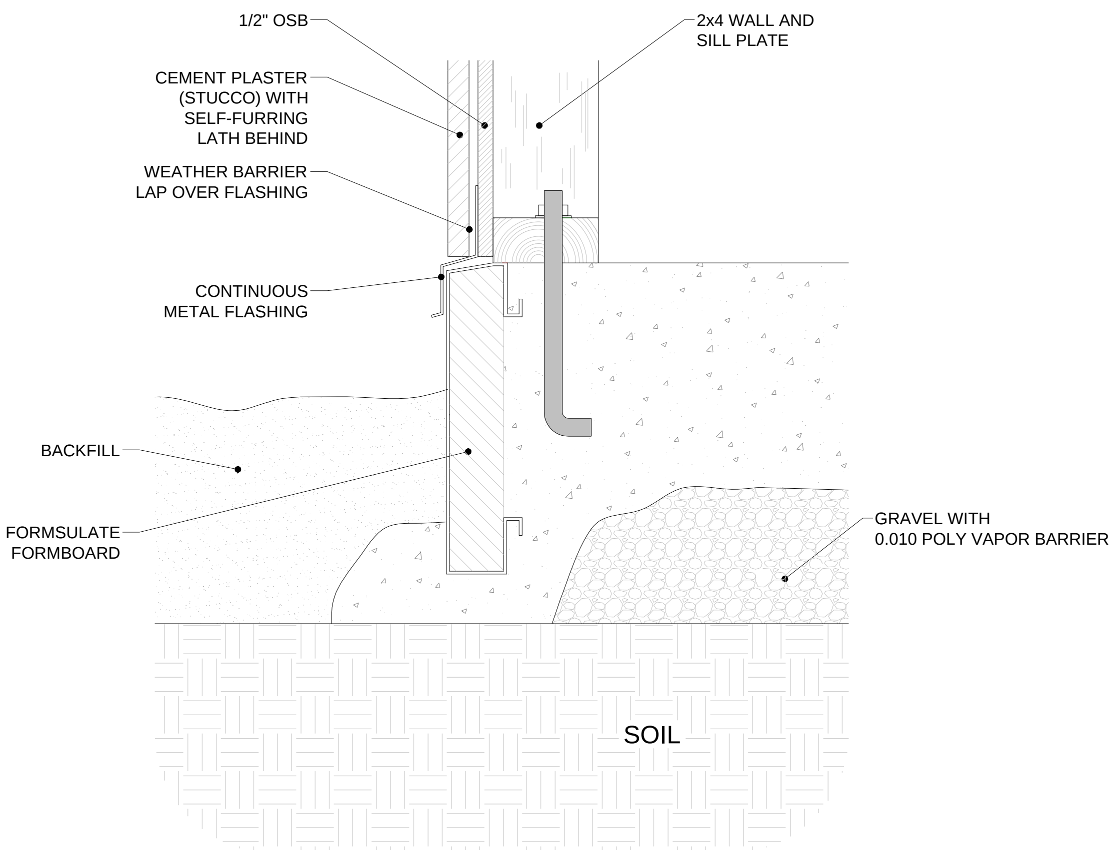


Figure 10: Phase 2 Formsulate Cross-Section Construction Detail

The team selected a new extrusion vendor, Profile Plastics of Hartsville, Ohio due to cost concerns and the Phase I vendor's desire to focus on core business opportunities. Die design, fabrication, and troubleshooting took about four months. After the team approved samples, Profile supplied 2000' of Phase II Formsulate extrusion, once again made from PVC. (PVC is sometimes derided for dioxin that may be produced during PVC processing; however the team felt that no other material, plastic or otherwise, could meet the project requirements for cost, rigidity, and weatherability.)

Early in Phase II, project partner Dow Chemical supplied 2000 board-feet of BlueGuard Styrofoam extruded polystyrene (XPS) for lab and field testing. BlueGuard had finally received its listing with the International Code Council Evaluation Service (ICC-ES) for ground-contact installation by demonstrating that termites would not eat BlueGuard (unlike conventional Styrofoam products). Together with the 2000' of extrusion from Profile, this was enough material for all Phase II activities. Figure 11 shows a short section of the Phase II extrusion filled with BlueGuard.

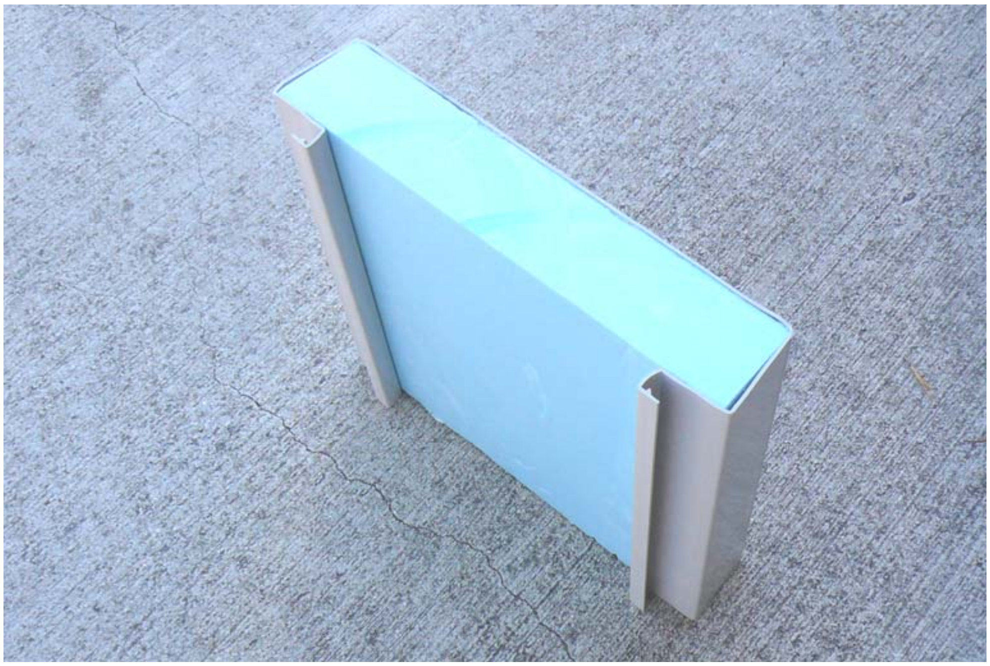


Figure 11: Phase II Extrusion (End View)

However in the fall of 2008, Dow Chemical chose to discontinue production of BlueGuard after less than a year on the market. This may seem odd in light of the long effort to get ICC-ES listing for Blueguard, but Dow underwent a company-wide restructuring due to the deteriorating economy, and the discontinuation of BlueGuard was collateral damage. As a result, the team has (at least) temporarily shifted to its backup foam option: borate-treated expanded polystyrene (EPS). Although not as rigid or as termite-resistant as BlueGuard,[3] borate-treated EPS has a much longer track record for use in ground-contact installations, and has been ICC-ES listed for many years. In addition, borate-infused EPS costs about one-third as much as BlueGuard and is available from several manufacturers in locations across the country. Dow has several Styrofoam plants, but had been producing BlueGuard only at their plant in Georgia.

Fortunately, Profile Plastics has an existing marketing relationship with Team Industries of Grand Rapid, Michigan, and a leading supplier of plain and borate-infused EPS for construction applications. Suppliers in California and Nevada would be closer to the initial California market,

[3] According to DOW

but the relatively short distance between Profile Plastics and Team Industries makes it possible to install the foam at Profile. Packing density is only moderately affected, and this integration of foam and extrusion at Profile limits the scope of the effort required to commercialize Formsulate from genuine manufacturing to simpler warehousing and logistics.

At Davis Energy Group, the linear and corner couplers were designed along with the revised extrusion. However, because of the high tooling costs associated with injection molding, the team chose to hold off ordering the coupler tooling until the first extrusion samples were delivered. Once ready, these samples were delivered to the injection molder, Magic Plastics of Valencia, California, so that they could match the couplers to the extrusion as much as possible. Although longer, this process results in better fit than “tolerance stacking.” Lead times for the injection molded parts were actually slightly shorter than the extrusion, despite manufacturing the molds in China, where the sample parts were run. Once the sample parts were approved by DEG, the molds were disassembled and shipped to Valencia, where Magic Plastics molded 500 of each part. This process took about four months from purchase order to parts received at DEG.

Magic Plastics’ tooling partner fabricated two molds. The first mold was a two-cavity mold that made two linear couplers in each cycle. The second mold was also two-cavity mold, but it produced one outside and one inside coupler in each cycle. Each cavity can be run separately in this mold (at a higher per-part cost), which is necessary because outside coupler are about three times as popular as inside couplers. Because of the high tooling costs ($18,250 for the linear coupler mold and $43,500 for the combination interior/exterior corner coupler mold, as compared to $8,525 for the extrusion) the team chose to make the corner coupler mold only after receiving samples of the linear coupler. This provided the opportunity to make any necessary corrections before the substantial outlay for the corner coupler mold.

When the first linear coupler samples were compared to the extrusion, the fit was good everywhere except at the very top, where the tapered angles differed enough to create a noticeable gap between the two parts as shown in Figure 12.

Figure 12: Excessive Gap at Extrusion/Coupler Interface

After conversations with both vendors, the team concluded that it was easier and cheaper to modify the extrusion rather than the injection molding equipment. However, after leaving the 6" thick extrusion die, the plastic profile passes through a vacuum calibrator for several feet. The vacuum holds the extruded shape against a segmented exterior profile as the plastic cools. After leaving the calibrator, the plastic is rigid enough to hold the shape. As Phase II was ending, Profile Plastics had completed modifications to the calibrator so that the extruded profile would better fit the couplers. It was not necessary to modify the tool, only the calibrator. The team chose to make the corner couplers match the geometry of the linear couplers, and gave Magic Plastics the go-ahead to begin mold production. The team was able to use the existing 2000' of extrusion for the Phase II activities. Early commercialization will use latest Formsulate extrusion. The finished Formsulate parts are shown in Figure 13, Figure 14, and Figure 15.

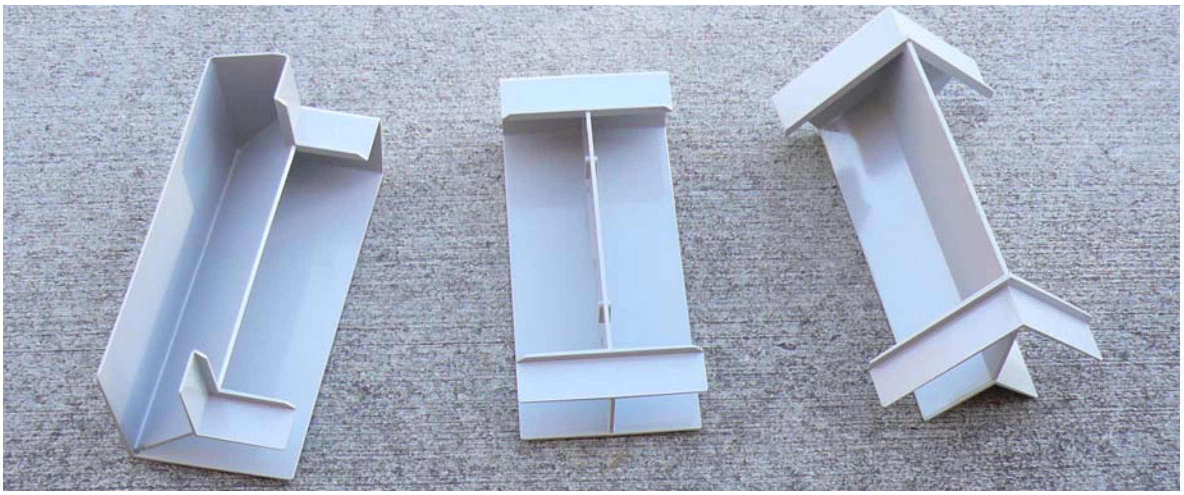


Figure 13: Outside, Linear, and Inside Couplers

Figure 14: Outside Corner, Extrusion, and Linear Coupler

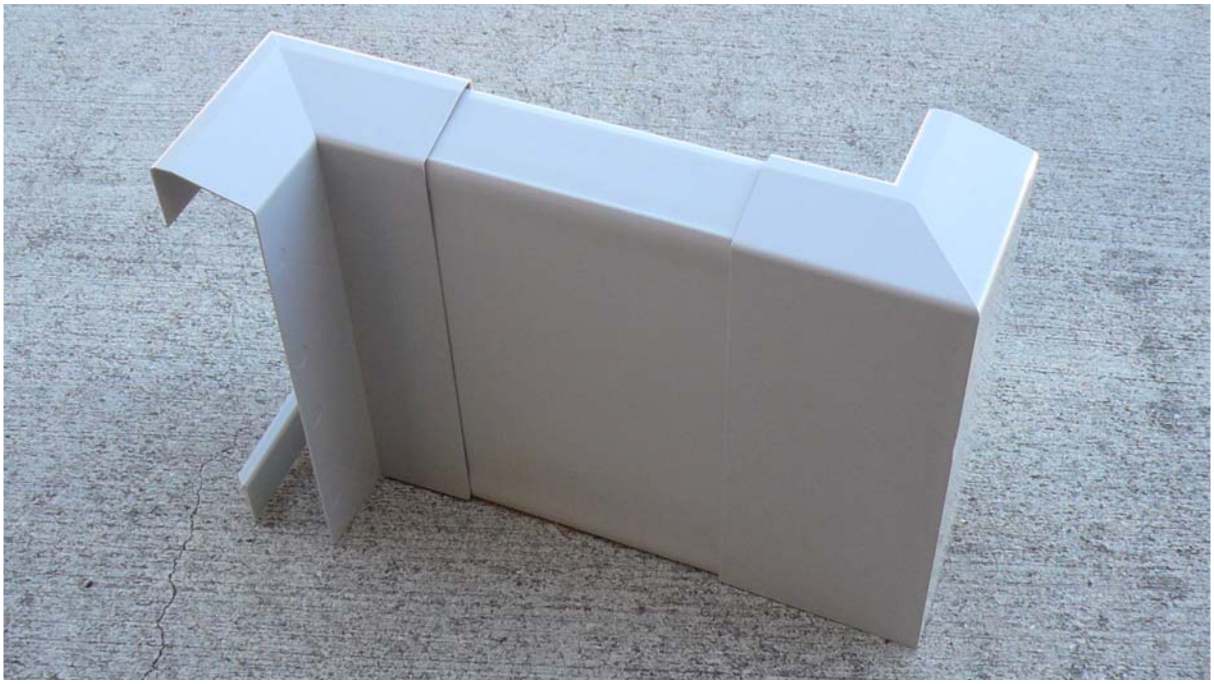


Figure 15: Inside Corner, Extrusion, and Outside Coupler

4. Detailed Ground Modeling

One of the more complicated areas in building energy simulations is to accurately model heat fluxes between a house slab, the soil below, and the slab perimeter edge. These heat fluxes are a function of many factors including:

- soil thermal characteristics (density, diffusivity, moisture content, homogeneity)
- deep ground temperature (primarily a function of latitude)
- climate
- the impact of varying soil strata close to the surface
- house geometry[4]
- conditions surrounding the house (snow, shading, pavement, precipitation, etc.)

A TRNSYS-based model developed by Thermal Energy System Specialists (TESS) of Madison, Wisconsin was ultimately used to assess expected energy impacts of slab edge insulation systems. The TRNSYS model was synthesized into a user-friendly TRNSED format that provides for a reduced set of data inputs specific to the application being evaluated. The TRNSED model utilizes a customized routine to model the energy transfers from the concrete floor slab to the soil beneath the surface and to the outdoor environment via the slab edge. The energy transfer is assumed to be conductive/convective only and soil moisture effects are not accounted for in the model. The model relies on a 3-dimensional finite difference model of the soil and solves the resulting inter-dependent differential equations using a simple iterative method. Heat transfers from the slab, the deep ground, and surface-influenced nodes affect the near-field soil temperatures. Figure 16 depicts examples of how the soil grid is developed for different applications. The finite element size is adjusted to focus maximum resolution in the areas where the highest resolution is needed.

The TRNSED model does have some modeling limitations. Due to the complexity of the finite element model and the need for a 15-minute time step, average model run times are on the order of three to four hours. To reduce this to a more manageable level, simplifications were made. By assuming the house has a rectangular footprint, symmetry allows for modeling only one quarter of the full slab footprint and associated underground thermal nodes. In addition, the rectangular assumption simplifies the finite element modeling by including only one corner to be modeled. This symmetry assumption is accurate for a rectangular slab configuration, but introduces some minor inaccuracy for “real world” slabs.

[4] A house with a square footprint would have a different “thermal bubble” under the house than a house with a large perimeter to area ratio.

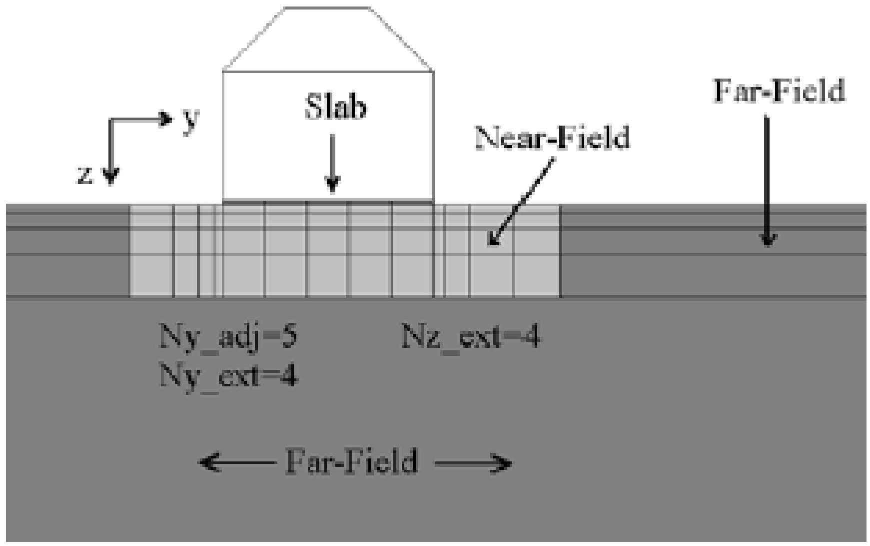


Figure 16: TRNSED Ground Modeling Configuration

The assumed characteristics of the prototype house used in the modeling, are as follows:

- Single-story 2,000 ft^2 house, with an exterior perimeter of 210 feet
- 20% glazing, uniformly distributed (100 ft^2 for each orientation)
- R-12 “average” walls and R-25 “average” ceiling
- Fixed heating and cooling thermostat settings of 70°F and 76°F, respectively
- 70% of slab area covered by R-2 carpeting; remainder hard surface flooring

Assumed soil properties were based on “heavy/damp soil” characteristics to reflect typically damp soil conditions during the winter months:

- Conductivity of 0.75 Btu/hr/ft-°F
- Density of 131 lbs/ft^3
- Thermal diffusivity of 0.60 ft^2/day
- Heat Capacity of 0.23 Btu/lb-°F

To evaluate the thermal performance impact of both traditional and post-tensioned slab construction, we modeled a “conventional” 4 inch thick slab with 12” x 12” perimeter footings and also an 8” monolithic post-tensioned slab. The TRNSED model has some constraints on how the model can simulate the insulating form, as shown in Figure 17. For footed slabs, 4” of slab is directly exposed to outdoors with the footing (and insulation, if present) extending 12” below grade. For the monolithic slab case, the full 8” slab is modeled as being exposed to outdoors. If insulation is installed, it is only assumed to extend to grade level. The net result of these assumptions is that footed slabs have less direct thermal connection to outdoor conditions and the impact of insulation is greater for the footed slab since the insulation is presumed to extend to the bottom of the footing. (The nominal Formsulate design has a height of ~12".)

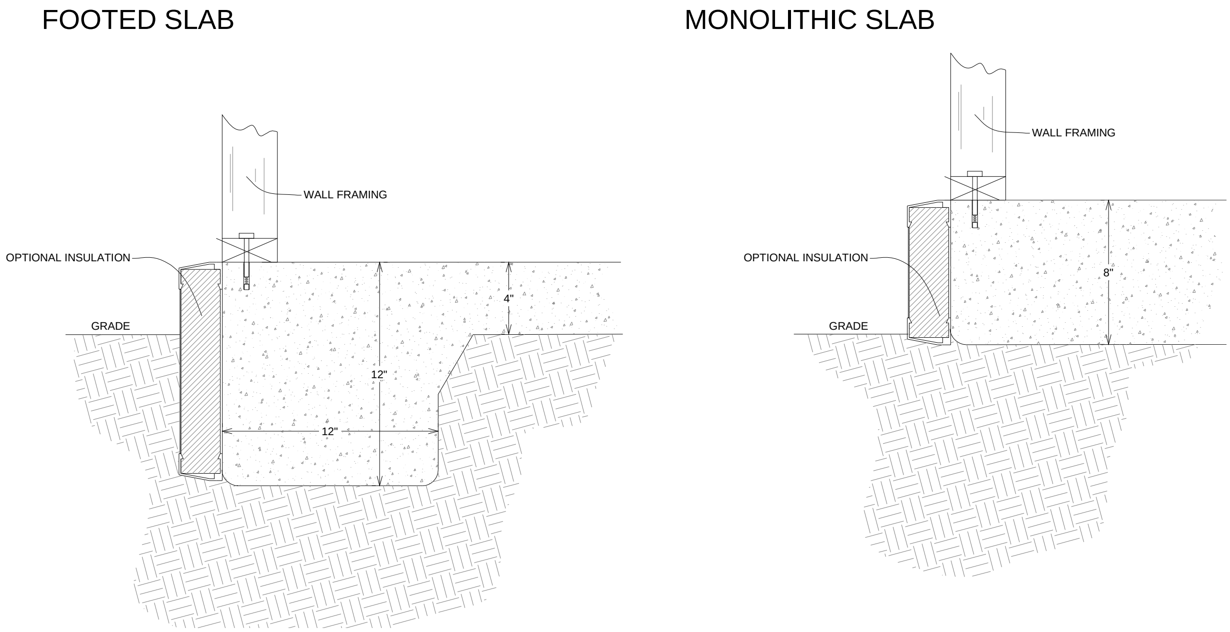


Figure 17: Ground Model Configuration

Five U.S. climates (Sacramento and Santa Maria, CA, Reno, NV, Ft. Worth, TX, and Atlanta, GA) were selected to evaluate the benefits of a slab edge insulation form system in different climates. Table 2 presents heating degree days and projected annual base case heating energy consumption for the five climates and two slab types. The higher heating energy use (on average 4%) is associated with the monolithic slab due to its greater exposure. Table 3 presents projected heating savings for insulation levels ranging from R-5 to R-15. The footed slab savings are greater because of the greater insulation depth. The monolithic insulated slab case still has a short path for heat to flow from the bottom of the slab. The incremental savings for additional insulation beyond R-5 is small for all cases, consistent with the physics of diminishing returns.

Table 2: Heating Degree Days and Base Heating Energy Use

Location	Heating Degree Days (base 65°)	Projected Annual Heating Use (therms)
Sacramento, CA	2666	478 – 500
Santa Maria, CA	2783	430 – 451
Reno, NV	5600	842 – 858
Atlanta, GA	2827	340 – 359
Ft. Worth, TX	2370	197 – 212

Table 3: Projected Annual Heating Energy Savings

Location	Footed Slab Projected Savings (therms/yr)			Post-Tensioned Slab Projected Savings (therms/yr)		
	R-5	R-10	R-15	R-5	R-10	R-15
Sacramento, CA	59	69	73	36	41	43
Santa Maria, CA	61	71	75	36	42	44
Reno, NV	101	117	124	58	65	68
Atlanta, GA	51	59	62	35	39	41
Ft. Worth, TX	35	40	42	24	27	29

Projected percentage savings reported in Table 3 range from 7-13% for the monolithic slab case to 12-21% for the footed slab. Footed slab savings projections are likely optimistic given the 16" assumed insulation depth. Savings in the 10% range are likely representative of expected system performance[5].

[5] At the time of completion of this report, an enhanced TRNSED model with greater flexibility and improved analytical capabilities has become available.

5. Thermal Performance Monitoring

5.1. Objectives

The primary goal of the slab monitoring effort was to instrument and monitor a heated "structure" with a slab on grade foundation. Half of the structure was insulated at the slab perimeter with Formsulate, and the other half had an uninsulated exposed slab edge. The above grade portion of the test setup was configured to be heated in either forced air mode or hydronic slab heating mode. The 10' x 20' structure was monitored with heat flux transducers, embedded slab and ground thermocouples, interior space temperature sensors, and an outdoor temperature sensor. The monitoring data would then be used in comparing to the TRNSED slab heat loss model to the extent possible. The validation effort is complicated by variations in soil properties and moisture levels that complicate the comparisons between field and model results.

5.2. Methods

To collect monitoring data a 10' x 20' slab was poured adjacent to the DEG workshop facility in Davis, CA. A small insulated "structure" was constructed on the slab and conditioned to simulate typical interior conditions within an occupied house. The slab was oriented with the longitudinal axis facing East-West to minimize differential solar gain impacts that might create unbalanced heating loads for one section relative to the other. The following figures document the construction and instrumentation of the test structure. Figure 18 depicts the slab during the forming stage with the insulated section shown at the rear of the photo.

Figure 18: Formed Slab Prior to Pour

Both slab sections had PEX hydronic tubing installed to allow for testing in radiant floor heating mode as well as conventional forced air (resistance heat) mode of operation. Figure 19 shows the slab forms prior to the concrete pour with thermocouples located on the steel mesh at the slab mid-point. Figure 20 shows the slab immediately after the pour with the PEX hydronic tubing penetrating the slab. Finally, Figure 21 shows the partially framed structure being constructed. The short walls and roof were insulated, and the slab floor was covered with a carpet and pad to mimic typical thermal connection between the interior space and the floor slab.

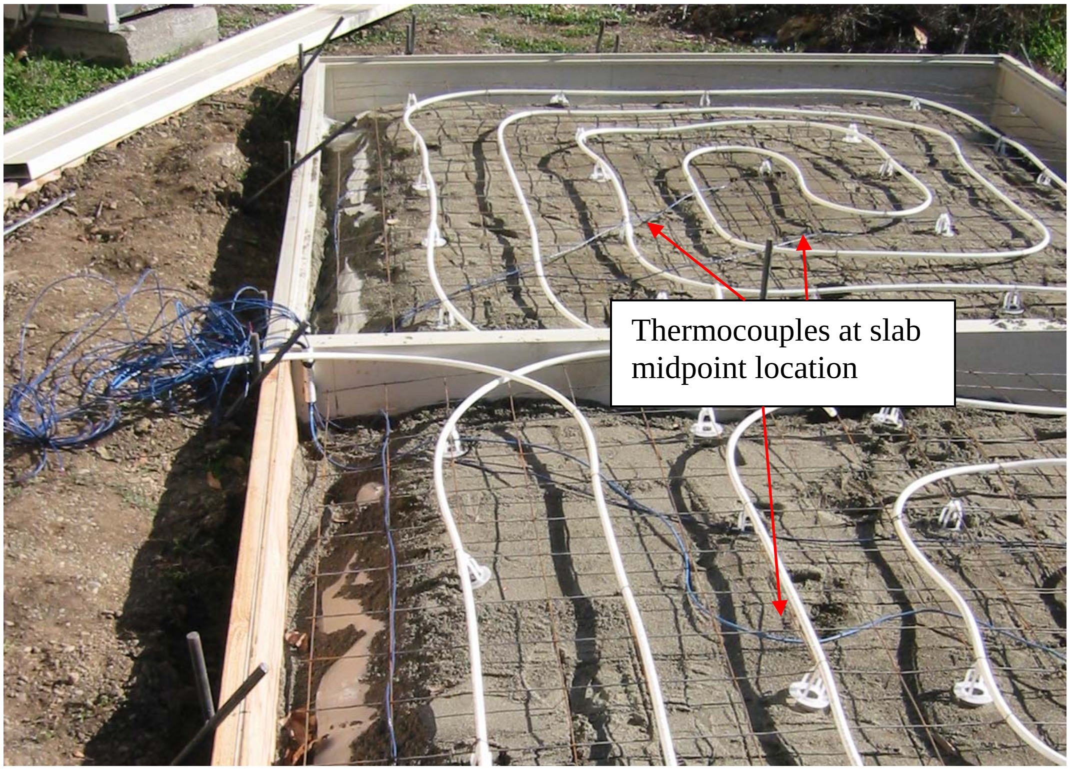


Figure 19: Hydronic PEX Tubing and Slab Thermocouple Installation

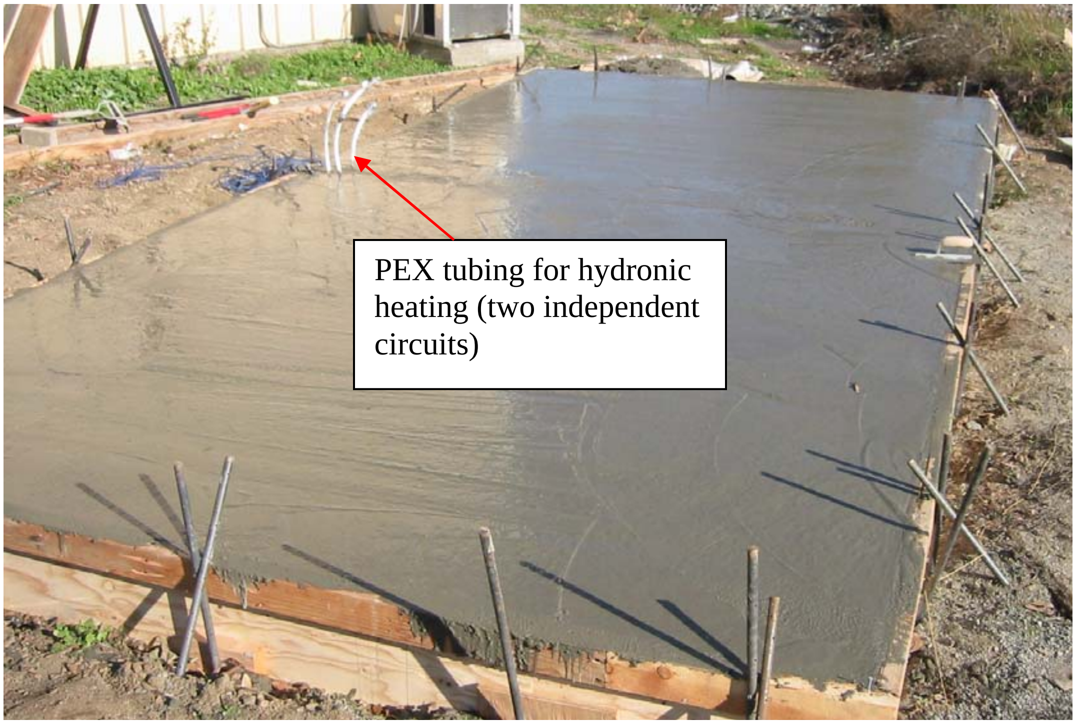


Figure 20: Slab After Pour

Figure 21: Framing of Above Grade Insulated Walls

Figure 22 shows a plan view of the structure with thermocouple ("T") and heat flux ("HF") sensor locations shown. As shown in Figure 19, thermocouples were located in the center of the six inch slab with T2 and T5 centered in the 10' x 10' slab, and the others located 12" from the slab exterior. In addition to the six slab thermocouples, a second set of six thermocouples were installed directly below T1-T6, at a depth of 12" below grade. The HF sensors, located at mid-height of the exposed slab, provide a snapshot of the heat flux through that portion of the slab. To fully characterize the slab edge heat loss, a grid of sensors would need to be employed on both insulated and uninsulated slab sections. This would be a costly proposition. A second order effect that complicates the use of the heat flux sensors to characterize "whole building" effects is the extent to which Formsulate affects ground temperature patterns under the slab, since reducing edge losses results in more downward heat flow.

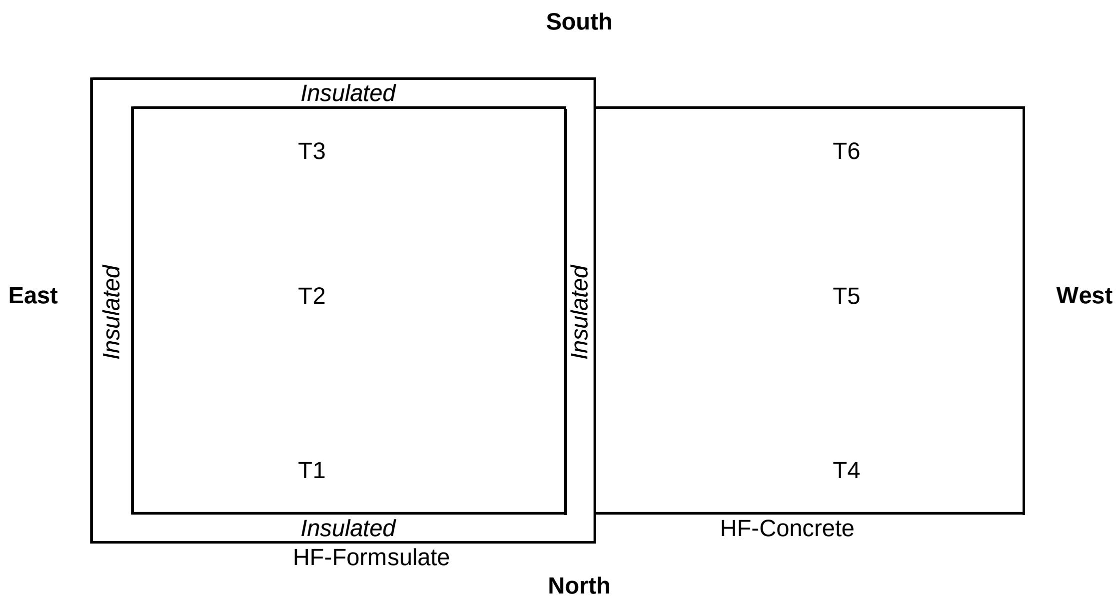


Figure 22: Location of Thermocouple and Heat Flux Sensors

A Data Electronics DT50 datalogger was installed and programmed to scan individual channels on 15 second intervals, and log average temperatures at 15 minute intervals. All the thermocouples were cross-calibrated prior to installation. The Vatell BF-03 heat flux transducers were installed at the midpoint of the exposed slab edge. For the insulated section, the transducer was installed on the Formsulate exterior face, and for the uninsulated section the sensor was installed on the bare concrete slab edge. To minimize air voids underneath the transducer, the rough slab edge surface was finished with a fine-grain cementitious product that provided better thermal contract with the concrete slab edge. Outdoor temperature and interior temperatures in each section were monitored using Type T thermocouples. Structure interior temperature sensors were used as datalogger control inputs to activate relays controlling the electric resistance heater or the hydronic circulating pumps, depending upon the mode of heating operation. Specifications on the monitoring hardware are provided in Table 4.

Table 4: Sensor Specifications

Type	Application	Accuracy/Sensitivity
Special Limits of Error Type T Thermocouple	Indoor, outdoor (shielded), in-slab, and in-ground temperatures	±0.5°C, or 0.4% of reading, whichever is greater
Vatell BF03 heat flux transducer	Slab edge heat flux	Factory calibrated to NIST traceable reference. Sensitivity of ~ 70mV/W/cm^2
Onicon System – 30 Btu meters	Energy Delivered to space	Flow: ±0.5% at calibrated velocity Differential temperature: ±0.15°F Computational error: ±0.05%

By operating experiments in both forced air and slab heating modes, we planned to characterize the relative impact of slab edge insulation in each mode. The testing began with forced air heating operation beginning in the late winter of 2007. An electric resistance heater located in the center of the structure was controlled to maintain a uniform 68°F temperature. An oscillating fan ran located in the structure, ran continuously to circulate heat uniformly. In January 2008, the hydronic heating mode was activated. Since Btu meters were installed on each of the hydronic loops, an interior partition was installed separating the Formsulate and uninsulated sections. The circulating pumps were individually controlled based on the corresponding interior temperature.

5.3. Results

The monitoring installation was completed and commissioned in February 2007. Initial data were collected through the remainder of the 2007 winter, but a mild spring required additional testing beginning in mid-November 2007. During the forced air testing, an interior thermocouple was used to control a resistance heater to maintain a uniform 68°F air temperature within the space. An oscillating fan provided air movement within the structure to maintain uniform interior temperatures. A second phase of testing utilizing the hydronic heating was initiated on January 30, 2008. Btu meters were installed on each of the two hydronic loops, one serving the Formsulate side and one serving the uninsulated side of the shed[6]. Varying heat losses, presumed to be entirely due to the presence of the slab edge insulation, would dictate the pump run time on each side of the shed.

Figure 23 shows ten days of the 15-minute interval hydronic monitoring data. Outdoor temperature is logged, as well as indoor temperature for each side (insulated and uninsulated), and Btu's delivered to each side, as reported by the Btu meters. Outdoor temperatures during the period ranged from 40 to 75°F. Indoor temperature variations between the two sides were minimal, even during daytime periods when solar gains would typically drive interior temperatures to ~80°F. The rate of AM indoor warm-up and PM cool-down are almost identical,

[6] To thermally separate the above grade sections, an insulated interior wall was added.

suggesting that the thermal characteristics of each half are fairly consistent. Heating via the individual hydronic loops occurred each night. The orange and green lines represented the energy delivered to the uninsulated and Formsulate halves, respectively. Over the ten day period, the amount of energy delivered to the Formsulate half was ~ 40% less than the uninsulated side. This result, although impressive, should not suggest that real world savings are in the range of 40%, since the test configuration is biased towards ground losses relative to above grade envelope losses (i.e. above grade heat loss per ft^2 of slab area is considerably less than that for a real house).

Heat flux data during nighttime hours (9 PM to 6 AM) were then plotted against outdoor temperature to demonstrate the impact of the insulated form board. Figure 24 plots 15 minute average heat flux for the forced air mode of operation and Figure 25 plots similar data during hydronic heating operation. The uninsulated slab edge data show a greater spread in results than the insulated data. This may be due to a variety of factors including proximity of the heat flux sensor to a slab heating tube, greater heat transfer variability due to higher edge temperatures, or radiative effects. Slab edge heat loss is about 90% lower for the insulated case than for the uninsulated case. Comparing the hydronic heating regression line to the corresponding forced air regression line suggests that slab edge losses in radiant heating mode are ~50% higher (at a 40°F outdoor temperature) than in forced air mode. This is consistent with our expectation that heat loss from a radiant heated slab should be considerably higher than a conventional unheated slab.

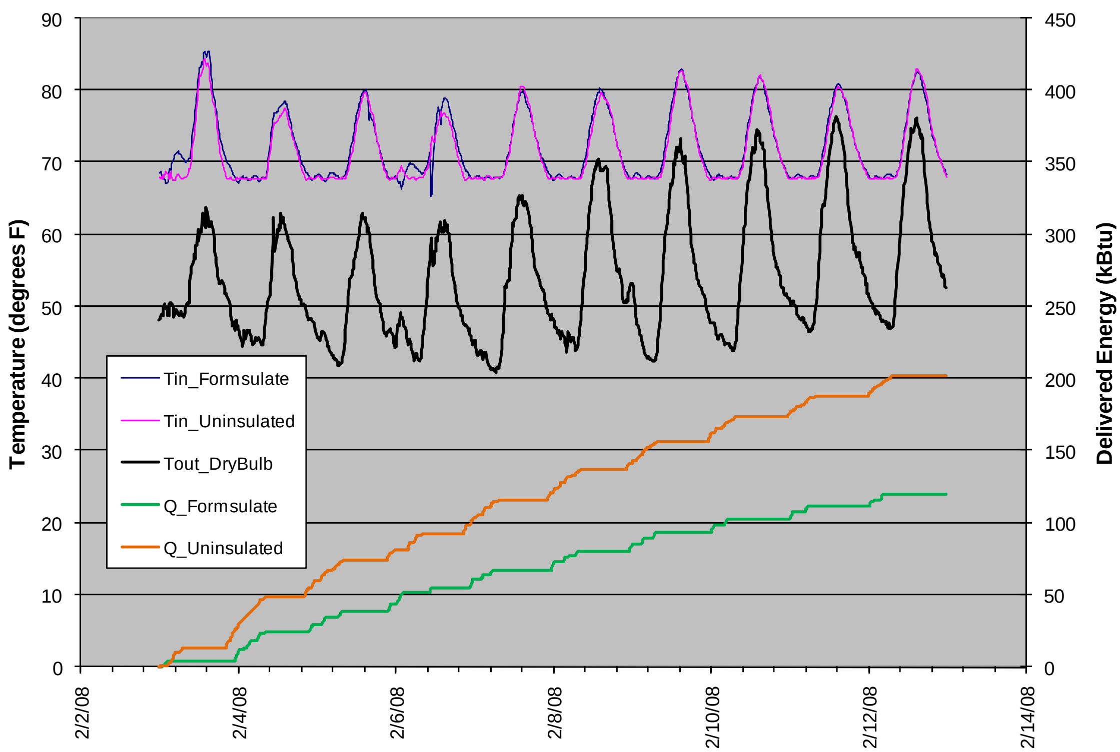


Figure 23: Hydronic Heating Mode Energy Delivered and Temperature Profiles

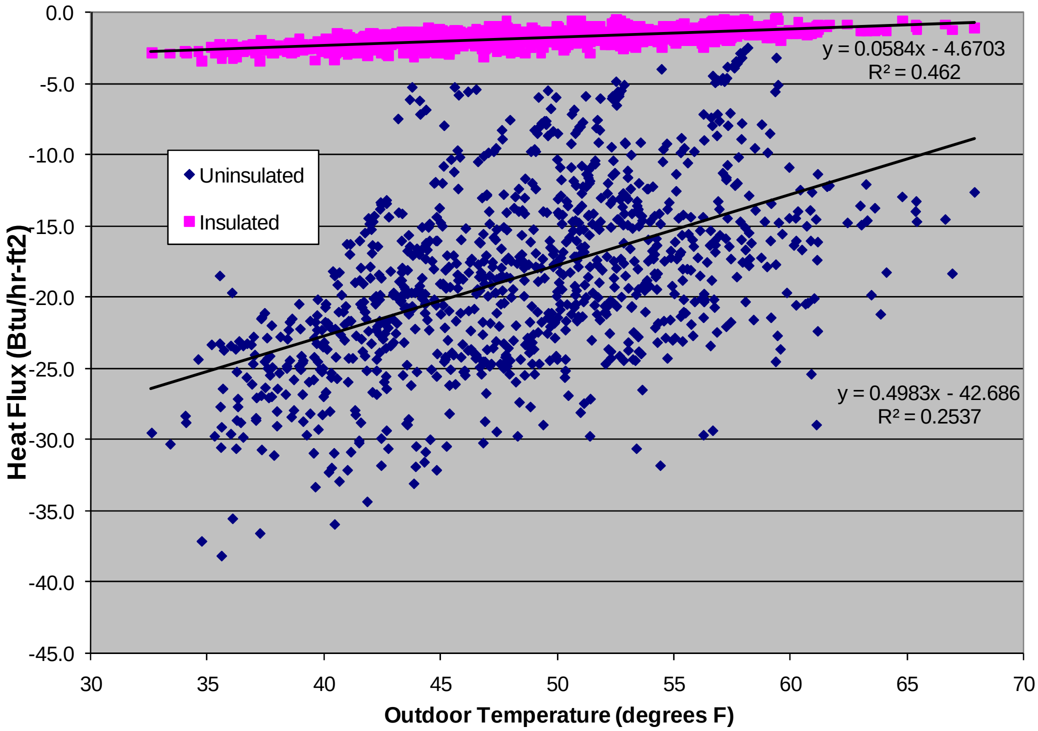


Figure 24: Hourly Heat Flux as a Function of Outdoor Temperature (Forced Air Mode)

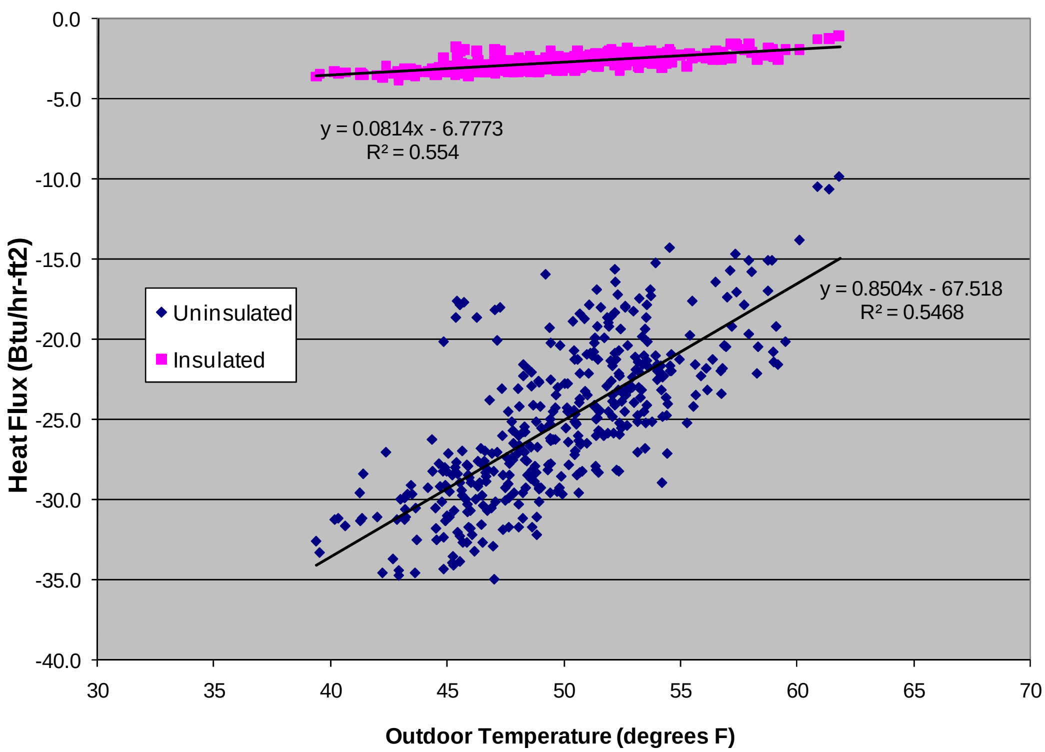


Figure 25: Hourly Heat Flux as a Function of Outdoor Temperature (Floor Heating Mode)

A final step in the performance assessment process is to compare field results relative to the TRNSED model projections. Hourly TRNSED output data generated from two Sacramento simulations (with and without R-10 edge insulation) were compared to assess the magnitude and source of projected heating season benefits. The TRNSED model outputs hourly building heating load, as well as slab top, side, and bottom heat fluxes. Figure 26 plots the full year and winter energy impacts ("+" = energy reduction, "-" = energy increase). Formsulate annual heat flux reductions are projected to be in the 11-17% range, with the higher reductions during the November – April heating season. Formsulate slab edge heat loss reductions are projected at ~88% relative to the uninsulated base case. Slab bottom (downward) heat loss is actually 5-8% greater with Formsulate, as the heat flow path is directed more downwards rather than towards the slab edge. The net impact for this Sacramento case is an overall 13% reduction in house heating load.

The rightmost two bars in Figure 26 compare the monitored edge loss results to TRNSED results. Hourly monitored edge loss was calculated based on the regression relationships in Figures 24 and 25 and the hourly temperatures used in the TRNSED simulation. The 88% TRNSED projected edge loss reduction is very comparable to the 88-91% range shown in Figure 26.

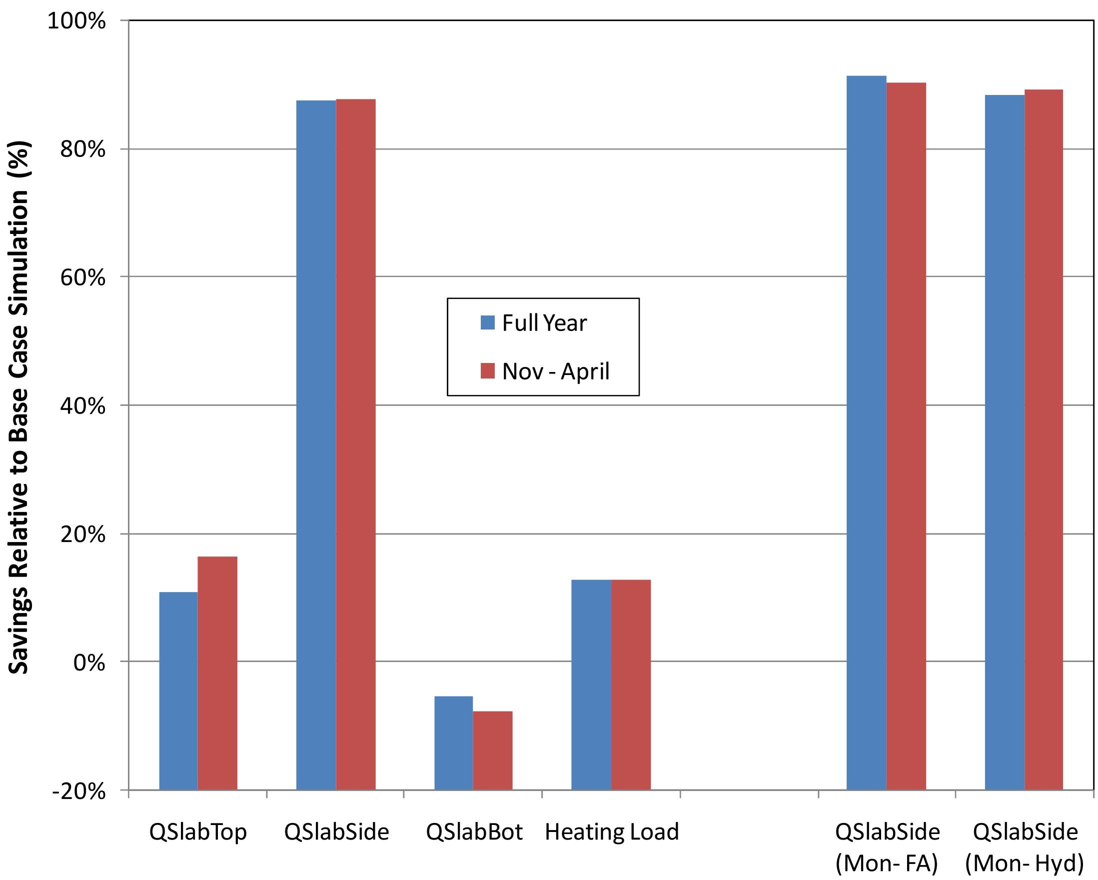


Figure 26: Comparison of TRNSED Results (R0 and R10 Edge) and Monitored Results

6. Phase II Formsulate Field Demonstrations

The following sections describe Formsulate field installations and provide feedback from the installing contractor.

6.1. Davis, CA Custom Home (December 2006)

In Fall 2006, DEG became aware of a local custom home project that was interested in using the prototype Formsulate product. DEG was interested in getting an initial field assessment of the Phase I designed form board, despite the fact that corner parts and linear couplers were not yet available. DEG met with the installing concrete subcontractor to present the prototype product and discuss staking options. The sub was firm in stating that he preferred to stake the material in a manner identical to a wooden form board. In December 2006 the Formsulate form board was installed with DEG staff working with the concrete subcontractor. The installation went relatively smoothly with only minor problems. Figures 27-29 show different stages of the Formsulate installation.

Figure 27: Staked Formsulate Prior to Pour

Figure 28: J-Bolt and Rebar Installation Details

Figure 29: Finished Slab

Concrete subcontractor Dave Leal's response to the installation survey follows.

1. **What did you like about how the system installed?**
   The installing contractor was very positive about the system and felt that the installation "turned out better than he thought it would." He thought that his crew would get a lot better at it over time and with some practice. He liked the interlocking foam and adjustment ability that meant the lengths didn't have to be spot on. The forms were very straight and easier to get level than wood. He liked not having to pull (and store) wood form boards and that the concrete doesn't stick to the PVC skin and is easy to clean.

2. **What didn't you like about the system?**
   - Some cut to the wrong length (panels were pre-cut in shop)
   - Needs a rib on the bottom inside to hold to the concrete
   - Angle on top on the form not so good
   - Rivets for the splice sections 'gotta go' (*Note: this was a temporary fix, since corner and coupler parts were not yet available*.)

3. **Does it appear to be durable enough?**
   This version is a little less stiff than the original one he saw (w/ two part foam.) However he didn't seem to feel like that was too big a deal.

4. **What suggestions do you have to improve the product?**
   Add interior rib on bottom to hold to concrete at both top and bottom. He also would like to need fewer different tools (i.e., all screws; the same screws and the same tool.)

5. **Is it advantageous to have the panels pre-cut and delivered to the jobsite? If it costs $1 / foot more to have pre-cut panels, is it still worthwhile?**
   Absolutely not; Dave really doesn't like the pre-cut idea and thinks we should ship
   i. Prefabricated corners and couplers
   ii. ~12' length pieces that will be cut on site

6. **Would an interior stake that finishes inside the termite strip be beneficial or would it make installation more difficult? How much benefit is there in not having to come back to pull stakes?**
   He didn't think returning to pull stakes was a big deal in his mind. The interior stake concept seemed too different and risky to him to be worthwhile.

7. **With an exterior staking system, would reusable snap in place exterior stake/stringer holders be beneficial?**
   He wasn't too hot on this idea: too many parts, the screws worked fine

8. **Would snap-in J-bolt holders be beneficial?**
   Yet again, Dave wasn't too hot on this idea
   i. Too many parts
   ii. The screws worked fine (especially if the top is square)

iii. The lack of adjustability is no-good

9. **Considering that you don't have to buy wooden form boards and that the insulated slab offers Title 24 energy credits to the builder (saves him money relative to other energy efficiency measures), how would you feel if the system cost you: $6 / foot? $8 / foot?**
   He indicated he can buy wood for forms @ $1.50 per foot. He didn't initially see much market beyond radiant heated slabs. I mentioned there were studies that indicated insulating the slab edge can save 15%-20% as well as provide Title 24 energy credits to the builder and his eyes lit up a bit and said "then it might be worth $6/foot".

6.2. Bodega Bay, CA Custom Home (June 2009)

In June 2009, after extensive fruitless searching for production home candidates, Davis Energy Group came in a contact with a Northern California builder who was starting a custom home project in Bodega Bay, CA, roughly one hour north of San Francisco. The builder was interested in installing Formsulate on the project. DEG met with the builder and his concrete subcontractor to present Formsulate and discuss any integration issues. Formsulate was installed mid-summer 2009 with Figures 30-32 showing the installation in progress. One issue with the slab perimeter was an area of the house with perimeter transitions at 45 and 135 degrees. DEG staff developed an approach for mitering the extrusion and fabricating metal brackets for stiffening the inside of the angled corners. Suggested Formsulate installation procedures are included in Appendix C.

Figure 30: Perimeter with 45° and 135° Angled Formboards

Figure 31: Formsulate Installation

Figure 32: Completed Formboard Installation

Brent Weiand provided the following feedback on the Formsulate installation.

1. **What did you like about how the system installed?**

   The product went together smoothly and quickly.

2. **What didn’t you like?**

The 45 degree angles took quite a bit of extra work to strengthen. (Note: Davis Energy Group developed a custom procedure to use the existing materials for 45 and 135 degree corner transitions. This is not a long term solution for dealing with these transitions, but the cost for obtaining molded parts was beyond the scope of this project.)

3. Does the form board appear stiff enough? If extra staking is needed, how big a concern is that for you?

The form board could be a little stiffer. Additional staking was needed, which means there are more screw holes to fill.

4. What suggestions do you have to improve the product?

- Create a flashing flange
- Create the 45 and 135 degree parts
- Develop panel systems (4' x 8') for stemwall retaining wall

5. With an exterior staking system, would reusable snap in place exterior stake/stringer holders be beneficial to avoid screw holes in the finished surface?

Yes.

6. Would snap-in J-bolt holders be beneficial?

Yes. With larger size holders (3/4", 7/8", 1-1/8") for Holddown bolts.

7. Considering that you don't have to buy, transport, and store the wooden form boards, the insulation protection is already in place, and that the insulated slab offers Title 24 energy credits to the builder (saves him money that he doesn't have to spend on other energy efficiency measures), how would you feel if the E-Form cost:

$6 / foot? This is OK with the system as-is.

$8 / foot?

$10/ foot? This would be OK with flashing system and other enhancements.

8. Any final comments?

Product was easy to use on straight runs. It became more difficult to use with drop-downs, step-ups, and especially retaining walls. We used a combination of wood forms and form boards to do this.

Would be nice to see a retrofit product that can be attached to existing slab edge or stemwall.

7. Market Assessment

7.1. Background

In the mid-1990's, Davis Energy Group (DEG) was involved with CertainTeed in a brief partnership to develop a slab edge insulated form (SEIF) system. A basic design emerged to work with the traditional two-pour slab that was the dominant slab construction method at the time. Although no physical hardware was developed, CertainTeed completed a market analysis based on the preliminary SEIF design. The Certainteed market analysis served as a starting point for the market and cost analysis effort undertaken in Phase I of this project.

Task 1 market research consisted of several activities:

- We discussed the Formsulate concept with concrete and residential construction industry professionals to gather feedback and design suggestions, and to learn about the latest trends in residential slab construction.
- We attended seminars, observed crews in the field, and met with industry members to understand the post-tension process and accommodate it in the Formsulate design.
- We researched the California Title 24 Building Standards to determine the potential energy benefits of the Formsulate design.
- After finalizing the Phase I design in Task 3, we developed a cost model based on quotes from extrusion, sheet metal and roll-forming vendors. Cost models were also developed to determine Formsulate economics under various scenarios.
- We analyzed U.S. Census Bureau data on new home construction to assess current slab construction rates and project future market success for Formsulate with a variety of marketing scenarios.

In California, the Title 24 Building Standards is the main driving force behind the selection and specification of energy efficiency measures required to demonstrate compliance. For each of the 16 California climate zones, a set of cost-effective energy efficiency measures defines a "standard" energy budget. The goal of the builder is to insure that the planned house design is less than the standard budget. The hourly compliance simulation model evaluates the energy benefits and penalties of each measure. For example, spectrally selective windows would improve summer performance, but hurt winter performance. SEIF systems offer a unique opportunity for energy credits relative to the "standard" case of an uninsulated slab. If the economics are favorable for SEIF, the Title 24 process could generate a significant market demand for a low cost compliance option.

7.2. Trends in Current Residential Slab Construction

To better understand the current construction environment, we conducted a wide-ranging survey of individuals and firms involved with residential slab construction. Some of those whom we interviewed are listed below.

- Daniel Kitts, Dow Chemical (Manages sales of all Dow building products to production home builders in Southern California.)
- Dave Leal, Leal Concrete (a small Davis, California concrete contractor specializing in custom home slabs.)
- Brent Weiand, BP Homes (small custom builder who installed Formsulate at a custom home project in 2009.)
- Mark Rutheiser, Pyramid Construction (Custom homebuilder based in Davis, California.)
- Terry Alexander, Janco Concrete (High-volume concrete contractor specializing in production homes in California's Central Valley and greater San Francisco Bay Area.)
- Steve Mueller, Mueller-Lewis Concrete (San Diego concrete contractor specializing in production home slabs.)
- Mike Bauer, Bauer Concrete (smaller San Francisco Bay Area concrete contractor specializing in slabs for apartments and townhomes.)
- Sandra Quinn, Fieldstone Homes (Senior procurement agent for production home builder in San Diego, formerly a buyer at Arcadian Homes in San Jose. 40 years of experience.)
- Jeff Jacobs, formerly of Centex Homes (Project manager for a Northern California production builder.)
- Ken Douglass, Suncoast Post-Tension (Largest post-tension firm in U.S.)
- Members of the Monterey Bay Chapter of the International Code Congress

In the decade since the CertainTeed SEIF project, we learned a significant change had taken place in the production home slab construction market in California. In the early 1990s, most slabs were made with a two-pour process. Trenches were dug at the perimeter and under load bearing walls and wooden forms were placed at the outer edge of the perimeter trenches. The first concrete pour filled the trenches to create a "footing." At least two inches of gravel and two inches of sand were placed in the interior of the slab area, and a steel wire mesh was secured to the forms so that it was submerged in the slab about two inches deep. The center of the slab itself was typically four inches thick.

In the past five to ten years, a significant percentage of California production homes have shifted to post-tensioned, single-pour, monolithic slabs in response to liability concerns related to cracking. Steel wire mat reinforcing was found to be insufficient at preventing cracks from spreading. Building inspectors and structural engineers began demanding steel rebar reinforcing at considerable additional expense, with only a slight improvement in slab durability. Post-tensioning quickly emerged as the preferred solution. The post-tensioning process, first developed in Texas to combat slab cracking in highly expansive soils, has found application across the U.S. for commercial and industrial applications where high slab strength is required.

Post-tensioning results in a much stronger slab, although construction costs are higher. Production homebuilders generally resist incorporating higher cost building materials and processes, but they have been far more enthusiastic in accepting post-tensioning than custom homebuilders, with whom the process remains rare. The main reason for this is construction defect litigation. As cracks develop in a slab, moisture can seep through and damage flooring materials. If the cracks grow enough, slab movement may destroy floor tiles and cause drywall cracks as the house settles. In addition, nearly all middle to high-end production homes in California has heavy concrete tile roofs, which require stronger slabs. Codes now require heavier and more numerous firewalls and shear wall assemblies that also increase slab loads. The passing of California state law SB800 (2002) allows plaintiffs to recover damages for construction defects that had not yet caused property damage or personal injury. This meant that if cracks emerged in a few slabs in a subdivision, homeowners throughout the subdivision could sue the builder even if there were no problems with their slabs.

Among the industry contacts we spoke to, the consensus was that more than 90% of new production homes in California use post-tensioned slabs. Much of the California construction is occurring on current or former floodplains, which are likely to have expansive soils requiring post-tensioned slabs. This includes the Central Valley, most of the San Francisco Bay Area and East Bay, and the Inland Empire (stretching from eastern Los Angeles to Palm Springs). Fear of litigation, liability insurance rates, and industry inertia appear to have pushed post-tensioned slabs into the population centers outside of those regions. In our discussion with industry experts, we found only two areas where current building practice is using the conventional two-pour system. One was in rural San Diego County and the other was in the fast growing cities of Rocklin/Lincoln northeast of Sacramento. Both of these projects were in foothill locations where builders felt confident enough that soil conditions were stable enough to allow conventional slabs to perform well.

The widespread adoption of post-tensioned slabs among production builders was the most dramatic outcome of the Formsulate market research. However, there were several other important insights that we gained into the slab construction market from our industry interviews.

- As is typical for many new technologies, the initial response from concrete contractors was lukewarm. Although they appreciate the potential for Title 24 credits, they are naturally skeptical of outsiders suggesting a significant change to their way of business. However, the builders contacted were far more positive of Formsulate's potential because of the opportunity to gain Title 24 credits, potentially at a lower cost than other building products. While we hope to develop a system that concrete contractors are comfortable with, the builder (in conjunction with the architect, structural engineer, and Title 24 consultant) decides which building products are used.
- Concrete forms are usually made from 2x10's or 2x12's. Although there are cheaper grades, #2 Douglas fir is typical because it has fewer knots and can be more easily reused. Contractors typically get an average of two uses out of each form board. In the summer the form boards need to be oiled to have any chance of salvaging them for future jobs.
- The basic structural hold-downs are J bolts, which are mostly commodity products available from a number of sources. The standard installation procedure involves attaching the J bolts to the form boards for building inspector review. The bolts are then removed prior to the pour and then "wet-set" immediately after the pour, making it easier to screed the concrete surface level with the top edge of the form. Wet-setting larger specialty hold-downs does not appear to be common.
- We heard of no examples of a post-tensioned slab also using radiant floor heating. This confirms that the custom homebuilders, who do the vast majority of the radiant-heated slabs, are still not using post-tensioned slabs. The two systems are not incompatible, but would make for a complicated slab with tensioning cables, PEX tubing, and tubing supports.

7.3. Formsulate Preliminary Code Review

We presented the Formsulate concept to the Monterey Bay Chapter of the International Code Congress in June 2006. This group of about 20 building officials invites companies to present new building products during their monthly meeting, providing an excellent opportunity for informal feedback on whether a new product will be allowed in their building jurisdiction. Some of their comments were:

- Their general response was lukewarm, which we consider a positive with building officials. They are usually only animated about products and technologies that they are concerned with. They have no incentive to approve energy or cost saving products since their main focus is safety.
- Any new hold-down system would need to have ICC-ES or similar listing before code approval is received.
- Hold-down systems must go at least 7” deep into the concrete.
- Foam insulating materials should either be fully encapsulated or be hydrophilic to avoid water-logging.
- Weatherability will need to be demonstrated before Formsulate achieves widespread acceptance.
- In the unlikely case that the PVC extrusion does not bond to the concrete, differential expansion and contraction may cause enough movement to wear through the PVC.

7.4. Title 24 Implications for Formsulate

All new residential construction in California must comply with the Title 24 energy code established by the California Energy Commission. The state is divided into 16 different climate zones. Homes built in the more extreme climate zones must be more efficient than those built in moderate climate zones. Most house designs require some manipulation of the installed energy features to arrive at a final set of energy features that meet the Title 24 energy budget. There are two basic compliance alternatives for Title 24.

- Prescriptive Method. This is a checklist of building products and design aspects that are pre-approved for compliance with Title 24. Examples are minimum ceiling insulation R-value and maximum total fenestration (window) area as a percentage of floor area. These values vary by climate zone. If the home design complies with the Prescriptive Method, no further energy calculation is required. However, this is rarely the case due to the inherent lack of flexibility in the Prescriptive Method.
- Performance Method. The most common reason that home designs do not comply with the Prescriptive Method is builder desire to add more glazing, in particular west facing, than allowed. In that case, software must be used to confirm that improvements to other design aspects bring the entire design into compliance. Energy consultants work with architects and builders to determining the most cost-effective manner in which to satisfy the Title 24 requirement. In addition to improving the standard building parameters (such as higher insulation R-value), other improvements such as high efficiency HVAC

equipment or solar water heating can be added, with resulting Title 24 credit. This is where Formsulate would be used, particularly if Formsulate represents a more cost effective compliance alternative than other competing measures.

7.5. Termite Issues

A concern with any exterior foundation insulation is the potential of increase termite infestation. Termites are not attracted to the foam materials themselves, but can create undetected tunnels through the foam to reach the softwoods within the home.

The International Code Congress (ICC) has established the map of termite infestation risk shown in Figure 33. Nearly all areas where slabs dominate residential construction are included in the Very Heavy termite regions.

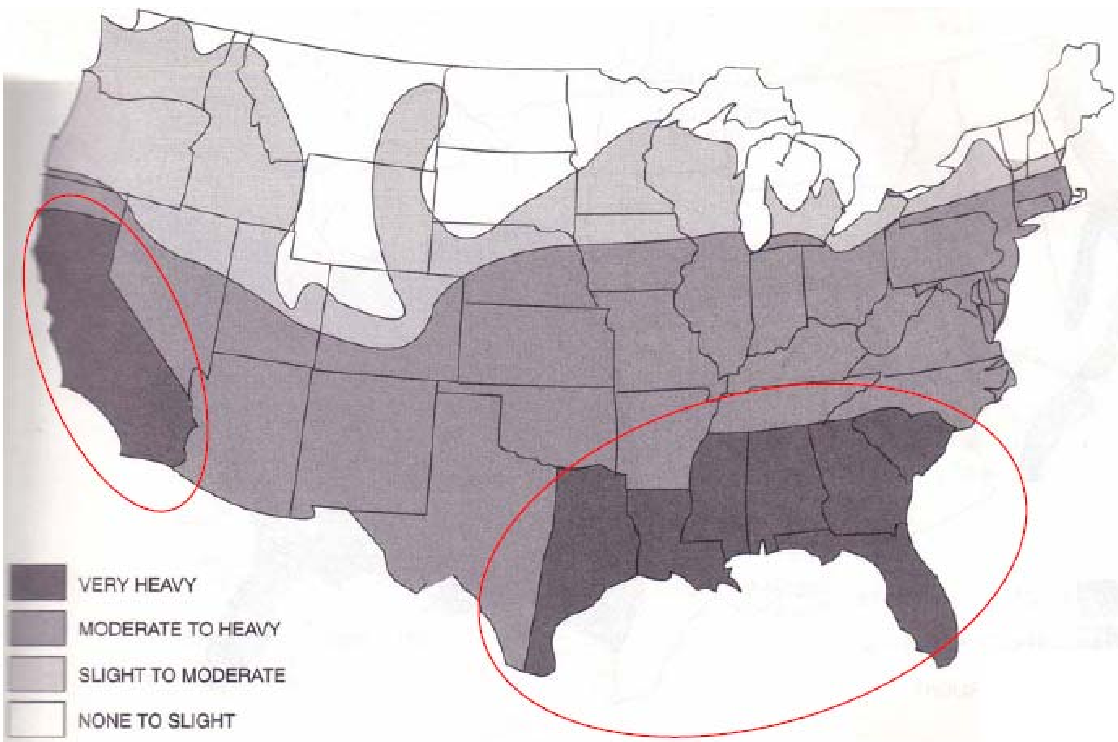


Figure 33: ICC Termite Infestation Risk Map

In 1999 the ICC banned the use of foam in below grade exterior applications in the Very Heavy termite regions.[7] Dow Chemical noticed a significant drop-off in the use of their foam products for foundation insulation in the Southeast. However, Section R320.4 had an exception when the foam plastic and structure are protected from subterranean termite damage by an *approved*

[7] Section R320.4 Foam plastic protection. In areas where probability of termite infestation is "very heavy" as indicated in Figure R301.2(6), extruded and expanded polystyrene, polyisocyanurate and other foam plastics shall not be installed on the exterior face or under interior or exterior foundation walls or slab foundations located below grade. The clearance between foam plastics installed above grade and exposed earth shall be at least 6 inches.

method. Approved foam materials include expanded polystyrene (EPS, or beadboard) treated with borate, and Dow's recently introduced termite-resistant version of Styrofoam using Deltamethrin termiticide that meets the ICC-ES acceptance criteria of ICC-ES EG-239 Evaluation Guide for Termite-Resistant Foam Plastic. BlueGuard first appeared on the market in early 2008, but by Fall 2008 production was halted due to a combination of factors including the housing downturn and internal marketing priorities. At this time it is not clear when BlueGuard will resume production.

Although the ICC defines the termite risk in California to be as severe as in the Southeastern U.S., the market behavior does not appear to reflect this. Termite damage to homes in California is relatively rare. Furthermore, we know that foam insulation is often applied to the perimeter of radiant-heated slabs due to Title 24 requirements. When insulating with rigid foam, a sheet metal "termite strip" is usually attached to the wooden form boards such that the inboard edge of the strip is embedded in the concrete as it is poured. After the forms are removed, the insulation is attached to the concrete and the outer edge of the termite strip is folded down over the insulation. This strategy requires termites to travel around the outside of the termite strip where their trails can be detected by pest management professionals.

7.6. Formsulate Cost Model

At the conclusion of Phase II, the Formsulate cost model is well-defined for the non-post-tension configuration. Costs at this time are based on extrusion stuffed with borate treated EPS. The breakdown for low and medium volume scenarios is show in Table 5. The medium volume scenario (250,000 ft of extrusion) shows a 16% reduction in overall component costs.

Table 5: Formsulate Cost Model

	Scenario	Low-Volume (Start-up)	Medium-Volume
	# of Houses/Production Batch	50	1,000
Component Costs	Extrusion (250'/house)	$679	$598
Component Costs	Foam (250 board feet/house)	$72	$67
Component Costs	Linear Couplers (36/house)	$103	$56
Component Costs	Outside Corners (6/house)	$32	$24
Component Costs	Inside Corners (2/house)	$9	$8
	Materials SUBTOTAL	$895	$753
	Materials Subtotal per linear foot	$3.58	$3.01
	Markup	100%	50%
	Wholesale Price per House	$1,790	$1,130
	Baseline Price (2 x 12 lumber)	$350	$350
	Wholesale Price per linear foot	$7.16	$4.52
	Annual Savings	$90/year (60 therms/year)	
	IRR (4% utility rate escalation)	8.5%	15.0%

The Phase II prices are less than the Phase I projections of $8.70/foot and $5.67/foot for each marketing scenario. Internal rates of return substantially exceed mortgage rates for both scenarios, making Formsulate a "cash positive" investment. (Both the baseline and Formsulate systems use the same number of re-useable steel stakes, so these were not included.)

7.7. Market Analysis and Sales Projections

The team conducted a detailed market analysis in Phase I that was based on a combination of historical housing construction trends and extrapolations. The residential construction market underwent a severe market correction in the last 18 months, making market projections challenging. Given this uncertainty, the team has chosen to re-use the Phase I market analysis and sales projections for this report. Based on the information included in the Phase I report, we project potential third-year sales after product commercialization to range from 8,400 slabs and $9.5 million per year (California niche market strategy), to 56,400 slabs and $63.7 million per year (national mass market strategy). If the product achieves widespread market acceptance, 500,000 Formsulate homes could be built per year, resulting in annual savings of 30 million therms.

In California where Title 24 offers a viable incentive for builders, a 50% market penetration for Formsulate (or similar competing products) does not seem like an unreasonable goal to achieve in ten years, especially given the strong state legislative push for zero energy new homes. This penetration level would result in ~ 70,000 Formsulate slabs in California alone, with projected annual energy savings of 4.2 million therms.

8. Conclusions and Next Steps

This project successfully developed a leave-in-place slab edge insulating form system that offers significant promise in reducing perimeter heat losses which contribute a steady load on homes throughout the heating season. Unlike other energy efficiency measures which represent an incremental improvement over standard practice, insulation of the slab edge transforms the edge from a thermal short to an insulated building component. Additional benefits include the elimination of the wooden form board, reduced material handling, and reduced construction waste. Unlike other measures that may require commissioning and/or maintenance to insure performance benefits, an insulated slab edge form offers reliable lifetime energy savings.

This project was successful in developing the required components for completing a conventional slab installation. Formsulate components included twelve foot long linear extrusions, linear couplers, and interior and exterior 90° corner couplers. Builder and concrete contractor reactions to the product were uniformly favorable. The main shortcoming of the project was the inability to develop and demonstrate a solution for the increasingly common post-tensioned slab systems. Although not part of the original project scope, satisfying the PT segment of the market will be an important goal of future product development activities.

The completion of this NETL funded project leaves Formsulate at a crossroads. With the California housing market in doldrums, it is unlikely that Davis Energy Group will have immediate success in building a market without financial assistance. To that end, DEG submitted a proposal in response to NETL's American Recovery and Reinvestment Act's "Advanced Energy Efficient Building Technology" solicitation to complete PT development and demonstration and to perform market transformation activities. Specific activities include the following:

1. DEG will work with product development engineering firm Green Mountain Engineering to fully develop the Formsulate post-tensioned design, develop and test system prototypes, and develop final production parts and installation procedures.

2. DEG will use the new TRNSYS model (available fall of 2009) to refine its quantitative analysis of the energy impact of slab-edge insulation; this data will provide a key component in our product development and marketing efforts.

3. DEG will collaborate with market research firm Polaris, Inc. to perform market research and develop an effective marketing strategy, and with Sierra Building Science to develop and present training classes for code officials, architects, builders, and contractors.

4. DEG will work with subcontractor Amaro Construction to find 40-60 field demonstration sites to test both the PT Formsulate design and the conventional design. The installations will be documented and contractor feedback will be provided.

These additional steps are essential in developing initial momentum in building market demand for slab edge insulated form systems such as Formsulate.

Appendix A:

Overview of the Post-Tensioned Slab Construction Process

Concrete can withstand very high compressive forces, but is relatively weak in tension. To counteract this material deficiency, historically steel reinforcing has been distributed at the mid-height of a residential slab before the concrete is poured. Traditional reinforcing such as steel mesh or rebar provides some tensile strength, but for higher performance engineers use ***pre-*** or ***post-***tensioned steel cables set into the concrete form. The tension ensures that the concrete is always under compression, enabling concrete structures to be stronger and less prone to cracking than a non-tensioned slab.

In ***pre-***tensioned slabs, steel cables are strung across the forms and stressed before the concrete is poured. After the concrete has cured sufficiently it bonds to the cables and the ends of the cables are cut. The ends are potted with grout to avoid corrosion. Pre-tensioned concrete forms must be very strong to hold the stressed cables in place.

The process for ***post-***tensioned concrete leaves the cables (also known as tendons) slack in the concrete form until after the concrete has cured, placing no load on the forms. After the forms are stripped, the cables are stretched to apply a sufficient compressive force to the concrete. The cables have a plastic sheath to prevent the concrete from bonding to cable. Grease on the inside of the sheath allows the cable to slide freely. As with pre-tensioned concrete, the ends of the cables are trimmed and potted to avoid corrosion. Because the cable is not bonded to the concrete, each end of the cable must be mechanically bonded to an anchor set in the concrete.

The post-tensioning process specific to slab-on-grade construction is described in detail below.

1. The form boards are cut and installed in a manner similar to conventional slab forming.

2. The ½" cables are delivered to the site pre-cut to match the footprint of the slab. SunCoast Post-Tension works with builders to deliver a custom tailored set of cables for each slab and uses only its own crews to install the cables and tension them after the slab has cured. Other vendors deliver cable to the site where they are prepared, installed and tensioned by a different post-tension firm.

3. The prepared cables already have one anchor installed, as shown below. Inside the anchor are two split wedges that bite into the cable as it is pulled through the anchor.

4. This end is attached to form board with nails so that there is space between the board and the anchor as shown below. This “static end” allows concrete to encase the anchor.

5. The cables are unrolled to the opposite form board. The opposite end of the cable also has an anchor pre-installed, but with about five feet of cable beyond the anchor. This extra cable is passed through a hole in the form and the anchor is nailed to the form as shown below. A white plastic part known as a pocket-former is slide onto the cable between the anchor and the form board. Where cable cross each other, they are wire tied together and/or placed in a cross support that maintains the height of the cable.


6. The concrete is poured. The top surface is screed flat and hold-downs are wet-set if necessary. Small additional cylinders of concrete are poured for testing of concrete strength.

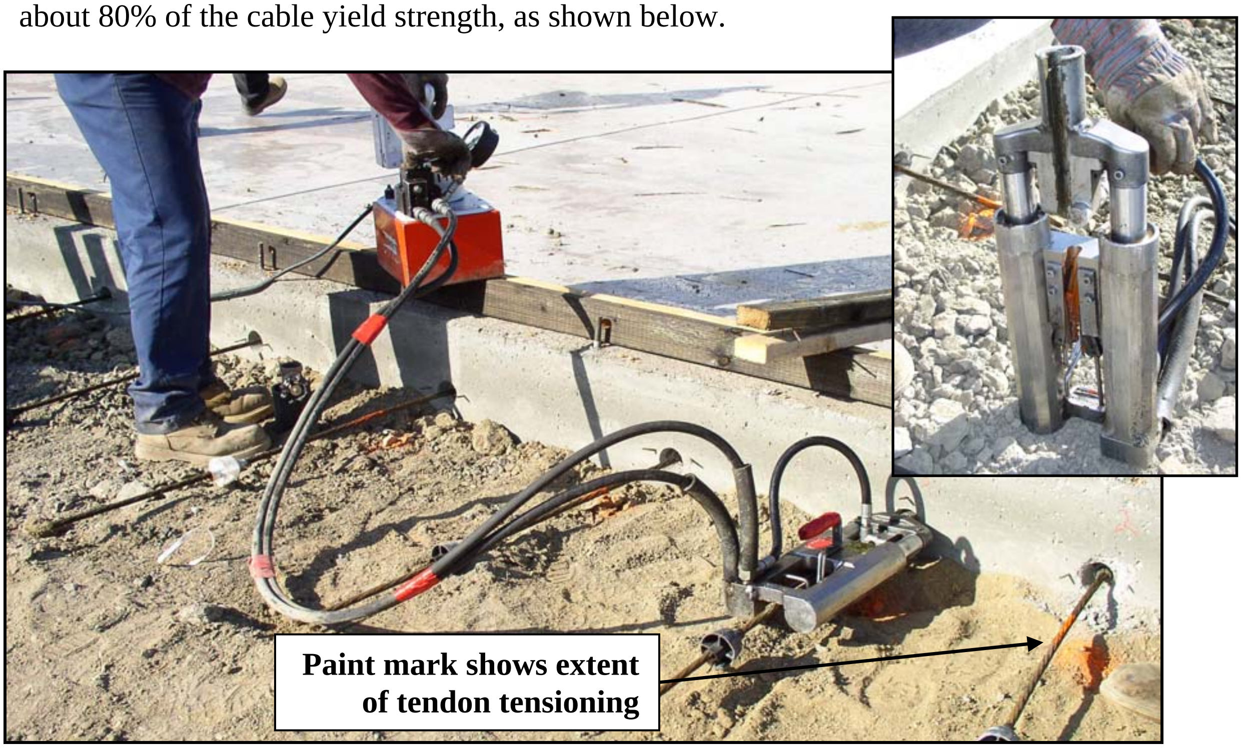
7. The form boards are removed the following day.

8. Two or three days after the concrete is poured, the samples are tested to confirm that the concrete has reached a compressive strength of at 2000 psi. A building inspector must be on-hand to confirm this. The cables can now be tensioned.

9. Remove plastic pocket formers from the visible cable ends. The concrete does not bond to the plastic, so they are easy to remove. This exposes the anchor and wedges as shown below.

10. Using a 2x6 up against the concrete as a guide, the cable is spray painted to indicate the cable strain after tensioning.

11. A specialized hydraulic ram is used to apply 33,000 lbs of tension to the cable, which is about 80% of the cable yield strength, as shown below.



12. The distance that the spray painted mark has moved is recorded. The cables typically stretch about 0.8 inches per foot of cable length.

13. The end of the cable is cut with an abrasive saw. A vinyl cap is placed over the end of the cable and the pocket is filled with grout, as shown below.

Post-tensioned slabs are referred to as monolithic because only one pour of each concrete structure can be post-tensioned, so two-pour designs with a separate footing are never used. The depth of the cables is always one-half of the thickness of the slab. The spacing of the cables is based on structural requirements and varies from 1' to 5', with typical spacings of 2 to 2.5 '.

Two different post-tensioned slab designs dominate California residential construction. Waffle slabs, which are used mostly in Southern California, have a similar perimeter appearance to conventional slabs. A 12" to 24" perimeter trench is dug with interior trenches crossing the interior based on structural calculations. The post-tension cables are slung down into the trenches as well as through the main part of the slab, which are spaced 18" to 5' apart. The 4" to 5" main part of the slab is slightly thicker than conventional slabs.

Most concrete contractors and structural engineers in Northern California prefer to use Uniform Thickness slabs. Such slabs do actually have a slight perimeter turn-down of 2" to 4" deep, but this is determined by the depth of the interior gravel. An advantage of Uniform Thickness slabs is that they do not require any trenching. Uniform Thickness slabs vary from 5" to 14", with 8 to 10" thickness common.

The Formsulate design needs to be versatile enough to work with both Waffle and Uniform Thickness slabs for production homes, and it must work with conventional two-pour slabs. It must be able to support post-tension cables at any depth ranging from 2" to 7".

Appendix B:

Phase I Final Report

DAVIS ENERGY GROUP, INC.

DOE Award: DE-PS26-04NT4214

Reporting Period Start Date: May 1, 2005
Reporting Period End Date: October 31, 2006

Report Issued: October 30, 2006

E-Form –
A Marketable Slab Edge Insulation Form System

Phase I Report

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1. Executive Summary

Project Background

Concrete slabs represent the primary foundation type in residential buildings in the fast-growing markets throughout the southern and southwestern United States. Nearly 75% of the 2005 U.S. population growth occurred in these southern tier states. Virtually all of these homes have uninsulated slab edges that transfer a small, but steady, flow of heat from conditioned space to outdoors during the heating season. It is estimated that new home foundations[1] constructed each year add 0.016 quads ***annually*** to U.S. national energy consumption; we project that half this amount can be attributed to heat loss through the slab edge and the other half to the deep ground transfers. With rising concern over national energy use and the impact of greenhouse gas emissions, it is becoming increasingly imperative that every cost-effective effort be made to improve energy efficiency. Adding even small increments of insulation to the uninsulated slab edge would markedly reduce heat loss. Unlike other building envelope components that have experienced increased levels of efficiency over the years, slab edge loss has been largely overlooked. Thus, there is a substantial opportunity for a marketable slab edge insulation system.

Conventional slab forming involves the process of digging foundation trenches and setting forms prior to the concrete pour. A first pour fills concrete in the footing trench. The slab is then poured after placement of gravel and steel mesh. Conventional wood forms (usually 2 x 10's) are supported by vertical stakes on the outer form board surface, and by "kickers" driven diagonally from the top of the form board into soil outside the trench. The kickers hold the boards plumb and resist outward pressure from the wet concrete during the pour. Typically, 2 x 10's can be used only twice before they become waste material, placing a significant environmental burden on conventional methods. Removal of the form boards and stakes requires a followup trip to the jobsite by the concrete subcontractor. The wood forming materials that becomes construction waste is estimated to amount to 400 pounds per house.

In the rare cases where the slab is insulated (typically custom homes with radiant floor heating), the most practical insulation strategy is to secure rigid foam insulation, such as DOW Styrofoam™, to the inside of the wooden slab edge forms. An alternative is to clad insulation to the perimeter of the slab after the slab has been poured and cured. In either case, the foam must have a "termite strip" that prevents termites from creating hidden tunnels through or behind the foam on their way to the wall framing above. Frequently this termite strip is a piece of sheet metal that must be fabricated for each project. The above-grade portion of the insulation should be coated for appearance and to prevent damage from construction, UV, and "weekend warrior" shovels. All these steps add time, complexity, and expense to the insulating process.

[1] An estimated 868,000 slab foundations in 2005

The Opportunity

Builders currently have the opportunity to install slab edge insulation on new homes, but as a rule they choose not to. Added cost, installation difficulties, construction slowdown, appearance, and termite issues (in some parts of the country), are all factors that affect their decision. A cost-effective, installer-friendly system could have huge market appeal. California, our target market for introduction of a slab edge insulation system, offers additional leverage to the situation. The statewide Title 24 residential energy code, the most aggressive in the nation, offers credits for perimeter slab insulation. Since the three year Title 24 update cycle has essentially harvested all of the low hanging (energy efficiency) fruit, a cost-effective slab edge insulation system would offer more bang for the buck than competing measures. These market forces should drive acceptance of a well-engineered slab edge insulation product.

E-Form Concept

The E-Form concept being developed in this project replaces wood forms with a PVC profile extrusion and replaces exterior wooden stakes with interior steel stakes. Interior stakes eliminate the need to return to the site after the slab has cured to strip the forms, saving labor and simplifying construction coordination. The interior hollows of the extrusion are filled with insulation, providing both thermal benefits and stiffening of the extrusion form. By delivering a pre-packaged kit of E-Form components to the jobsite, we hope to streamline the forming process. In short, we will focus on an improved product and processes that save construction time compared to current slab edge forming practices, while providing insulation that substantially improves energy performance, offers value to builders, and reduces greenhouse gas emissions.

Project Team

The E-Form team includes three organizations:

- Davis Energy Group: product development and project management
- Dow Chemical: expertise in plastic foams, building materials and code issues
- Amaro Construction: construction services and Home Energy Rating Services (HERS)

Project Objectives

The key project objective is to successfully commercialize a slab edge insulation form ("E-Form") systems that has benefits for the builder (favorable first costs and potential energy credits), operating cost savings for the homeowner, and societal benefits for all by reducing heating energy consumption and the associated environmental impacts. To successfully penetrate the production home new construction market, the E-Form system should provide the following benefits:

- Favorable builder economics
- Easy to install
- Accommodate conventional two-pour slabs, as well as the emerging post-tensioned slab construction process
- Proven termite mitigation

- Long-term durability

Phase I Results and Accomplishments

Task 1: Market Research. We completed a review of code issues and current slab construction practice with input from builders, concrete subcontractors, post-tension contractors, building officials, and other parties that influence the selection and specification of construction materials. We developed a detailed cost model based on two production scenarios, and a nationwide market analysis based on U.S. Census Bureau data for four different commercialization strategies.
Task 2: Insulation Optimization. A highly regarded TRNSYS three-dimensional finite difference model was used to evaluate potential E-Form savings in five U.S. climates with three different insulation levels (R-5, R-10, and R-15). Reasonable national savings estimate for a typically sized new home with a central gas furnace is on the order of 60 therms per year.
Task 3: Design Options and Details. We evaluated various design alternatives in terms of cost, ease of installation, durability, construction industry acceptance, and structural performance using Finite Element Analysis. We developed designs for the staking system and linear and corner joints, and evaluated each design for thermal expansion, termite resistance, weatherability and other issues. Together with Dow Chemical, we evaluated foam material options.
Task 4: Prototype Development. We selected an extrusion vendor and procured a die for the PVC profile. We installed Styrofoam and foam-in-place polyurethane into profiles to create sample forms and strength testing. A staking system was prototyped and installation evaluated in a variety of soil conditions.

Market Viability

Extensive communications with construction industry experts indicated a strong shift away from standard two-pour slab construction to a monolithic post-tensioned process. The significant market share of PT slabs strongly suggests that the E-Form product must be compatible.

The potential market for a viable slab on grade insulation system is huge. U.S. Census Bureau data indicate that 868,000 slab foundations were constructed nationally in 2005. At this point, projected E-Form costs appear to be competitive, especially in the current custom home market where slab edge insulation is typically installed with radiant floor heating systems. In the more cost-competitive production home market, E-Form incremental costs may pose a small hurdle. However in states with aggressive energy codes such as California, E-Form “benefit per unit cost” are likely considerably more favorable than other competing measures.

Termites represent a key code issue for E-Form. E-Form must provide a continuous termite barrier and use insulating materials that are treated with approved chemicals.

Phase 2 and Steps to Commercialization

We feel that the potential for a slab edge insulation product is significant and the market is primed for introduction of a viable product. In Phase 1, our team has made significant progress in understanding the market, assessing potential savings, and developing a prototype design.

Significant work remains to be completed and Phase 2 funding is essential in moving E-Form from proof-of-concept to a product ready for commercialization.

Phase 2 activities will focus on the following key issues:

1. Finalizing extrusion design based on field results and input from industry officials
2. Finalize insulation material selection and application method with Dow
3. Fabricate and test extrusion connectors and corner assemblies
4. Finalize staking systems to work in all soil types
5. Complete field prototyping efforts
6. Review and optimize field installation procedures
7. Monitor both E-Form and uninsulated slab heat transfer performance in small-scale prototype test configurations
8. Demonstrate E-Form performance in real world installations in both custom and production home environments
9. Gather contractor feedback on E-Form installation issues and cost-effectiveness
10. Hold meetings and interviews with builders, architects, concrete subcontractors, code officials, and homeowners
11. Assess builder interest in E-Form based on construction feedback, meetings, and cost data
12. Procure all tooling necessary for cost-effective volume production
13. Plan for commercialization by preparing production facility and marketing materials

Conclusions and National Energy Impacts of E-Form

Based on the market analysis, we estimate that 56,000 E-Form homes will be built nationwide in the third year of product commercialization. Based on estimated 60 therm/year savings, we project the first-year energy savings of these homes will be 3.4 million therms. With a 20% growth rate, the cumulative energy savings of E-Form will be 214 million therms in the first 10 years after market introduction. Sales could be even higher after the 2008 revision of Title 24 in California as builders search for the most cost-effective compliance options.

In Phase 1 we demonstrated that E-Form is a viable substitute for wood concrete slab forms, and that the market demand and potential energy savings warrant further investment. The greatest barrier to E-Form success will be acceptance by concrete contractors, who will be strongly influenced by its ease of use. Should Phase 2 funding be awarded, we will focus our efforts on refinement and iteration of the staking and joiner parts. With production tooling of all E-Form components procured with Phase 2 funding (minus cost match), E-Form will be ready for commercialization immediately after the project completion.

2. Introduction

2.1. Background

Concrete slab-on-grade construction is the predominant foundation type for new low-rise homes in fast-growing residential markets throughout the southern and southwestern U.S. According to the National Association of Home Builders, over 2 million homes were built in 2005 (1.7 million single-family and 350,000 multi-family). U.S. Census data indicates that the six states with the greatest population increase from 2004 to 2005 (Florida, Texas, Georgia, California, Arizona, and North Carolina)[1] are all located in the southern tier of states where slab-on-grade construction is the predominant foundation construction technique. Improving the energy efficiency of production home slabs could have a noticeable impact on new home heating energy use. Since most "envelope" components in new buildings have evolved to fairly high levels of energy efficiency, the uninsulated slab edge stands out as one of the few building features that have not improved over the past fifty years. It is estimated that new home foundations add 0.016 quads annually to U.S. energy consumption; we estimate that half this addition is due to un-insulated slab edges.

Slab edge insulation is used on a small number of new homes, most commonly on custom homes with radiant floor heating. The current process is cumbersome, time-consuming, and costly. With typical slab-on-grade construction, the most practical insulation strategy is to secure rigid foam insulation (typically extruded polystyrene such as Dow Styrofoam™) to the inside of the wooden slab edge forms. An alternative is to attach insulation to the perimeter of the slab after the slab has been poured and cured. In either case, the rigid foam must have a "termite strip" (often a sheet metal piece) that prevents termites from creating hidden tunnels through the foam on their way to the wall framing above. The above-grade portion of the insulation should be coated for appearance and to prevent damage from construction, ultraviolet degradation, and "weekend warrior" shovels. For applications other than radiant floor heating, the high cost for slab edge insulation typically deters its use.

California is an ideal market for introduction of a slab edge insulation system, because the state's stringent Title 24 residential energy code forces builders to adopt increasingly costly measures to demonstrate compliance and also offers credits for perimeter slab insulation. Since a builder must invest in energy efficiency to demonstrate Title 24 compliance, the viability of a slab edge insulation product is further enhanced if it is more cost-effective than competing measures. Since the first increment of insulation is always the most cost-effective, the economics of slab edge insulation should be highly favorable. In addition, Title 24 requires that all radiant-heated slabs have slab edge insulation. Radiant-heated slabs are increasingly popular with custom home builders.

[1] Representing 57% of the total U.S. population growth in the year 2005.

2.2. Project Partners

The project team is comprised of Davis Energy Group, Dow Chemical, and Amaro Construction.

Davis Energy Group (DEG) has provided energy consulting and product development services geared toward energy efficient construction over the past 25 years. One product development involved a cooperative effort between DEG and the Certainteed Corporation. In 1993 Davis Energy Group (DEG) and Certainteed agreed to co-develop an advanced slab edge insulated form system. Certainteed extrudes unique plastic shapes for the construction industry. The two firms invested more than $50,000 over a two-year period before a management change at Certainteed ended the project. This investment completed a substantial market analysis, developed and refined a range of design concepts, and completed several initial prototype efforts.

Dow Chemical is a leader in science and technology, providing innovative chemical, plastic, building materials, and agricultural products to many essential consumer markets. Dow's strong connection to the building products industry and it's key market position in both rigid polystyrene and spray urethane foams make it an ideal project partner.

Amaro Construction is a small firm serving the California construction industry with Home Energy Rating Services. Their connection to the building industry and experience with construction practice will help in the field demonstration portion of the project.

In addition to the formal members of the team, DEG cultivated relationships with builders, concrete subcontractors, post-tension contractors, and building officials to further the design and market acceptance of the slab edge insulation system developed in this project.

2.3. Objectives

The key project objective is to successfully commercialize a slab edge insulation form ("E-Form") systems that has benefits for the builder (favorable first costs and potential energy credits), operating cost savings for the homeowner, and societal benefits for all by reducing heating energy consumption and the associated environmental impacts. The insulated forms will take the place of conventional wood forms during the concrete pour, but will remain in place to provide permanent slab edge insulation.

To successfully penetrate the production home new construction market, a slab edge insulation system should provide the following benefits:

- <u>Favorable builder economics.</u> By replacing the wood used in conventional forms, additional material costs can be minimized. A user-friendly staking system can reduce field labor. Slab edge insulation can be an inexpensive compliance method for local energy codes such as Title 24 in California. Energy savings enhance marketability.
- <u>Easy to install.</u> Acceptance with concrete contractors depends on a streamlined installation process that reduces field labor over conventional wood forms.
- <u>Accommodate post-tension process.</u> Post-tensioned concrete slabs now dominate the residential production home market in the Sunbelt states of California and Texas, and are

likely to gain acceptance in all residential slab markets. The ability of the form system to accommodate the post-tensioning process is critical.

- Proven termite mitigation. Most of the slab market is in areas of heavy termite risk. To comply with building codes the form system cannot allow termites to reach the wood structure undetected, and should be made of termite-resistant materials.
- Long-term durability. As a permanent building product, the form materials must have a lifetime of 30 years or more. However, durability is most related to cosmetic appearance because the form is loaded only during the concrete pour. Weatherability factors such as UV- and corrosion-resistance have the greatest impacts.

2.4. E-Form Concept

The E-Form concept replaces wood forms for residential slab construction with a closed PVC profile extrusion with integral foam insulation. Unlike conventional forms that are stripped after the slab has cured, the E-Form will remain in place to provide a permanent insulation value of roughly R-10. The steel staking system will attach to the inside of the PVC forms, eliminating the need to return to the site to remove form parts for labor savings and faster home construction. E-Form sets will be delivered to each home site as a kit with all forms cut to size and all necessary staking and connection hardware included. Detailed E-Form drawings are contained in the confidential sections 5 and 6 of this report. However, the basic E-Form design is described below.

- PVC Extrusion. A closed rigid PVC profile provides the strength necessary to resist the static and dynamic loads of a concrete pour. The 12” tall profile has details for attaching the stake system and structural hold-downs, and includes a continuous strip that will embed in the concrete to prevent termites from passing between the form and slab. The profile has hollows to accommodate 2” wide foam insulation. The profile is made by one of the largest PVC extruders in North America using window-grade PVC, which will exceed our weatherability and UV-resistance requirements. (No other component of E-Form will be exposed.)
- Foam Insulation. We have two leading candidates for foam insulation: extruded polystyrene foam (Styrofoam™) and polyurethane foam. Both foam materials have R-5 per inch insulative performance. Dow Chemical will soon begin production of Blueguard Styrofoam, a new termite-resistant insulation approved for below grade use in heavy termite risk areas. Polyurethane foam can be foamed-in-place for maximum form strength.
- Stake system. All stake materials will be inside of the forms, eliminating the need for the concrete contractor to return to the site. The stake design will be refined through trial and error to develop a low cost system that can be quickly and accurately installed in a range of soil types.
- Structural hold-downs. A track system at the top of the PVC profile will accommodate all popular structural hold-down products. Long term E-Form plans include developing a custom hold-down system that does not interfere with screeding (leveling) the wet concrete.
- E-Form fabrication and installation. To reduce field labor over conventional wood forms, E-Form kits will be delivered to the site ready for installation. E-Form will develop an

automated system to calculate form cut lengths and hardware quantities from slab footprint drawings. In addition, E-Form will work with the post-tension contractor to locate and cut all holes necessary to mount the post-tension equipment, saving field labor for the post-tension crew.

2.5. Phase 1 Accomplishments

The goal of Phase 1 was to update market research, analyze insulation performance, develop the E-Form design including all accessory details, and fabricate prototypes of the basic form system. The Phase 1 work was divided into the following tasks:

Task 1: Market Research. We completed a review of code issues and current slab construction practice with input from builders, concrete subcontractors, post-tension contractors, building officials, and other parties that influence the selection and specification of construction materials. We developed a detailed cost model based on two production scenarios, and a nationwide market analysis based on U.S. Census Bureau data for four different commercialization strategies.

Task 2: Insulation Optimization. A sophisticated finite difference model was needed to understand the heat transfer processes between house and the ground in a variety of climates. We investigated available tools, selected a preferred model, and completed simulations to determine optimal insulation thickness in a variety of climates. Reasonable national savings estimate for a typically sized new home with a central gas furnace is on the order of 60 therms per year.

Task 3: Design Options and Details. We evaluated various design alternatives in terms of cost, structural and thermal performance, ease of installation, durability, and construction industry acceptance. To optimize the extrusion design, we used Finite Element Analysis (FEA) and coordinated closely with the extrusion vendor. We developed designs for the staking system and linear and corner joints, and evaluated each design for thermal expansion, termite resistance, weatherability and other issues. Together with Dow Chemical, we evaluated foam material options.

Task 4: Prototype Development. We selected an extrusion vendor and procured a die for the PVC profile. The vendor developed the die and produced an initial run of 1000’ of the profile. Both DEG and Dow installed Styrofoam and foam-in-place polyurethane into profiles to create sample forms for strength testing. A staking system was prototyped and installation evaluated in a variety of soil conditions.

2.6. Phase 2 Tasks

The goal of Phase 2 is to finalize all aspects of the system, including procurement of all production tooling, in anticipation of E-Form commercialization.

Task 5: Mockup & Prototype Testing. An E-Form insulated concrete slab mockup will be completed for a small (approximately 10’ x 10’) slab. The slab will be divided to create baseline uninsulated and insulated slab sections for thermal testing. The test bed will be instrumented with temperature and thermal flux sensors to measure slab edge loss for insulated vs. uninsulated perimeters. (The mockup test plan is included in this report in Appendix B.)

Task 6: Field Testing. Both production builders and custom builders will be contacted to determine interest in participating in field testing of the E-Form system. Our goal is to work with at least one custom builder and one production builder in implementing the system. Ideally we would like to install the E-Form system on three or four of production homes to thoroughly assess the installation learning curve and overall satisfaction with the product. A new extrusion will most likely be required based on design changes required from Tasks 4 and 5, and production tooling will be procured for all staking and joiner components.
Task 7: Evaluation, Reporting, and Technology Transfer. To maximize the value of the project, we will hold meetings and/or interviews with builders, architects, concrete subcontractors, code officials, and homeowners. Project findings will be presented at a Building America Experts Meeting, presentations to manufacturers, and in a technical journal paper.

2.7. Conclusions and Next Steps

The E-Form design concept developed in Phase 1 has evolved considerably from the preliminary design presented in the original project proposal. Substantial progress has been made in better understanding and quantifying the market, modifying the design based on both structural and durability concerns, and more rigorously understanding the potential savings. A key finding that significantly affected the E-Form design path was the discovery of the rapid and significant market impact of post-tensioned slab construction. Understanding how the post-tensioned process works and developing a compatible design represented a major diversion from our original plan.

We are confident that Phase 2 funding will bring us to a point where a market ready E-Form product will be ready for commercialization. Much of our confidence comes from having Dow as a key player on the development team. Their connection to the building supply industry, experience with code issues (especially the critical termite issue), and insulation products experience is invaluable.

The market for a slab edge insulation system is huge with nearly 900,000 slab-on-grade homes currently being built per year, virtually all with uninsulated perimeters. Addressing this huge market will provide significant energy savings and corresponding greenhouse gas reductions. In addition, in states like California where strict energy codes drive builders to the most cost-effective improvement options, a cost-effective E-Form system should experience significant early market demand. Using realistic market penetration rates, we estimate E-Form volume will reach ~56,000 homes in the third-year of commercialization. With an average heating energy savings of about 60 therms per year for Sunbelt locations, we estimate the cumulative savings over the first 10 years of 214 million therms. In a mature market, 500,000 E-Form homes could be built per year, resulting in savings of 30 million therms in the first year alone.

In California where Title 24 offers a significant incentive for builders, a 50% market penetration for E-Form (or similar competing products) seems reasonable after five to ten years. That would result in 70,000 E-Form slabs in California alone, with first year energy savings of 4.2 million therms.

Despite the significant potential of the E-Form system, hurdles remain. The staking system design has proven more difficult than expected due to the reality of the significant variations in soil conditions, both geographically and seasonally (moisture content). Corner and connector details have been designed, but not prototyped and tested. Although the existing extrusion design appears workable, changes in the staking system and/or connectors may affect a change in the extrusion design. Optimization of the insulation process is also a critical step in balancing strength, cost, and insulation performance. Field thermal testing in Phase 2 will document E-Form heat reduction characteristics. An ICC Evaluation Service evaluation report is a critical step in addressing termite concerns.

E-Form product development efforts in Phase 2 will focus on the following areas of concern:

- Ease of use of staking system. A two-element stake will allow different driving tips for different soil conditions and allow height adjustability for elevation of stake top.
- Foam selection. Blueguard Styrofoam is already approved for use in heavy termite regions, but will not add structural strength to form boards like foam-in-place polyurethane foam. Styrofoam also resists water absorption more than polyurethane foam.
- Sealing of form boards. A completely sealed form board will most likely eliminate the termite risk should we decide to use polyurethane foam, but poses technical and cost problems.
- Structural requirements. The extruder has requested additional ribs to increase extrusion speed and strengthen the part. Additional ribs will probably prevent the use of Styrofoam insulation, so the alternative is greater wall thickness or some degree of waviness in the PVC profile.
- Corner and linear joiners. We developed several designs for joiners in Phase 1, but were not able to construct mockups or prototypes.

The thermal modeling, cost analysis and market analysis of Phase 1 indicate that E-Form has the potential to provide significant energy savings on a national level. As other residential building components have achieved increased levels of efficiency over the years, heat losses at the slab perimeter represent an increasingly larger percentage of annual heating loads and one of the last remaining holes to plug. Combined with the incentives of local energy ordinances such as California's Title 24, the market appears ready for a leave-in-place concrete slab form with integral insulation. The elimination of post-pour finishing work for the concrete subcontractor should be another strong incentive for industry adoption. The Phase 1 prototype showed that the PVC profile should be strong enough, particularly with polyurethane foam reinforcing.

In Phase 1 we demonstrated that E-Form is a viable substitute for wood concrete slab forms, and that the market demand and potential energy savings warrant further investment. The greatest barrier to E-Form success will be acceptance by concrete contractors, who will be strongly influenced by its ease of use. Should Phase 2 funding be awarded, we will focus our efforts on refinement and iteration of the staking and joiner parts, and optimization of the installation process. With production tooling of all E-Form components procured with Phase 2 funding (minus cost match), E-Form will be ready for commercialization immediately after the project completion.

3. Market Research

3.1. Introduction

In the mid-1990's, Davis Energy Group (DEG) was involved with CertainTeed in a brief partnership to develop a slab edge insulated form (SEIF) system. A basic design emerged to work with the traditional two-pour slab that was the dominant construction method at the time. Although no physical hardware was developed, CertainTeed did complete a market analysis based on the preliminary SEIF design. This market analysis served as a starting point for the current market and cost analysis effort undertaken during Task 1 of this project.

Task 1 market research consisted of several activities:

- We discussed the E-Form concept with concrete and residential construction industry professionals to gather feedback and design suggestions, and to learn about the latest trends in residential slab construction.
- We attended seminars, observed crews in the field, and met with industry members to understand the post-tension process and accommodate it in the E-Form design.
- We researched the California Title 24 Building Standards to determine the potential energy benefits of the E-Form design.
- After finalizing the Phase 1 design in Task 3, we developed a cost model based on quotes from extrusion, sheet metal and roll-forming vendors. Cost models were also developed to detemine E-Form economics under various scenarios.
- We analyzed U.S. Census Bureau data on new home construction to assess current slab construction rates and project future market success for E-Form with a variety of marketing scenarios.

In California, the Title 24 Building Standards is the main driving force behind the selection and specification of energy efficiency measures required to demonstrate compliance. For each of the 16 California climate zones a set of cost-effective energy efficiency measures define a "standard" energy budget unique for each house being built. The goal of the builder is to insure that the house they want to build meets that budget. The hourly simulation model used to demonstrate compliance evaluates the energy benefits and penalties of each measure. For example, spectrally selective windows would improve summer performance, but hurt winter performance. SEIF systems offer a unique opportunity to offer energy credits relative to the "standard" case of an uninsulated slab. If the economics are favorable for SEIF, the Title 24 process could generate a significant market demand for a low cost compliance option.

3.2. Trends in Current Residential Slab Construction

To better understand the current construction environment, we conducted a wide-ranging survey of individuals and firms involved with residential slab construction. Some of those whom we interviewed are listed below.

- Daniel Kitts, Dow Chemical (Manages sales of all Dow building products to production home builders in Southern California.)
- Dave Leal, Leal Concrete (a small Davis, California concrete contractor specializing in custom home slabs.)
- Mark Rutheiser, Pyramid Construction (Custom homebuilder based in Davis, California.)
- Terry Alexander, Janco Concrete (High-volume concrete contractor specializing in production home slabs in California's Central Valley and greater San Francisco Bay Area.)
- Steve Mueller, Mueller-Lewis Concrete (San Diego concrete contractor specializing in production home slabs.)
- Mike Bauer, Bauer Concrete (smaller San Francisco Bay Area concrete contractor specializing in slabs for apartments and townhomes.)
- Sandra Quinn, Fieldstone Homes (Senior procurement agent for production home builder in San Diego, formerly a buyer at Arcadian Homes in San Jose. 40 years of experience.)
- Jeff Jacobs, formerly of Centex Homes (Project manager for a Northern California production builder.)
- Ken Douglass, Suncoast Post-Tension (Largest post-tension firm in U.S.)
- Members of the Monterey Bay Chapter of the International Code Congress

In the decade since the CertainTeed SEIF project, a revolution has taken place in the production home slab construction market in California. In the early 1990s, most slabs were made with a two-pour process. Trenches were dug at the perimeter and under load bearing walls and wooden forms were placed at the outer edge of the perimeter trenches. The first concrete pour filled the trenches to create a "footing." At least two inches of gravel and two inches of sand were placed in the interior of the slab area, and a steel wire mesch was secured to the forms so that it was submerged in the slab about two inches deep. The center of the slab itself was typically four inches thick or less.

In the past three to five years, the vast majority of production homes in California have shifted to post-tensioned single-pour slabs. Steel wire mat reinforcing was found to be insufficient at preventing cracks from spreading. Building inspectors and structural engineers began demanding steel rebar reinforcing at considerable additional expense, with only a slight improvement in slab durability. Post-tensioning quickly emerged as the preferred solution. The post-tensioning process, first developed in Texas to combat highly expansive soils, has found application across the U.S. for commercial and industrial applications where high slab strength is required.

Post-tensioning results in a much stronger slab, although construction costs are higher. Production homebuilders generally resist incorporating higher cost building materials and processes, but they have been far more enthusiastic in accepting post-tensioning than custom homebuilders, with whom the process remains rare. The main reason for this is construction defect litigation. As cracks develop in a slab, moisture can seep through and damage flooring materials. If the cracks grow enough, slab movement may destroy floor tiles and cause drywall cracks as the house settles. In addition, nearly all middle to high-end production homes in California has heavy concrete tile roofs, which require stronger slabs. Codes now require heavier and more numerous firewalls and shear wall assemblies that also increase slab loads.

The final nail in the coffin for conventional two-pour slabs was California state law SB800 (passed in 2002) allowing plaintiffs to recover damages for construction defects that had not yet caused property damage or personal injury. This meant that if cracks emerged in a few slabs in a subdivision, homeowners throughout the subdivision could sue the builder even if there were no problems with their slabs.

Among the industry contacts we spoke to, the consensus was that more than 90% of new production homes in California use post-tensioned slabs. Much of the California construction is occurring on current or former floodplains, which are likely to have expansive soils requiring post-tensioned slabs. This includes the Central Valley, most of the San Francisco Bay Area and East Bay, and the Inland Empire (stretching from eastern Los Angeles to Palm Springs). Fear of litigation, liability insurance rates, and industry inertia appear to have pushed post-tensioned slabs into the population centers outside of those regions. In our discussion with industry experts, we found only two areas where current building practice is using the conventional two-pour system. One was with Fieldstone in rural San Diego County and the other was in the fast growing cities of Rocklin/Lincoln northeast of Sacramento. Both of these projects were in foothill locations where builders felt confident enough that soil conditions were stable enough to allow conventional slabs to perform well.

The widespread adoption of post-tensioned slabs among production builders was the most dramatic outcome of the E-Form market research. However, there were several other important insights that we gained into the slab construction market from our industry interviews.

- As is typical for many new technologies, the initial response from concrete contractors was lukewarm. Although they appreciate the potential for Title 24 credits, they are naturally skeptical of outsiders suggesting a significant change to their way of business. However, the builders contacted were far more positive of E-Form’s potential because of the opportunity to gain Title 24 credits at a lower cost than other building products.
- Popularity with concrete contractors is not a requirement for E-Form success. While we hope to develop a system that concrete contractors enjoy working with, the builder (in conjunction with the architect, structural engineer, and Title 24 consultant) decides which building products are used.
- Concrete forms are usually made from 2x10 or 2x12 wood boards. Although there are cheaper grades, #2 Douglas fir is typical because it has fewer knots and so can be reused easier. Contractors typically get an average of two uses out of each form board. In the summer the drier form boards need to be oiled to have any chance of salvaging them.
- The basic structural hold-downs are J bolts, which are mostly commodity products available from a number of sources.
- The standard installation procedure involves attaching the J bolts to the form boards for building inspector review. The bolts are then removed prior to the pour and then “wet-set” immediately after the pour, making it easier to screed the concrete surface level with the top edge of the form. Wet-setting larger hold-downs does not appear to be common.
- Simpson makes a wide variety of structural hold-downs. These are value-added products that are used for either specialized applications in conjunction with J bolts, or as a substitute for J bolts. Several of these products appear to serve the same purpose, indicating that different structural engineers have preferences for one product over the

other. Our first design used a proprietary female hold-down component. This will likely be a liability for two reasons:

  - Any new hold-down system would require listing with an evaluation service such as ICC-ES to confirm code compliance. Review and listing with ICC-ES costs at least $20,000.
  - Some structural engineers might refuse to work with E-Form if it did not accommodate their preferred hold-down system.

- We heard of no examples of a post-tensioned slab also using radiant heating. This confirms that the custom homebuilders, who do the vast majority of the radiant-heated slabs, are still not using post-tensioned slabs. The two systems are not incompatible, but will make for a busy slab.

3.3. E-Form Preliminary Code Review

We presented the E-Form concept to the Monterey Bay Chapter of the International Code Congress on June 15, 2006. This group of about 20 building officials invites companies to present new building products during their monthly meeting, providing an excellent opportunity for informal feedback on whether a new product will be allowed in their building jurisdiction. Some of their concerns were:

- Their general response was lukewarm, which we consider a positive with building officials. They are usually only animated about products and technologies that they are concerned with. They have no incentive to approve energy or cost saving products since their main focus is safety.
- Any new hold-down system would need to have ICC-ES or similar listing before code approval is received.
- Hold-down systems must go at least 7” deep into the concrete.
- They are willing to tolerate a left-behind wooden stake. This may contradict code passages that require wood in contact with the ground be at least 12” away from the top of the slab, but they were not concerned about a small wooden stake in our system near the bottom of the slab because it would not create a conduit for termites to enter the house undetected.
- Foam insulating materials should either be fully encapsulated or be hydrophilic to avoid water-logging.
- Weatherability will need to be demonstrated before E-Form achieves widespread acceptance.
- In the unlikely case that the PVC extrusion does not bond to the concrete, differential expansion and contraction may cause enough movement to wear through the PVC.

3.4. Post-Tensioned Slab Construction Process

Concrete can withstand very high compressive forces, but is relatively weak in tension. To counteract this material deficiency, steel reinforcing is distributed throughout the form before the concrete is poured. Traditional reinforcing such as steel mesh or rebar provides some tensile strength, but for higher performance engineers use ***pre-*** or ***post-***tensioned steel cables set into the concrete form. The tension ensures that the concrete is always under compression, enabling concrete structures to be stronger and less prone to cracking than a non-tensioned slab.

In ***pre***-tensioned slabs, steel cables are strung across the forms and stressed before the concrete is poured. After the concrete has cured sufficiently it bonds to the cables and the ends of the cables are cut. The ends are potted with grout to avoid corrosion. Pre-tensioned concrete forms must be very strong to hold the stressed cables in place.

The process for ***post***-tensioned concrete leaves the cables (also known as tendons) slack in the concrete form until after the concrete has cured, placing no load on the forms. After the forms are stripped, the cables are stretched to apply a sufficient compressive force to the concrete. The cables have a plastic sheath to prevent the concrete from bonding to cable. Grease on the inside of the sheath allows the cable to slide freely. As with pre-tensioned concrete, the ends of the cables are trimmed and potted to avoid corrosion. Because the cable is not bonded to the concrete, each end of the cable must be mechanically bonded to an anchor set in the concrete.

The post-tensioning process specific to slab-on-grade construction is described in detail below.

1. The form boards are cut and installed in a manner similar to conventional slab forming.

2. The ½” cables are delivered to the site pre-cut to match the footprint of the slab. SunCoast Post-Tension works with builders to deliver a custom tailored set of cables for each slab and uses only its own crews to install the cables and tension them after the slab has cured. Other vendors deliver cable to the site where they are prepared, installed and tensioned by a different post-tension firm.

3. The prepared cables already have one anchor installed, as shown below. Inside the anchor are two split wedges that bite into the cable as it is pulled through the anchor.

4. This end is attached to form board with nails so that there is space between the board and the anchor as shown below. This “static end” allows concrete to encase the anchor.

5. The cables are unrolled to the opposite form board. The opposite end of the cable also has an anchor pre-installed, but with about five feet of cable beyond the anchor. This extra cable is passed through a hole in the form and the anchor is nailed to the form as shown below. A white plastic part known as a pocket-former is slide onto the cable between the anchor and the form board. Where cable cross each other, they are wire tied together and/or placed in a cross support that maintains the height of the cable.

6. The concrete is poured. The top surface is screed flat and hold-downs are wet-set if necessary. Small additional cylinders of concrete are poured for testing of concrete strength.

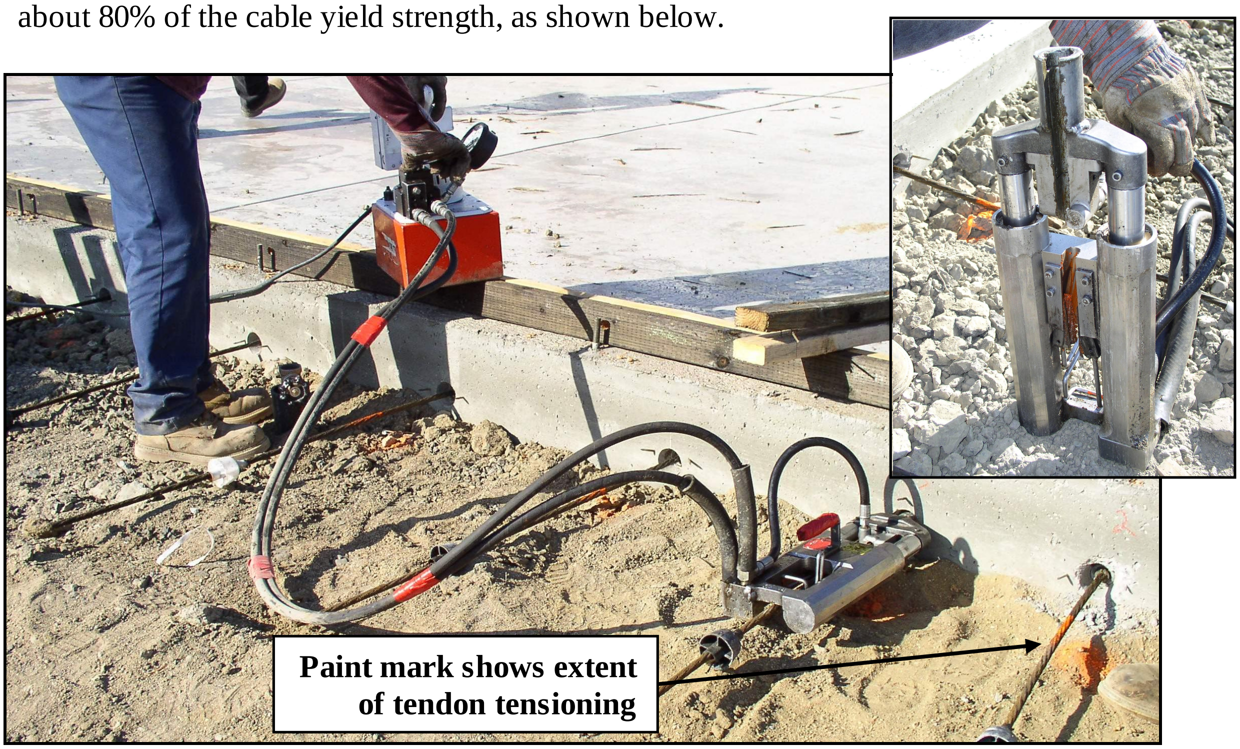
7. The form boards are removed the following day.

8. Two or three days after the concrete is poured, the samples are tested to confirm that the concrete has reached a compressive strength of at 2000 psi. A building inspector must be on-hand to confirm this. The cables can now be tensioned.

9. Remove plastic pocket formers from the visible cable ends. The concrete does not bond to the plastic, so they are easy to remove. This exposes the anchor and wedges as shown below.

10. Using a 2x6 up against the concrete as a guide, the cable is spray painted to indicate the cable strain after tensioning.

11. A specialized hydraulic ram is used to apply 33,000 lbs of tension to the cable, which is about 80% of the cable yield strength, as shown below.



12. The distance that the spray painted mark has moved is recorded. The cables typically stretch about 0.8 inches per foot of cable length.

13. The end of the cable is cut with an abrasive saw. A vinyl cap is placed over the end of the cable and the pocket is filled with grout, as shown below.

Post-tensioned slabs are referred to as monolithic because only one pour of each concrete structure can be post-tensioned, so two-pour designs with a separate footing are never used. The depth of the cables is always one-half of the thickness of the slab. The spacing of the cables is based on structural requirements and varies from 1' to 5', with typical spacings of 2 to 2.5 '.

Two different post-tensioned slab designs dominate California residential construction. Waffle slabs, which are used mostly in Southern California, have a similar perimeter appearance to conventional slabs. A 12" to 24" perimeter trench is dug with interior trenches crossing the interior based on structural calculations. The post-tension cables are slung down into the trenches as well as through the main part of the slab, which are spaced 18" to 5' apart. The 4" to 5" main part of the slab is slightly thicker than conventional slabs.

Most concrete contractors and structural engineers in Northern California prefer to use Uniform Thickness slabs. Such slabs do actually have a slight perimeter turn-down of 2" to 4" deep, but this is determined by the depth of the interior gravel. An advantage of Uniform Thickness slabs is that they do not require any trenching. Uniform Thickness slabs vary from 5" to 14", with 8 to 10" thickness common.

The E-Form design needs to be versatile enough to work with both Waffle and Uniform Thickness slabs for production homes, and it must work with conventional two-pour slabs. It must be able to support post-tension cables at any depth ranging from 2" to 7".

3.5. Title 24 Implications for E-Form

All new residential construction in California must comply with the Title 24 energy code established by the California Energy Commission. The state is divided into 16 different climate zones. Homes built in the more extreme climate zones must be more efficient than those built in moderate climate zones. Most house designs require some manipulation of the installed energy features to arrive at a final set of energy features that meet the Title 24 energy budget. There are two basic compliance alternatives for Title 24.

- Prescriptive Method. This is a checklist of building products and design aspects that are pre-approved for compliance with Title 24. Examples are minimum ceiling insulation R-value and maximum total fenestration (window) area as a percentage of floor area. These values vary by climate zone. If the home design complies with the Prescriptive Method, no further energy calculation is required. However, this is rarely the case due to the inherent lack of flexibility in the Prescriptive Method.
- Performance Method. The most common reason that home designs do not satisfy the Prescriptive Method is builder desire to add more glazing, in particular west facing, than allowed. In that case, software must be used to confirm that improvements to other design aspects bring the entire design into compliance. Energy consultants work with architects and builders to determining the most cost-effective manner in which to satisfy the Title 24 requirement. In addition to improving the standard building parameters (such as higher insulation R-value), other improvements such as high efficiency HVAC equipment or solar water heating can be added and given credit by Title 24. This is where E-Form would be used, particular if E-Form is a less expensive alternative for compliance.

In the 1994 CertainTeed SEIF market analysis, slab edge insulation was found to be worth about six Title 24 points. The actual number varies by home size and climate zone. ConSol estimated these points to be worth about $125 each, based on the incremental cost of energy efficiency measures. As Title 24 has become more restrictive over the years and building costs have increased, the current value of each credit could be as high as $200. Since we did not repeat this analysis, we conservatively assumed a value of $150 per credit for the market analysis.

Title 24 is revised every three years as part of a public process that reviews the cost effectiveness of new energy efficiency measures based on measure costs and current valuation of electricity and natural gas. The most recent revision in October 2005 further tightened the energy loopholes. An example lies with air conditioning systems. In the prior version of Title 24, builders were rewarded for using a 12 SEER air conditioner. With the 2005 NAECA requirement mandating 13 SEER air conditioning systems, less costly improvement options (e.g. 11 or 12 SEER units) have been eliminated. Slab edge losses continue to stand out as one area where credits are available, but no viable commercial options exist.

3.6. Termite Issues

A concern with any exterior foundation insulation is the potential of increase termite infestation. Termites are not attracted to the foam materials themselves, but can create undetected tunnels through the foam to reach the softwoods within the home.

The International Code Congress (ICC) has established the map of termite infestation risk shown in Figure 3-1. Nearly all areas where slabs dominate residential construction are included in the Very Heavy termite regions.

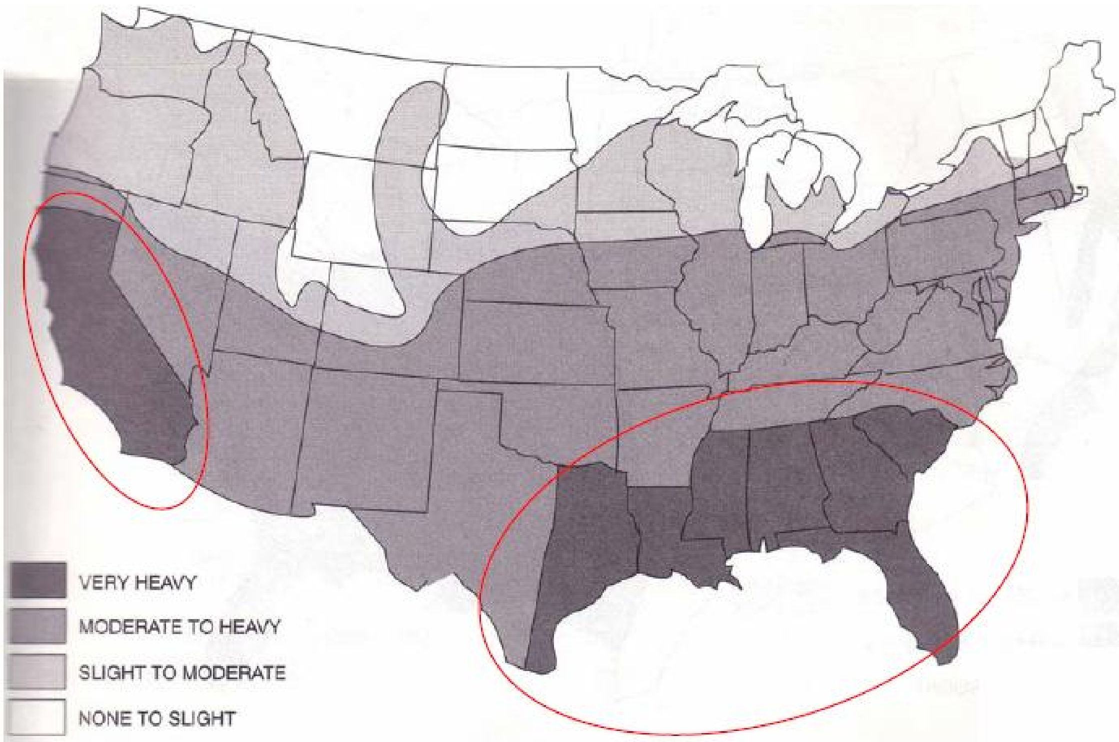


Figure 3-1: ICC Termite Infestation Risk Map

In 1999 the ICC banned the use of foam in below grade exterior applications in the Very Heavy termite regions.[1] Dow Chemical noticed a significant drop-off in the use of their foam products for foundation insulation in the Southeast. However, Section R320.4 had an exception when the foam plastic and structure are protected from subterranean termite damage by an *approved* method. The only foam material to be approved at this time is expanded polystyrene (beadboard) with borate. Dow has developed a termite-resistant version of Styrofoam extruded polystyrene using Deltamethrin that should have ICC-ES approval in the next few months.

Although the ICC defines the termite risk in California to be as severe as in the Southeastern U.S., the market behavior does not appear to reflect this. Termite damage to homes in California is relatively rare. Furthermore, we know that foam insulation is applied to the perimeter of radiant-heated slabs because Title 24 requires it. This apparent conflict with the ICC may become a larger issue in 2007 when the IBC building code is finally accepted as the statewide building code in California. When insulating a slab perimeter in California, a sheet metal “termite strip” is usually attached to the wooden form boards such that the inboard edge of the strip is embedded in the concrete as it is poured. After the forms are removed, the insulation is attached to the concrete and the outer edge of the termite strip is folded down over the insulation. This strategy requires termites to travel around the outside of the termite strip where their trails can be detected by pest management professionals.

[1] Section R320.4 Foam plastic protection. In areas where probability of termite infestation is "very heavy" as indicated in Figure R301.2(6), extruded and expanded polystyrene, polyisocyanurate and other foam plastics shall not be installed on the exterior face or under interior or exterior foundation walls or slab foundations located below grade. The clearance between foam plastics installed above grade and exposed earth shall be at least 6 inches.

3.7. Cost Models

Our first step in assessing potential E-Form market success was to develop cost models for E-Form and the two baseline construction scenarios of interest. The "low volume" end of the market is characterized by California custom homes with radiant-heated slabs. While rather limited in size, this market should be a "sure thing" for E-Form given the Title 24 requirement that all radiant-heated slabs have perimeter insulation. Success in this market would likely translate to the radiant heating market in other states. At the "high volume" end of market are production homes with uninsulated slabs. Due to the size of this market, even modest success marketing to California production homebuilders would drive E-Form costs as low as they can go within the existing vendor supply chain[2].

The model home used in the cost model was based on a conditioned floor area of 2400 ft^2, slightly more than the U.S. Census Bureau's 2005 national average of 2227 ft^2. Based on census data indicating 55% of U.S. new home starts in 2005 had a second story, floor area was divided into 1550 ft^2 on the first floor and 850 ft^2 on the second floor. An additional 350 ft^2 of slab area was included for the garage resulting in a total slab area of 1900 ft^2. This mimics the "top-heavy" and slightly larger homes found in California. All of the cost models were based on a typical residential slab with 240 lineal feet of perimeter.

The baseline cost model for the custom home slab with radiant floor heating is shown in Table 3-1. Material and labor costs were taken from interviews with local concrete contractors working with custom homebuilders. A key material cost is the sheet metal flashing used to provide a continuous termite block to prevent termites from entering the home undetected.

Table 3-1: Baseline Cost Model for Custom Home with Perimeter Insulation

Current Custom Builder Costs: Insulated Slab	Cost per house			Cost per lineal ft
Total Material Cost	**$2,036**			**$8.48**
Form boards materials		$240	1	
Stake materials		$45	2	
Foam materials		$384	3	
Termite strip flashing		$960	4	
Materials markup		25%		
Total Installation Labor Cost	**$2,408**			**$10.03**
Install form boards labor		$768	5	
Strip form boards labor		$256	6	
Install insulation labor		$180	7	
Labor markup		100%		
Concrete Form Cost to Builder	**$4,444**			**$18.52**

[1] 2x10s used twice, 240 LF x $2.00/ft x 2 uses
[2] Stakes at $0.50 each used every 3 feet
[3] Bought through a distributor at $0.60/board foot
[4] $3/ft for sheet metal flashing

[2] Bringing the PVC extrusion process in-house could drive total E-Forms costs down by an additional 5-10%.

[5] 2 days x 3 person crew x $16/hour
[6] Assumed at 1 day x 2 person crew x $16/hour
[7] $1.50/ft to install

The baseline cost model for the "high volume" uninsulated production builder slab is shown below in Table 3-2.

Table 3-2: Baseline Cost Model for Production Home without Perimeter Insulation

Current Volume Builder Costs: Uninsulated Slab	Cost per house			Cost per lineal ft
Total Material Cost	**$307**			**$1.28**
Form boards materials		$210	8	
Stake materials		$36	9	
Materials markup		25%		
Total Installation Labor Cost	**$1,024**			**$4.27**
Install form boards labor		$384	10	
Strip form boards labor		$128	11	
Labor markup		100%		
Concrete Form Cost to Builder	**$1,331**			**$5.55**

[8] 240 LF x $1.75/ft x 2 uses
[9] $0.40 each, used every 3 feet
[10] 1 day x 3 person crew x $16/hour
[11] 0.5 days x 2 person crew x $16/hour

In developing the E-Form cost model we relied on component prices based on actual vendor quotes, and the estimated time required for each labor step. Based on the 2,400 ft^2 floor plan, we developed a representative slab footprint and estimated the labor steps that would be required to fabricate a set of forms for the model slab. For comparison purposes, we created two E-Form cost models: one for the low volume custom builder market, and a second for the high-volume production home market. The results for the custom builder cost model are shown in Table 3-3.

Table 3-3: E-Form Custom Home Cost Model

Custom Builder E-Form Costs	Cost per house			Cost per lineal ft
Total Material Cost	**$2,008**			**$8.36**
Direct materials cost		$1,004		
Materials markup		100%		
Total Factory Labor Cost	**$83**			**$0.34**
Direct labor cost		$33		
Labor markup		150%		
Total Installation Labor Cost	**$512**			**$2.13**
Install form boards labor		$256	12	
Labor markup		100%		
Concrete Form Cost to Builder	**$2,602**			**$10.84**

[12] 1 day x 2 person crew x $16/hour

For the custom homebuilder required to insulate the slab perimeter of radiant-heated slabs, converting to E-Form slab construction is projected to save $1,842, or $8.10 per linear foot. Material costs are roughly the same, with the bulk of the projected savings coming from reduced field labor. As there is no significant difference in energy performance between E-Form and standard slab edge insulation practice, first cost savings represent the bulk of the benefit. However, because this up-front cost savings benefits the builder or concrete contractor directly, it should be popular. We did not include indirect benefits from streamlining the construction scheduling by eliminating the need to return to the site to remove the form boards. For the custom homebuilder marketing radiant-heated slabs, E-Form is clearly superior to conventional forming and perimeter insulation practices.

The production homebuilder "high volume" E-Form cost model is shown in Table 3-4.

Table 3-4: E-Form Production Home Cost Model

Volume Builder E-Form Costs	Cost per house		Cost per lineal ft
Total Material Cost	**$1,294**		**$5.39**
Direct materials cost		$863	
Materials markup		50%	
Total Factory Labor Cost	**$66**		**$0.28**
Direct labor cost		$33	
Labor markup		100%	
Total Installation Labor Cost	**$384**		**$1.60**
Install form boards labor		$192 [13]	
Labor markup		100%	
Concrete Form Cost to Builder	**$1,745**		**$7.27**

[13] 0.75 day x 2 person crew x $16/hour

E-Form economics for production homebuilders is not as favorable as for the custom homebuilder scenario. We project that switching to E-Form will increase builder costs by $414 per house, or $1.72 per linear foot. In California this is countered by the Title 24 credits and by the increased home energy efficiency. When the estimated $900 benefit of six Title 24 credits is taken into consideration, the $414 additional cost of E-Form becomes a net savings of nearly $500 to the builder. Furthermore, as Title 24 credits become even harder to attain with the 2008 revision, builders will be forced to look harder for products to satisfy Title 24 calculations, and E-Form should enjoy rapid market success with a large share of the residential slab market in California.

3.8. Market Analysis and Sales Projections

For the market analysis we relied on U.S. Census Bureau data presented on an annual basis as Survey of Construction (SOC) Microdata files. Annual microdata files contain all SOC sample houses started, sold, and/or completed during the year, with the exception of houses abandoned after start, which are not included. SOC is a national sample survey of new houses selected from building permits and a canvassing of areas not requiring permits. Builders or owners of the houses selected are interviewed for information including start, sale, and completion dates, and more than 40 physical and financial characteristics of the houses. The overall national sampling rate is about 1 in 50 new houses, although this varies considerably by individual survey location based on construction activity. Characteristics are broken down by the nine Census geographical regions, and the number of new home starts is broken down by state.

We focused our market analysis on single-family construction, although E-Form has market potential in some types of two- and three-family construction. We were mostly concerned with the following single-family residential characteristics:

- Number of new home starts
- Average square feet of floor area
- Types of foundation (divided into basement, crawl space, and slab/other)
- Number of stories

The potential market for E-Form is very large. According to the U.S. Census Bureau, 868,000 homes with slab foundations were built in 2005. With an assumed average slab perimeter of 245 linear feet, about 213 million linear feet of slab forms were used in 2005. Based on the cost model results and the importance of the California market due to Title 24, we focused on four marketing scenarios:

1. <u>California Niche Market Strategy</u>. This includes homes with radiant-heated slabs and a subset of the progressive builders constructing energy efficient homes meeting Energy Star or LEED-H. It is the likely trial market for E-Form since it includes the low-volume custom builders and the cutting edge builder exploring the best way to stringent energy efficiency requirements. (Table 3-5)
2. <u>National Niche Market Strategy</u>. Expands scenario #1 to include homes nationwide that feature radiant floor heating or are promoted as energy efficient. Market still dominated by California sales due to Title 24 requirement. (Table 3-6)
3. <u>California Mass Market Strategy</u>. After a first year of sales targeted mostly to radiant-heated slabs, marketing is quickly expanded to promote Title 24 benefit to the broad spectrum of California production builders. (Table 3-7)
4. <u>National Mass Market Strategy</u>. Expand scenario #3 nationwide with sales still dominated by California due to Title 24 requirements and benefits. (Table 3-8)

For all marketing scenarios, we extrapolated the Census data to predict slab activity for 2006 through 2009. We planned the market introduction of E-Form for early 2007, with sales activity projected for the first three years. Although unrealistic from a logistical perspective, this limited how far into the future we needed to predict market behavior. The data shown for 1999 to 2005 is Census data, except for the estimated "Second Floor Footprint Factor" which is used to calculate the estimated slab area and perimeter.

To avoid slab cracking or plumbing damage due to frost heaving, the perimeter turn-down of a slab must reach below the long-term freeze line. In northern U.S. climates with significant freeze danger, the perimeter turn-down of the slab needs to be so deep that the cost savings of slab construction is usually reduced to the point where it is outweighed by the storage benefit of basements. As a result, we confined our market analysis to the South and West Census divisions for the nationwide marketing scenarios. Insulation below grade is largely forbidden in the South due to termite infestations, which will likely limit E-Form success in that region.

For the niche market strategies, we first estimated the size of the “Energy Niche” and then estimated E-Form market penetration. For the niche market strategies we used a selling price of $8.70 per linear foot to calculate estimated E-Form sales. $8.70 is the combined materials and factory labor costs from Table 3-3. For the mass market strategies, we used the lower selling price of $5.67 per linear foot calculated from Table 3-4. The results of the market analysis are shown in Tables 3-5 to 3-8. We project third-year sales to range from 8400 slabs and $18.2M (California energy niche market strategy), to 56,400 slabs and $81.3M (national mass market strategy).

The market penetration is modest for most scenarios; although in 2009 we project demand to increase in California significantly due to the adoption of tougher Title 24 standards in late 2008. Even for the niche market scenarios, sales should be robust enough to attract the necessary investment to facilitate manufacturing and marketing start-up costs. With some good luck, $100 million in sales are attainable.

The greatest benefit will be felt in California due to Title 24 requirements and benefits. Other states have expressed interest in establishing similar residential energy standards, but we do not know of any serious initiatives. In the meantime, widespread acceptance of E-Form in California should have a noticeable benefit on the stability and pricing of electricity and natural gas markets in that state. Given the absence of any other product with the features of E-Form, it should be able to seize a large percentage of the slab market quickly, establishing itself as a well-known and profitable product with useful macro energy benefits.

Table 3-5: California Energy Niche Market Strategy

Year	Avg. sq. feet	% 2 story	2nd story footprint factor	Avg. footprint	Avg. slab perimeter	% slab	# of starts	# of slab starts	Energy Niche Size	E-Form % market share	# of E-Form slabs	Estimated Volume (ft)	Estimated Sales @ $8.70/ft
1999	2584	51%	75%	2019	241	85%	102750	87338					
2000	2594	50%	75%	2038	242	85%	105018	89265					
2001	2667	54%	75%	2050	243	85%	107361	91257					
2002	2700	53%	75%	2087	245	85%	123013	104561					
2003	2737	54%	75%	2104	246	85%	139870	118890					
2004	2702	54%	75%	2077	245	85%	151568	128833					
2005	2784	57%	75%	2104	246	85%	154703	131498					
2006	2809	57%	75%	2124	247	85%	166536	141555					
2007	2841	58%	75%	2137	248	85%	176588	150100	5%	6%	450	111,721	$971,971
2008	2873	59%	75%	2150	249	85%	186641	158645	8%	15%	1904	473,767	$4,121,777
2009	2905	60%	75%	2163	250	85%	196693	167189	10%	50%	8359	2,086,561	$18,153,078

Table 3-6: National Energy Niche Market Strategy

Year	Avg. sq. feet	% 2 story	2nd story footprint factor	Avg. footprint	Avg. slab perimeter	% slab	# of starts	# of slab starts	Energy Niche Size	E-Form % market share	# of E-Form slabs	Estimated Volume (ft)	Estimated Sales @ $8.70/ft
1999	2573	51%	65%	2056	243	47%	1246665	585933					
2000	2616	52%	65%	2080	245	46%	1198067	551111					
2001	2674	53%	65%	2116	247	48%	1235550	593064					
2002	2670	52%	65%	2123	247	50%	1332620	666310					
2003	2680	53%	65%	2120	247	52%	1460887	759661					
2004	2699	52%	65%	2146	249	54%	1613445	871260					
2005	2784	55%	65%	2181	251	53%	1681986	891453					
2006	2790	54%	65%	2191	251	55%	1733039	957133					
2007	2820	55%	65%	2209	252	57%	1817399	1027609	2%	3%	617	155,512	$1,352,958
2008	2850	55%	65%	2227	253	58%	1901758	1100303	3%	8%	2641	668,753	$5,818,154
2009	2880	56%	65%	2245	254	59%	1986117	1175214	5%	18%	10577	2,689,262	$23,396,576

Table 3-7: California Mass Market Strategy

Year	Avg. sq. feet	% 2 story	2nd story footprint factor	Avg. footprint	Avg. slab perimeter	% slab	# of starts	# of slab starts	E-Form % market share	# of E-Form slabs	Estimated Volume (ft)	Estimated Sales @ $5.67/ft
1999	2584	51%	75%	2019	241	85%	102750	87338				
2000	2594	50%	75%	2038	242	85%	105018	89265				
2001	2667	54%	75%	2050	243	85%	107361	91257				
2002	2700	53%	75%	2087	245	85%	123013	104561				
2003	2737	54%	75%	2104	246	85%	139870	118890				
2004	2702	54%	75%	2077	245	85%	151568	128833				
2005	2784	57%	75%	2104	246	85%	154703	131498				
2006	2809	57%	75%	2124	247	85%	166536	141555				
2007	2841	58%	75%	2137	248	85%	176588	150100	5%	7505	1,862,013	$10,557,613
2008	2873	59%	75%	2150	249	85%	186641	158645	10%	15864	3,948,062	$22,385,513
2009	2905	60%	75%	2163	250	85%	196693	167189	25%	41797	10,432,803	$59,153,995

Table 3-8: National Mass Market Strategy

Year	Avg. sq. feet	% 2 story	2nd story footprint factor	Avg. footprint	Avg. slab perimeter	% slab	# of starts	# of slab starts	E-Form % market share	# of E-Form slabs	Estimated Volume (ft)	Estimated Sales @ $5.67/ft
1999	2573	51%	65%	2056	243	47%	1246665	585933				
2000	2616	52%	65%	2080	245	46%	1198067	551111				
2001	2674	53%	65%	2116	247	48%	1235550	593064				
2002	2670	52%	65%	2123	247	50%	1332620	666310				
2003	2680	53%	65%	2120	247	52%	1460887	759661				
2004	2699	52%	65%	2146	249	54%	1613445	871260				
2005	2784	55%	65%	2181	251	53%	1681986	891453				
2006	2790	54%	65%	2191	251	55%	1733039	957133				
2007	2820	55%	65%	2209	252	57%	1817399	1027609	0.8%	8221	2,073,499	$11,756,738
2008	2850	55%	65%	2227	253	58%	1901758	1100303	2.0%	22006	5,572,944	$31,598,595
2009	2880	56%	65%	2245	254	59%	1986117	1175214	4.8%	56410	14,342,729	$81,323,271

4. Insulation Optimization

4.1. Introduction

One of the more complicated areas for detailed building energy simulations to accurately model is the characterization of heat fluxes between a house and the soil below. Ground heat transfer is a complicated process because it is a function of many factors including:

- soil characteristics (density, thermal diffusivity, moisture content, homogeneity)
- deep ground temperature (primarily a function of latitude)
- the impact of varying soil strata close to the surface
- house geometry[1]
- conditions surrounding the house (snow, shading, pavement, precipitation, etc.)

A 2005 DOE review of existing building simulation models found that most simulation models provide only one-dimensional modeling of slab heat loss. One-dimensional models are limited in their ability to handle the modeling complexities and the impact of the house footprint on the undisturbed soil conditions. Communications with Michael Deru of NREL suggested four models with advanced ground heat transfer modeling capabilities. The four included SUNREL (a model under development from NREL), EnergyPlus (uses a simplification of a more sophisticated model developed at Penn State University by Bill Bahnfleth), ESPR (a Canadian model that is based on work completed by Mitalas), and TRNSYS (a modularized model developed for simulating building and thermal systems). Davis Energy Group also has some experience in ground modeling with prior work with a beta version of an hourly ground model coupled to a version of the MICROPAS hourly building simulation model.

To learn more about the latest developments in ground modeling, Davis Energy Group attended a Building America sponsored Ground Coupling Expert's Meeting at Florida Solar Energy Center in August 2005. In attendance were several ground modeling experts including Joe Huang of Lawrence Berkeley National Laboratory, Michael Deru, and Bill Bahnfleth. Based on information gleaned at the meeting and from our prior communications with Michael Deru, we decided that the TRNSYS simulation model provided the most analytically detailed ground model in a fully developed simulation package[2].

The TRNSYS model is a flexible simulation model that provides a modularized approach to simulating thermal system performance. Thermal Energy System Specialists of Madison, Wisconsin specializes in packaging custom TRNSYS models for specific applications in a user-friendly format. These TRNSED models allow for a reduced set of data inputs specific to the application being evaluated, facilitating the users ability to input data and generate results.

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[1] A house with a square footprint would have a different "thermal bubble" under the house than a house with a large perimeter to area ratio.

[2] The TRNSYS ground loop model is currently being evaluated as the reference model to be used in the HERS BESTEST process.

The TRNSED model utilizes a customized routine to model the energy transfers from a horizontal surface (commonly a concrete slab) to the soil beneath the surface. The energy transfer is assumed to be conductive only and soil moisture effects are not accounted for in the model. The model relies on a 3-dimensional finite difference model of the soil and solves the resulting inter-dependent differential equations using a simple iterative method. The user enters the temperature of the zone side surface of the slab, the slab U value, the soil properties and grid geometry, and the initial conditions outside of the slab (near-field). Heat transfers from the slab, the deep ground, and surface-influenced nodes affect the near-field soil temperatures. The far-field soil temperatures are only affected by the surface conditions (time of year) and depth. In return, the model calculates the slab/ground interface temperature, which is passed back to the building model to determine the heat flux over the 15-minute simulation interval. Figure 4-1 depicts examples of how the soil grid is developed for different applications. The finite element size is adjusted to focus maximum resolution in the areas where the highest resolution is needed.

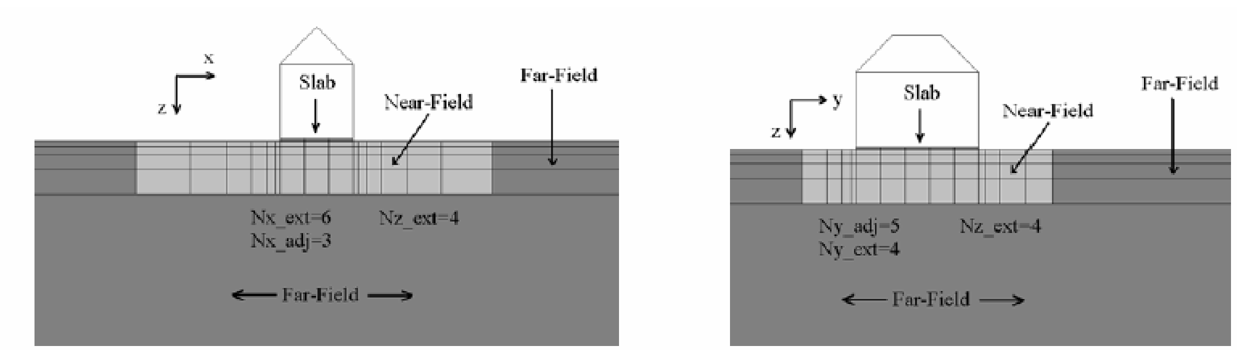


Figure 4-1: TRNSED Ground Modeling Configuration

4.2. Modeling Assumptions

The TRNSED model does have some modeling limitations. Due to the complexity of the finite element model and the need for a 15-minute time step, average model run times are on the order of three to four hours. To reduce this to a more manageable level, simplifications were made. By assuming the house has a rectangular footprint, symmetry allows for modeling only one quarter of the full slab footprint and associated underground thermal nodes. In addition, the rectangular assumption simplifies the finite element modeling by including only one corner to be modeled.

The assumed characteristics of the prototype house are as follows:

- 2,000 ft^2 floor area
- Single-story
- Perimeter of 210 feet
- 20% glazing, uniformly distributed (100 ft^2 for each orientation)
- R-12 average walls (including framing factors and insulation defects)
- R-25 average ceiling (including framing factors and insulation defects)

- Fixed heating and cooling thermostat settings of 70°F and 76°F, respectively
- 70% of slab area covered by R-2 carpeting; remainder hard surface flooring

Soil properties have a significant impact on the projected heat fluxes from a slab. Dry, sandy soil behaves very differently than dense, saturated soil. Since the benefits of a slab edge insulation system largely accrue from minimizing winter season heat losses, we decided to model soil properties based on "heavy/damp soil" characteristics to reflect typically damp soil conditions during the winter months. Assumed soil thermal properties include:

- Soil conductivity of 0.75 Btu/hr/ft-°F
- Density of 131 lbs/ft^3
- Thermal diffusivity of 0.60 ft^2/day
- Heat Capacity of 0.23 Btu/lb-°F

As we learned during the market research effort, the traditional two-pour slab forming process is becoming less common in several areas of the country where post-tensioned slab construction is gaining sizable market share. To evaluate the thermal performance impact of both traditional and post-tensioned slab construction, we modeled a standard 4" thick slab with 12" x 12" perimeter footings and also an 8" monolithic post-tensioned slab. The current configuration of the TRNSED model results in differences in how each of these slab types are model. Figure 5-2 depicts the footed and monolithic slabs. For footed slabs, 4" of slab is directly exposed to outdoors with the footing (and insulation, if present) extending 12" below grade. For the monolithic slab case, the full 8" slab is modeled as being exposed to outdoors. If insulation is installed, it only extends to grade level. The net result of these assumptions is that footed slabs have less direct thermal connection to outdoor conditions and the impact of insulation is greater for the footed slab since the insulation is presumed to extend the bottom of the footing.

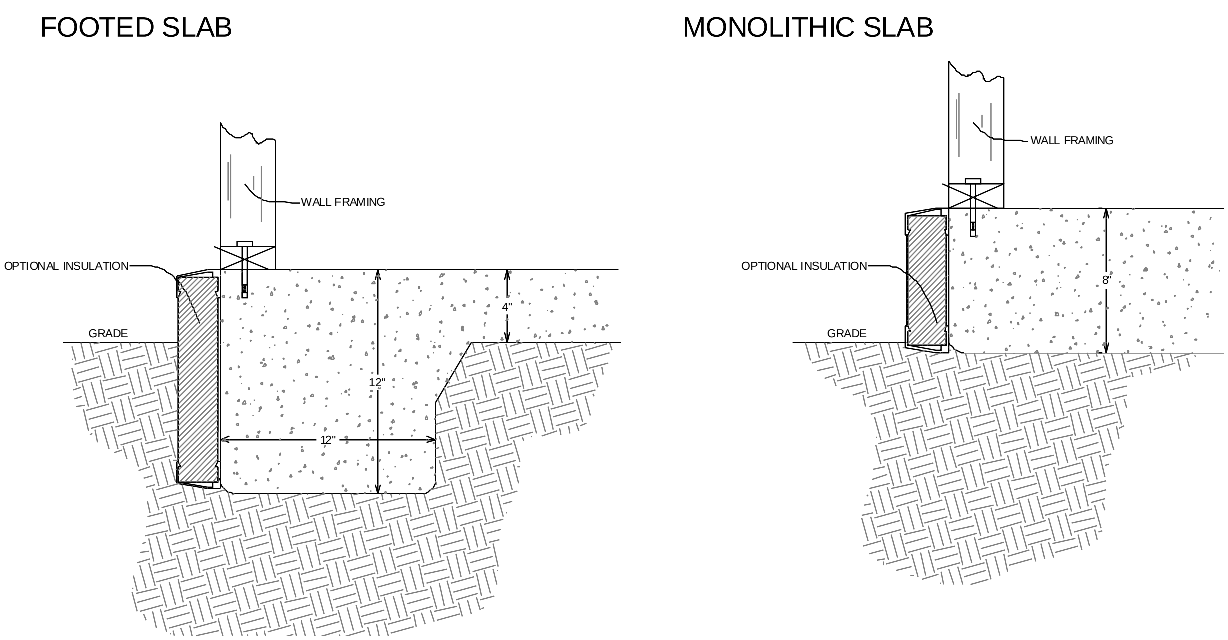


Figure 4-2: Ground Model Configuration

Five U.S. climates (Sacramento and Santa Maria, CA, Reno, NV, Ft. Worth, TX, and Atlanta, GA) were selected to evaluate the benefits of a slab edge insulation form system in different climates.

4.3. Modeling Results

Table 4-1 presents heating degree days and projected annual base case heating energy consumption for the five climates and two slab types. The higher heating energy use (on average 4%) is associated with the monolithic slab due to its greater exposure. Table 4-2 presents projected heating savings for insulation levels ranging from R-5 to R-15. The footed slab savings are greater because of the greater insulation depth. The monolithic insulated slab case still has a short path for heat to flow from the bottom of the slab. The incremental savings for additional insulation beyond R-5 is small for all cases, consistent with the physics of diminishing returns.

Table 4-1: Heating Degree Days and Base Heating Energy Use

Location	Heating Degree Days (base 65°)	Projected Annual Heating Use (therms)
Sacramento, CA	2666	478 – 500
Santa Maria, CA	2783	430 – 451
Reno, NV	5600	842 – 858
Atlanta, GA	2827	340 – 359
Ft. Worth, TX	2370	197 – 212

Table 4-2: Projected Annual Heating Energy Savings

	Footed Slab Projected Savings (therms/yr)			Post-Tensioned Slab Projected Savings (therms/yr)		
Location	R-5	R-10	R-15	R-5	R-10	R-15
Sacramento, CA	59	69	73	36	41	43
Santa Maria, CA	61	71	75	36	42	44
Reno, NV	101	117	124	58	65	68
Atlanta, GA	51	59	62	35	39	41
Ft. Worth, TX	35	40	42	24	27	29

Projected percentage savings reported in Table 4-3 range from 7-13% for the monolithic slab case to 12-21% for the footed slab. Footed slab savings projections are likely optimistic given the 16" assumed insulation depth. Savings in the 10% range are likely representative of expected system performance.

Table 4-3: Projected Heating Energy Savings (%)

Location	Footed Slab Projected % Savings			Post-Tensioned Slab Projected % Savings		
	R-5	R-10	R-15	R-5	R-10	R-15
Sacramento, CA	12	14	15	7	8	9
Santa Maria, CA	14	17	18	8	9	10
Reno, NV	12	14	15	7	8	8
Atlanta, GA	15	17	18	10	11	11
Ft. Worth, TX	18	20	21	11	13	13

To evaluate the economic trend in optimal insulation thickness, insulation costs were combined with the Table 5-2 footed slab therm savings to develop a "savings per unit cost" metric. Figure 5-3 plots "savings per unit cost" for each of the three insulation thickness and five climates. The graphic clearly demonstrates that the cost-effectiveness of additional insulation falls off quickly after R-5. A similar trend was found for the monolithic slab simulation runs. Although this thermal analysis points to thinner insulation as the economic optimum, structural concerns may dictate additional insulation for added strength.

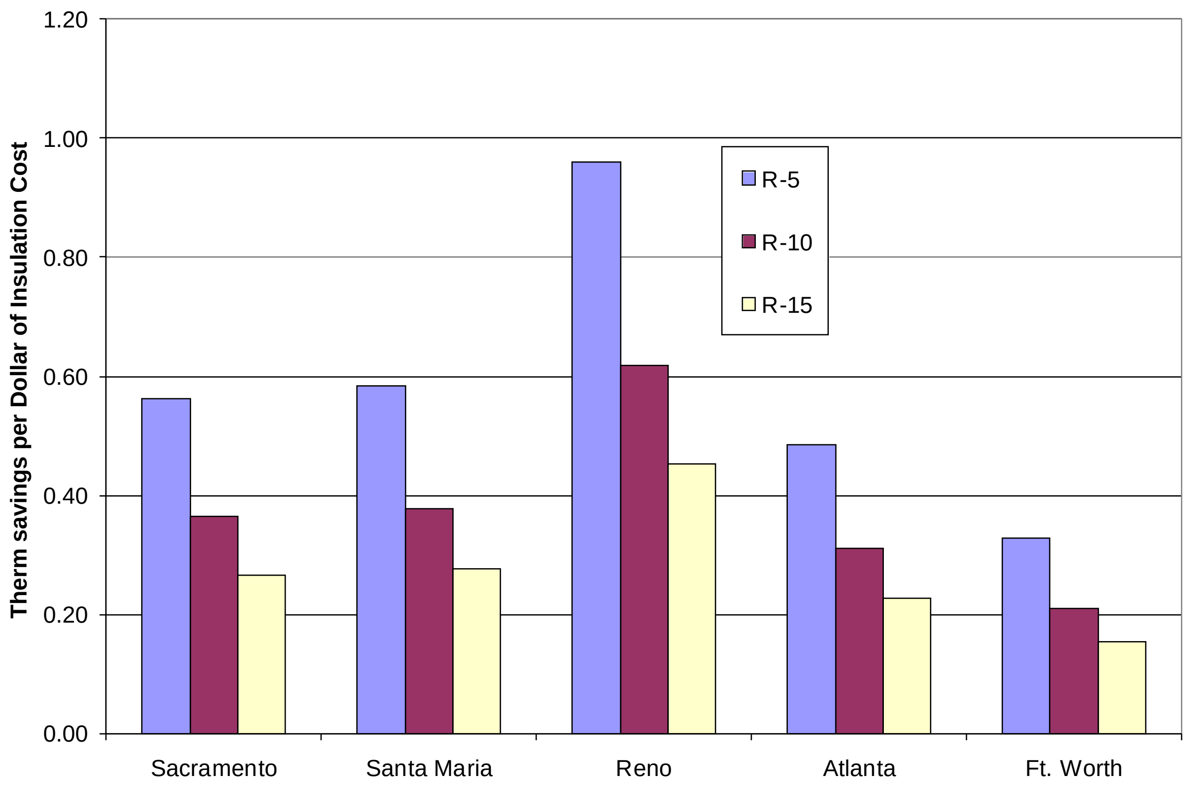


Figure 4-3: Insulation Optimization

4.4. Projected Savings Impact

The market analysis results presented in Table 3-8 project third-year E-Form sales ranging from of about 56,000 homes per year based on a nationwide mass market strategy. If mid-range E-Form savings of 60 therms per year are assumed, we estimate these homes would save 3.4 million therms in the first year. Using a modest growth rate of 10% in years four through ten, we conservatively project cumulative energy savings of 214 million therms during the ten years after E-Form market introduction. A fully commercialized E-Form product installed in 500,000 homes would save 30 million therms in the first year.

5. Design Options and Details

5.1. Introduction

During Phase 1 of the project we developed three iterations of the E-Form design. The first design was completed immediately after the start of the project. Intended for use with conventional two-pour slabs, the design featured a PVC profile extrusion at the top edge for strength in the horizontal direction, but relied on extruded polystyrene insulation to provide strength from the top edge to the bottom stake connection point.

After initial market research indicated that the majority of production homes were being built with post-tensioned slabs, the design was revised to accommodate post-tension cables and to be compatible with both a uniform thickness “monolithic” slab (trenchless) and a waffle slab (with perimeter and interior trenches). In contrast to the original design in which the PVC extrusion was used only at the top, Finite Element Analysis (FEA) indicated that a bottom extrusion was also needed to provide additional strength.

After learning more about weatherability and termite issues, the design was revised to use a closed PVC profile. FEA was used on both the extrusion and stakes to ensure sufficient deflection resistance. To reduce overall E-Form costs, labor steps, and a potential tripping hazard associated with the prior interior staking system, we designed a staking system relying on only a diagonal stake just below the extrusion.

FEA computer simulations reduce design cycle time relative to physical prototypes and optimize designs more accurately than would otherwise be possible without fabricating a large number of prototypes. FEA is particularly well suited to production processes with high tooling costs such as plastic profile extrusions. For FEA modeling we used COSMOSworks software running on a modern engineering workstation computer. COSMOSworks was selected because of its close integration with the SolidWorks software that was used for design. Through all Phase 1 work, we performed more than 25 analyses on E-Form designs requiring more than 150 hours of processor time.

5.2. E-Form Version 1 Design

Based mostly on the concept described in the original project proposal, our first E-Form design established the basic layout of a PVC extrusion, 2” of insulating foam and an interior staking system that becomes hidden inside the concrete slab, eliminating the need to return to the site to strip any form parts.

5.2.1. Material Selection

We chose PVC for the extrusion material due to its high strength, low-cost, and strong resistance to UV damage and other weathering. In addition, it is a building material that is widely accepted with the trades and building officials. The weatherability is not inherent in PVC, but there are cost-effective PVC additives that have proven to work well in outdoor applications.

For the foam we selected Styrofoam-brand extruded polystyrene for its relatively high modulus (among foam materials), good insulation performance, and moderate cost. Styrofoam is frequently used for envelope insulation and is even marketed for below-grade foundation applications. It must be UV radiation protected, so an external skin is required. In our case we planned to use a 0.020" thick hard plastic polystyrene laminate. Insulfoam applies a similar skin to their expanded polystyrene insulation panels. Termites do not consume Styrofoam, but in areas where termite infestions occur, foam insulation can not be installed in contact with the ground. The concern is that termites can eat their way through the Styrofoam to get to the wood structure. Because the termite paths would be inside the Styrofoam, they would not be visible during an inspection. (Termites are detected in slab homes by the presence of the tunnels that they create on the outside of the foundation perimeter.) In some areas of the country termite inspection companies will not provide warranties where rigid foam materials are exposed below grade. Dow Chemical is in the final stages of commercializing Blueguard, a Styrofoam production with a termiticide that has proven to be effective and safe in EPA testing. In the near future, Dow expects Blueguard to receive an ICC-ES listing for compliance with building codes. By using an ICC-ES listed insulation or fully encapsulating the insulation within the PVC extrusion, E-Form should be free of termite concerns.

For stake options, we chose plain cold-rolled steel. Steel is strong, low-cost and easier to drive than wood in hard soils. The strength of the stake system is no longer necessary after the concrete has cured, so corrosion is not a concern.

5.2.2. How it Works

Components for the first E-Form design are listed in Table 5-1 and a design schematic is shown in Figure A-1. (see Appendix A for confidential A-*X* figures)

Table 5-1: E-Form Version 1 Component List

Item No.	Name/Description
1	Insulation - 2" thick Styrofoam
2	Exterior skin - polystyrene
3	Extrusion with integral termite strip - PVC
4	Bottom clip made - made from same PVC extrusion as #3
5	Hat section roll-formed main stake - steel
6	Tie bar - made from 1/4" steel wire
7	Back stake - aluminum
8	Mudsill hold-down - steel
9	Rivets
10	Self-threading sheet metal screw
11	Steel wire mat concrete reinforcement
12	Ground with perimeter trench (12" deep x 12" wide)
13	2x4 wood mudsill
14	1/2" washer
15	1/2" hex head cap screw

The following installation process was envisioned:

1. Assemble top extrusion, foam, and skin in factory. Cut to length and package all E-Form materials and deliver to jobsite.
2. Drive main stakes.
3. Slide bottom clips onto main stakes.
4. Install form assemblies on bottom clips and main stakes.
5. Install tie bars.
6. Adjust stake/form alignment if necessary and drive back stakes.
7. Install steel wire mat.
8. Pour concrete.
9. Install mudsill.

We designed the PVC extrusion to be submerged into the concrete to create an effective termite barrier (inside channel at top of form) that prevents termites from entering the structure by passing between the slab and E-Form. The top exterior channel was angled to drain water away from the structure. The extrusion was designed to accommodate both the 1” tall hat section (shown as #5 in Figure A-1) and ¾” conduit, which is a component easily sourced and inexpensive even in small quantities.

We designed the hat section stake for both roll-forming volume production and sheet metal prototypes. Roll formed parts are very inexpensive, but require expensive custom tooling and large order volumes. Sheet metal parts laser cut from steel sheets usually do not require tooling for fabrication and can be procured in about two weeks.

Developing a hold-down system that used a female connection to avoid the need to wet-set hold-downs was a design objective originally identified in the project proposal. For the first version, we envisioned a foam plug or surround that would protect the female threads and create a hole above the hold-down for a bolt passed through the mudsill.

5.2.3. FEA

When the first E-Form design was evaluated using FEA software, we found that the Styrofoam alone would not be able to withstand the hydrostatic and dynamic forces of the concrete pouring process. Dow Chemical performed deflection tests on a variety of potential Styrofoam materials (varying material densities and use of facers) to establish a foam modulus input for the FEA simulations.

5.2.4. Conclusions

FEA simulations indicated that based on the modulus data provided by Dow, the Version 1 E-Form design was not stiff enough to meet our deflection tolerances. In addition, our market research effort indicated that post-tensioning slab design was a rapidly growing technology in many parts of the country. A successful E-Form design would need to accommodate this approach.

5.3. E-Form Version 2 Design

As described in Section 3 (Market Analysis), the residential slab construction market in California has shifted the last few years from conventional two-pour slabs with steel mesh reinforcement to monolithic (single-pour) or waffle PT slabs. This means that for any SEIF system to have success with production home builders, it would need to accommodate the PT equipment and not interfere with the PT process. (Although a non-PT compatible SEIF system could find success in the growing custom home market with radiant-heated slabs, we anticipate some or all of this market also shifting to PT in the future.)

5.3.1. Material Selection

Material choices were largely unchanged from the first E-Form design. With the steel main stake there is some risk of creating a corrosion path to the post-tension cables, but it should be less risk than with current PT practice. The nails currently used to attach the PT anchors to the wooden forms remain embedded in the concrete when the forms are stripped (see Step 9 Figure on Page 3-7). The exposed ends of the nails are cut flush with an abrasive saw, but the cut surface remains a direct corrosion path to the anchor/wedge/cable assembly.

5.3.2. How it Works

The components for the second E-Form design are listed in Table 5-2 and design is shown in Figure A-2. We developed the following installation process for the second E-Form design.

1. Notch or cut slots in the bottom extrusion for the stakes. Assemble top extrusion, foam, bottom extrusion and skin in factory. Cut to length and drill holes in foam for post-tension cables and plugs. Package all E-Form materials and deliver to jobsite.
2. Drive main stakes.
3. Slide form assemblies onto main stakes.
4. Install tie bars.
5. Adjust stake/form alignment if necessary and drive back stakes.
6. Pour gravel and cove with vapor barrier.
7. Attach post-tension anchors to anchor hangers.
8. Install static end of post-tension cables by driving anchor hangers into main stakes at depth to match middle of slab.
9. Slide dynamic end anchors and pocket formers onto cable ends.
10. Pass cable ends through holes in opposite forms so that the pocket former contacts the foam.
11. Drive dynamic end anchors and hangers onto main stakes.
12. Install hold-down pocket former/thread protectors.
13. Pour concrete.
14. Remove pocket formers and stress cables.
15. Cut cable ends with abrasive saw.
16. Seal exposed cable end (dynamic end only) access holes with grout.
17. Remove hold-down pocket former/thread protectors and install mudsill.

Table 5-2: E-Form Version 2 Component List

Item No.	Name/Description
1	Insulation with exterior skin - 2" thick Styrofoam
2	Extrusion - PVC
3	Extrusion - PVC (same profile as item #2)
4	Hat section roll-formed main stake - steel
5	Back stake - aluminum
6	Tie bar - made from 1/4" steel wire
7	Mudsill hold-down - steel
8	Rivets
9	Self-threading sheet metal screw
10	Post-tension anchor
11	Post-tension anchor hanger
12	Machine screw
13	2x4 wood mudsill
14	1/2" washer
15	Ground without trench (Uniform Thickness slab)
16	2” to 4” thick gravel layer with 0.020” polyethylene vapor barrier

5.3.3. FEA

Only the extrusion and foam were modeled during the first design revision. Because of the longer lead-time in ordering the extrusion mold, the extrusion design needed to be quickly finalized. We were confident that a sufficiently strong staking system could be designed, although the gauge of steel staking material might be greater than we would hope.

The resulting stresses of the FEA simulations on the second E-Form design are shown in Figures A-3 and A-4. We modeled an 18” long extrusion assembly with symmetry constraints at one end, to mimic the behavior of a span between stakes 36” apart. This allowed us to use smaller finite element sizes to increase accuracy without increasing computational time. Looking at the stress levels shown in Figure A-3, nearly all of the extrusion is blue or green, with a localized maximum stress of 467 psi. The PVC yield strength was 6000 psi, meaning a factor of safety greater than 10. In the insulation, the top of the scale indicates 50 psi, which is the yield stress we used for Styrofoam. The interference joint between the extrusion teeth and the foam are difficult to model without significant research and perhaps even a customized FEA solver. This would need to be evaluated by experimentation. As indicated by the solid blue color, the foam does not appear to be vulnerable elsewhere. We felt confident that the polystyrene skin would prevent the foam from tearing or otherwise failing at the connection with the extrusion. Failing that, Dow sells a Styrofoam with a fibrous laminated facer that would add sufficient strength.

We also examined the actual deflection to see if it was within our target range of less than 1/8” (0.125”) at the center of the top edge. This maximum deflection would occur at the midpoint between stakes. The FEA deflection output shown in Figure A-5 shows a top-center deflection of about 0.10”.

5.3.4. Conclusions

The FEA results indicated that the PVC top and bottom extrusions would not fail or deflect excessively. However, we were concerned by the possibility that the Styrofoam might fail even with the mitigating factors mentioned earlier. This was the driving factor that led us to switch to a closed PVC profile that would completely surround the foam insulation. Although a closed extrusion involves more PVC and therefore higher cost, we felt the following advantages more than offset this:

- the wider variety of insulation options that could be used (potentially lower cost)
- the ability to create a completely sealed form board that would minimize termite, moisture and weatherability concerns, and
- potentially simpler and less costly coupler and corner parts.

We changed two other areas of the E-Form system design. The post-tension process results in considerably more activity inside the forms than for a steel wire reinforced slab. To alleviate the potential tripping hazard, we sought an alternative to the tie bar and back stake interior staking. Also, given the market resistance to a dedicated hold-down system as well as the cost of ICC-ES listing for any new hold-down system, we decided that E-Form must be designed to work with most or all of the existing commercially available hold-down products.

5.4. Final Phase 1 E-Form Design

With the design changes described above, we arrived at the final Phase 1 E-Form design. We utilized FEA with the goal of designing a PVC extrusion to resist the concrete loads without any structural contribution from the foam filling the hollows. The staking system was revised completely to use a diagonal stake just below the bottom of the extrusion, and the post-tension anchors were moved from the stake to decouple the PT anchor/cable spacing from the stake spacing. (PT cable spacing varies from 18” to 5’, with typical spacing of 24 to 30 inches. The stake spacing will likely be 3’ to 4’, depending upon soil conditions and slab thickness.) This also eliminated the potential corrosion path through the stakes to the PT anchors and cables.

5.4.1. Material Selection

We made two changes to the E-Form system. Rigid polystyrene insulation was replaced with polyurethane (PU) foam. A two-part PU solution is injected or poured into the extrusion hollows. PU foam can have a higher R-value than Styrofoam, but it can be hard to control the density. PU foams are usually open cell, although closed cell varieties are available and would be a preferable product for E-Form. To our knowledge, there is currently no termite-resistant grade of PU foam, but since Dow Chemical manufactures PU foam solutions it is possible that the same termiticide (Deltamethrin) used in Blueguard Styrofoam may be used in the PU products. If not, pre-cut strips of Blueguard Styrofoam expanded polystyrene foam could be inserted into the extrusion hollows for locations where termite concerns are paramount. Other insulation options are possible. Tracks could be added to the extrusion to hold 1” or 1-½” thick stripes of foil-faced Tuf-R polyisocyanurate foam insulation such that there is a consistent air gap on both sides of the foam to limit radiant heat losses. The cheapest foam insulation option would likely be strips of 2” expanded polystyrene foam (beadboard), however unlike the other options beadboard is not a Dow Chemical product. Beadboard does have an approved termiticide additive (Borate powder), but it is not believed to be as effective as Blueguard Styrofoam. Dow is currently investigating the feasibility of various options for insulating the E-Form extrusions.

The other material change was to use wood for the diagonal stake. Wood is a common material for use with concrete slab forms; however it is not normally left behind like the diagonal stake. This does pose a potential termite risk, but because it will create a blind hole in the slab exterior it should not allow for an undetected termite path. Termites may consume the diagonal stake, but that should not be a concern since the stake is no longer a structural item after the concrete has cured. A wood diagonal stake is inexpensive and allows for more installation flexibility than a metal diagonal stake because the hole locations do not have to be pre-determined. Our fallback plan is to use a metal diagonal stake if code conflicts prevent the use of wood.

5.4.2. How it Works

The third and final Phase 1 E-Form design is shown in Figure A-6, A-7 and A-8. The components are listed in Table 5-3. We developed the following installation process for the design.

1. Foam-in-place polyurethane insulation in factory.
2. Cut extrusion/foam forms to length, insert screw strips, drill holes in foam for post-tension cables and plugs, insert standoffs for static PT anchors. Package all E-Form materials and deliver to jobsite.
3. Drive main stakes.
4. Drive diagonal stakes.
5. Slide form assemblies onto main stakes.
6. Install upper sheet metal screw.
7. Hold bottom clip in place while adjusting the main stake alignment. Drive sheet metal screw to secure assembly.
8. Pour gravel and cover with vapor barrier.
9. Install static end of PT cables by screwing anchors into standoffs pre-riveted to forms.
10. Slide dynamic end anchors onto cable ends.
11. Pass cable ends through holes in opposite forms.
12. Rivet dynamic end anchors to forms.
13. Pour concrete.
14. Stress cables.
15. Cut cable ends with abrasive saw.
16. Seal cable end (dynamic end) access holes with grout or solvent welded PVC plug.
17. Install mudsill.

Table 5-3: E-Form Final Phase 1 Design Component List

Item No.	Name/Description
1	Ground without trench (Uniform Thickness slab)
2	2” to 4” thick gravel layer with 0.010” polyethylene vapor barrier
3	Box section roll-formed main stake - steel
4	Closed extrusion - PVC
5	Diagonal stake - wood
6	Post-tension anchor (static end)
7	Standoffs (pre-attached to form in factory)
8	Insulation - foam-in-place polyurethane
9	Screw strip - steel
10	Bottom clip - steel
11	Self-threading sheet metal screw
12	Post-tension cable
13	J-bolt hanger
14	J-bolt
15	Self-threading sheet metal screw
16	Rivet
17	Concrete slab
18	Backfill
19	2x4 wood mudsill
20	1/2" washer
21	1/2" hex nut

5.4.3. FEA

Using FEA simulations, we concluded that the closed PVC extrusion should have 0.080” thick walls while maintaining acceptable deflection levels. Figures A-9 and A-10 show the FEA results on the closed extrusion with a 36” span between stakes. . The legend for these figures is in terms of “factor-of-safety” (FOS). The lowest FOS in the extrusion is 4.4 (shown in red) which means that structural failure is extremely unlikely.

To more accurately gauge deflection, we analyzed a simplified version of the assembly, rather than individual parts, to gauge the interactions. This was of particular interest at the termite strip, which we were concerned might “uncurl” and allow the form to escape the restraint imposed by the top of the main stake. The alternative would be to use a sheet metal screw at the top of the main stake. FEA on assemblies rather than individual parts requires much more computer resources because it requires an iterative process, while most individual part analyses can be solved in one operation. The results are shown in Figures A-11 and A-12.

With 18” spans between stakes, there was no yellow on the outer surface, indicating that deflection would be less than our limit of 0.125”. Stress levels in the assembly are shown in Figure A-13. The legend is capped at 6000 psi, the yield stress of PVC. This confirms the high FOS values shown in Figures A-9 and A-10 for the PVC extrusion. The steel stake was revised after the Figure A-13 analysis was run, but it this shows that a steel stake with a yield stress of 50 kpsi (AISI 1020 cold-rolled steel) should not fail since the maximum stress level shown is 41 kpsi.

5.4.4. Construction Integration

The E-Form system has been carefully designed to work with existing residential construction practices where required. Based on our extension market research on the process, we believe the E-Form will work well with concrete slab post-tensioning. We developed a flashing for stucco exterior, which represent the majority of residential construction in the U.S. slab market. The flashing design is essentially the same as recommended by major manufacturers such as Technocem and LaHabra, but tailored to work with the E-Form dimensions. A similar flashing design would be used for shiplap or shingle wood siding.

A typical E-Form construction detail is shown in Figure A-14. The detail shown is for a single-story post-tensioned slab in Northern California (2x4 lumber instead of 2x6, uniform thickness slab type). The design is compatible with all other common slab construction methods (waffle slab, two-pour, radiant heated, 2x6 lumber, etc.) 2x6 lumber is easier to use with E-Form because the inner edge is moved inward, meaning the structural hold downs can be moved away from the slab edge. It also can be cantilevered over the tapered top edge of the E-Form to improve appearance by blending the outside surfaces of the siding and the foundation.

5.4.5. Conclusions

We are confident that the PVC extrusion and steel/wood staking system will be able to withstand the hydrostatic and dynamic forces of a concrete pour. With positive FEA results in hand, we ordered the extrusion die in late May 2006. The first samples arrived in mid-August 2006. The final Phase 1 E-Form design was designed for 36" spans between stakes. Concrete contractors willing to tolerate larger deflections could get away with 48" spans to save stake materials and installation labor. Variations in soil conditions may also affect the staking interval.

The simplest way to market E-Form to builders and concrete contractors is to sell pre-foamed PVC extrusions in standard 8' lengths. The staking components would be supplied in bulk. However we feel strongly that for E-Form to be a success, preparing a kit of forms for each slab would be popular with contractors and create more added-value for the E-Form manufacturer. Supplied with the foundation plans that post-tension firms currently receive, the E-Form manufacturer would develop an automated system to determine cut lengths and feed the information directly to the machines on the factory floor. At the same time, or in a different operation, the holes would be cut or drilled for the post-tension anchors and cable pass-through. The standoffs for the static end anchor would be installed in the factory as well. For each slab, the software would produce a "pick" list indicating the number of each additional component to be bundled with the PVC extrusion form boards. Due to the delicate nature of the forms, the E-Form manufacturer would probably deliver the sequentially numbered forms and stakes directly to the jobsite.

5.5. Linear Coupler and Corner Design

We developed three systems for linear joints and internal and external corners. We considered internal and external socket joiners, but rejected them due to high tooling cost and interference with the mudsill (for the external case).

We selected a design using a vertical **H** shape extrusion and shown in Figures A-15, A-16, and A-17. A dedicated corner part is not used, but rather linear form sections are mitered and joined using adhesives and/or brackets. This reduces tooling cost and gives the corner the same appearance as the rest of the forms. Typical corner pieces will be 12” long on the inside of both legs. The **H** shape is an open profile extrusion, which has less expensive tooling than the hollow profiles used by the socket couplers. The overall size is much smaller, which reduces both tooling and part costs. The drawback of the H shape is that it requires use of caulking, tape or steel flashing to seal the tops of the extrusion joints.

6. Prototype Development

6.1. Introduction

During Phase 1 of the project we fabricated several prototypes that we used to evaluate the form and fit of the final E-Form design discussed in section 5.4. Additionally, we used the prototypes to perform a number of tests to evaluate the design and its performance. The prototyping and testing that we performed included:

- Extrusion
- Insulation
- Thermal Expansion
- Extrusion Deflection Testing
- System Usability and Enhancements
- System Deflection Testing

6.2. Extrusion

One of the more important and successful tasks in Phase I was design and fabrication of 1000 feet of PVC extrusion that will serve as the heart of the E-Form system. We incorporated a number of design features into this extrusion to add significant value without adding cost. A photograph looking down the length of the extrusion (laying flat) is shown in Figure A-18. (see Appendix A) Upon completion of the design, we solicited bids from various PVC extruders. We selected Royal Sierra of Reno, Nevada, one of 23 extrusion plants owned by Royal Group Technologies.

Production of the extrusion at Royal Sierra's Nevada plant went reasonably well. The main issue that they encountered was a tendency of the extrusion to pull inwards towards the interior cavities as it progressed through the calibrator, thereby breaking their vacuum seal. This reduced throughput somewhat because scrap was increased. Additionally, the tendency of the walls to pull in was accentuated when the extrusion was cut.

Although Royal Sierra can produce product with the current design, the addition of two more webs to split the two cavities into four could reduce the tendency of the outer walls to pull in. This added stiffness would enhance the product by allowing the form to bridge larger distances between stakes and increase its general robustness. However, addition of these webs would create four instead of two cavities and make addition of foam-in polyurethane foam to the extrusion more complicated, and rigid foam virtually impossible.

6.3. Insulation

We believe that the two part polyurethane foam-in-place option offers the most attractive option for E-Form. To experiment with the foaming process, we procured AeroMarine two part polyurethane pour foam. In addition to being relatively inexpensive, the closed cell nature of this foam reduces the impact of water that may infiltrate the extrusion.

In our first foam-in-place trial, we poured an appropriate amount of the two liquid components of the foam into each cavity while holding the extrusion vertical. We used a piece of Styrofoam to seal the bottom end. The foam expanded as advertised and filled the cavities tightly. However, this first trial indicated that more precise control for dispensing liquid into the cavity would be needed since the composition of the foam at the bottom appeared to be more solid than the foam at the top. Additionally, the expansion of the foam caused the cavities of the form to bow out, further indicating the need for more control during the foaming process, as well as use of a reinforcing form to keep the expanding foam from deforming the extrusion.

To remedy the out bowing phenomena, we constructed a wood form to support the outer perimeter of the extrusion as it was foamed. This proved successful and foaming within the form actually straightened out the inward bowing exhibited by the extrusion. The wood form is shown in Figure 6-1.

In Phase II, we will continue experimentation with insulating strategies. Dow is currently evaluating the use of both polyurethane foams and rigid Blueguard™ (Styrofoam treated with Deltamethrin termiticide). We are interested in determining the strength characteristics of the extrusion with rigid foam. For the foam-on-place option, we would evaluate a more continuous process using a moving nozzle or other means to meter out more precise quantities of foam. This would provide for more consistent foam and structural integrity. Additionally, we may need to develop a production-ready reinforcing form that would slide along the outside of the extrusion to keep the foam from forcing the extrusion to bow out.

Figure 6-1: Form for Extrusion Foaming Process

6.4. Thermal Expansion

The use of PVC for a foundation form presents a potential problem in thermal expansion and contraction. If the forms are installed in a hot and dry area they may see a 40-50ºF ambient temperature swing between early morning and mid afternoon. This temperature swing could result in a 0.2" change in length for a 12 foot extrusion resulting in buckling or opening of gaps depending on conditions[1]. An additional factor is how the insulation affects thermal expansion.

As part of our prototype evaluation, we chose to experimentally quantify the expansion of a foamed extrusion between early morning shade and mid afternoon sun. The baseline morning temperature measurement was 65ºF and the surface temperature of the extrusion in mid-day was 125ºF. A 12 foot foamed extrusion (Figure 6-2) grew approximately ¼" under those conditions. This confirmed that our coupler system (discussed in Section 5.7,) must be able to account for at least this amount of expansion or contraction.

[1] Based on PVC thermal expansion of 3.5×10^{-5} inches/inch-°F.

Figure 6-2: Extrusion Thermal Expansion Testing

6.5. Extrusion Deflection Testing

For E-Form to be successful, it must be stiff enough to not deflect substantially during a foundation pour. Actual failure would be unacceptable for obvious reasons, but the form must also not deflect appreciably since such deflection would make wall construction difficult, and create a visual anomaly. The limit we set for acceptable extrusion deflection was 1/8", thus allowing 1/16" of stake deflection to keep within the architectural standard of 3/16".

We tested a number of options using a three point bending test to evaluate E-Form's ability to meet stiffness and strength requirements. In this test, the extrusion was supported by two sides of a 3 foot wood frame square and loaded with a point load in the middle. A piece of webbing was connected to a strain gauge that in turn was connected to a bolt anchored to the floor. We used a webbing cam to tighten the webbing to load the form and measured the deflection in the middle via a dial caliper. The test setup is shown in Figure 6-3 testing an un-reinforced piece of 2" Styrofoam.

Results of form deflection testing are shown in Figure 6-4. A variety of materials were tested including a Douglas fir 2x10, foamed and unfoamed E-Form extrusions, a 2 inch Styrofoam panel, and a section of CertainTeed Form-a-Drain. Form-a-Drain is manufactured from PVC and is used as a foundation wall drainage system. The E-Form prototype demonstrated stiffness nearly identical to the Form-a-Drain. Based on these results and initial reactions from a concrete subcontractor, we believe that prototype E-Form is sufficiently stiff.

Figure 6-3: Deflection Testing

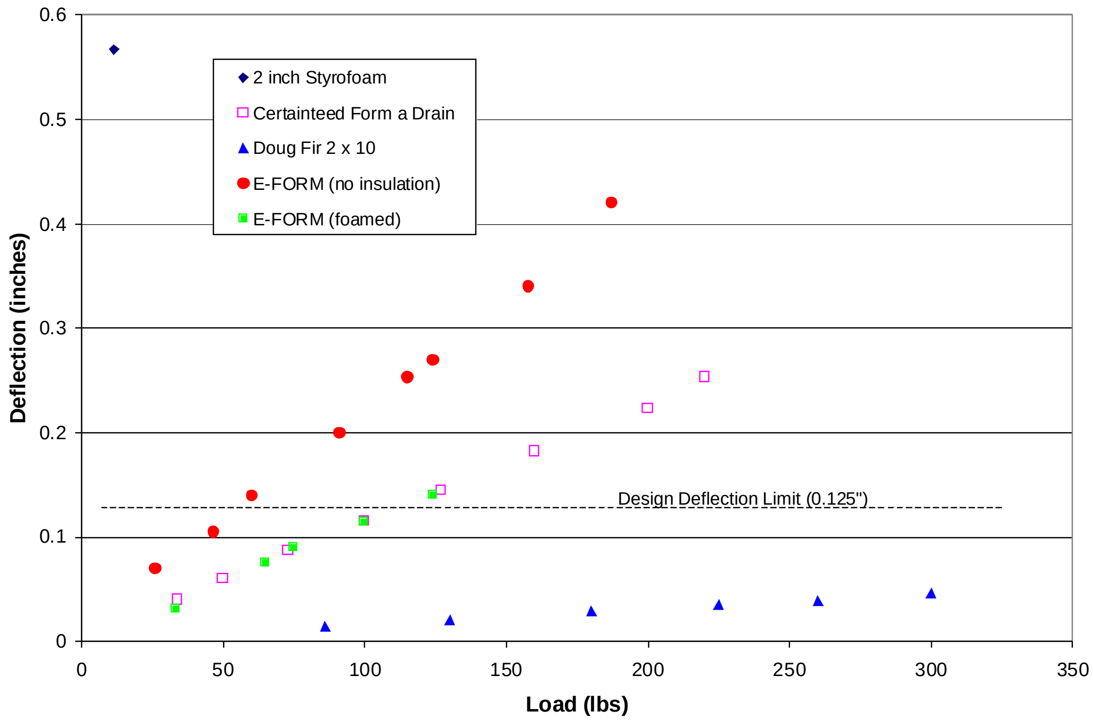


Figure 6-4: Form Deflection when Center Loaded between 3' Supports

6.6. System Usability Evaluation and Enhancements

6.6.1 Testing as Designed

In addition to the extrusion, we procured samples of the steel main stake, the metal clip, and some standard wood form stakes that we could cut down and use as diagonal brace stakes. We then proceeded to try to mockup forms based on both the E-Form system and traditional wood framing methods. Our intent was to evaluate how much more or less difficult the E-Form system was to construct than a traditionally constructed form. Unfortunately, we attempted this testing in mid-July in the Central Valley of California at a construction site with rock-hard soil. Both the steel main stake and standard wood form stakes proved nearly impossible to drive into this hard ground. Interestingly, the concrete crews on site were not driving their wood stakes very deep and were actually using small amounts of concrete to support the vertical wood stakes prior to the foundation pour.

A contributing factor to the difficulty of driving the main stake was that we specified that our main stake be fabricated with a point with the intent of making them easier to drive. However, in order to make the stake easy to prototype, we specified that the points be formed by grinding down the end of the stake to form a point centered on the two sides as shown in Figure 6-5. We found that this geometry was not ideal since the points could easily bend when driven into the ground, making the stake more difficult to drive.

Figure 6-5: Main Stake Point Before and After Driving

6.6.2 Testing with Improvements

To make the main stake easier to drive, we cut the points off of a number of stakes and these proved at least as easy to drive as standard wood form stakes. We used the modified stakes to mockup a 3 foot section of E-Form in less rocky soil than the original test. The combination of less resistant ground and a better stake design made for much easier driving and we were able to construct an E-Form mockup. Time and difficulty of construction of the E-Form mockup seemed on par with the conventional method.

During the mockup exercise, we learned a number of things:

- As long as the main stakes remain in the plane of the form, they may deviate from vertical and still be used to effectively support and brace the extrusion.
- Moving the clip to be between the main stake and the diagonal brace stake made the assembly slightly easier to put together and eliminated the torque that tended to twist the main stakes.
- The self-drilling screws for securing the middle of the extrusion to the main stake were somewhat difficult to assemble since they tended tilt up and down a vertical plane. If possible, we will eliminate the metal strip and potentially the fastener altogether.
- Driving the main stake to a precise height can be difficult. One potential solution is to use a smaller 'ground stake' that is adapted to differing ground conditions (soil "hardness" and moisture level) and works in concert with a main support stake. The main support stake would slip fit over a post built into the ground stake and thereby provide a more consistent resistance when driving so is easier to control its height.
- Ideally, the bottom clip would be redesigned to be tool-less and not require a separate fastener to clamp the diagonal to the main stake. This would eliminate the cost of the fastener and save time during installation.

6.7. System Deflection Testing

In addition to assessing usability, we used our form mockups to compare form stiffness of the E-Form system and the traditional forming method. To evaluate the stiffness of the two systems, we loaded the form boards laterally with webbing and use appropriately placed strain gauges and dial indicators to measure force and deflection. These test arrangements are shown in Figures 6-6 and 6-7.

Figure 6-6: E-Form System Deflection Testing

Figure 6-7: Traditional Method Deflection Testing

Force and deflection data for both the E-Form system and the traditional method are shown in Figure 6-8. Note that the traditional system was constructed with the top of the board only 13 inches above the ground while the E-Form system was constructed with the top of the form 19 inches above the ground. This difference in height was in part to simulate the use of E-Form in a trench in addition to the traditional system at the 19-inch height not being sturdy enough to support testing. Despite this handicap, the E-Form system is nearly as stiff as traditional methods for lower loads and actually stiffer at higher loads as it appears the traditional method becomes nonlinear and starts to 'give'.

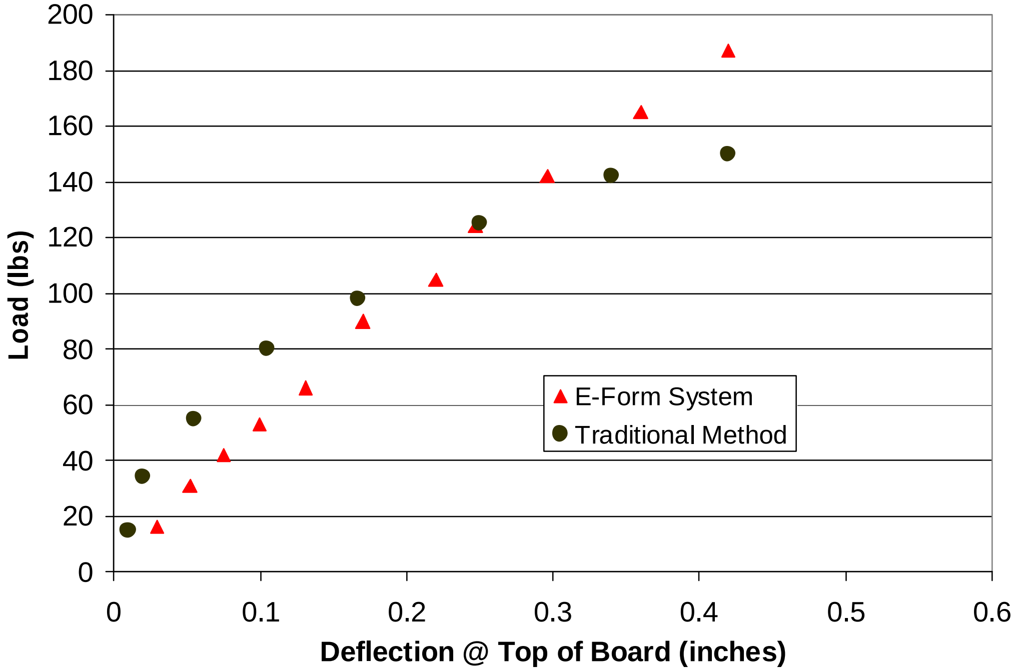


Figure 6-8: Deflection Testing with Stakes 3' Apart

6.8. Phase 1 Prototyping Conclusions

Limited testing of the prototype E-Form system suggest that the foamed extrusion should provide sufficient stiffness. The staking system has proven workable, but there are still concerns about how well it will work in the full range of expected soil types. Connectors and corners have been designed, but not physically prototyped. Phase 2 funding will allow for thorough evaluation of all these issues and determining how to fully satisfy termite concerns, which may affect insulation selection and if complete encapsulation of the insulation is needed. We feel confident that the basic E-Form premise has been demonstrated in Phase I, however significant details remain that require additional Phase 2 funding prior to product commercialization.

Appendix B – Small-Scale Mockup Test Plan

Task 5: Thermal Testing

Objectives

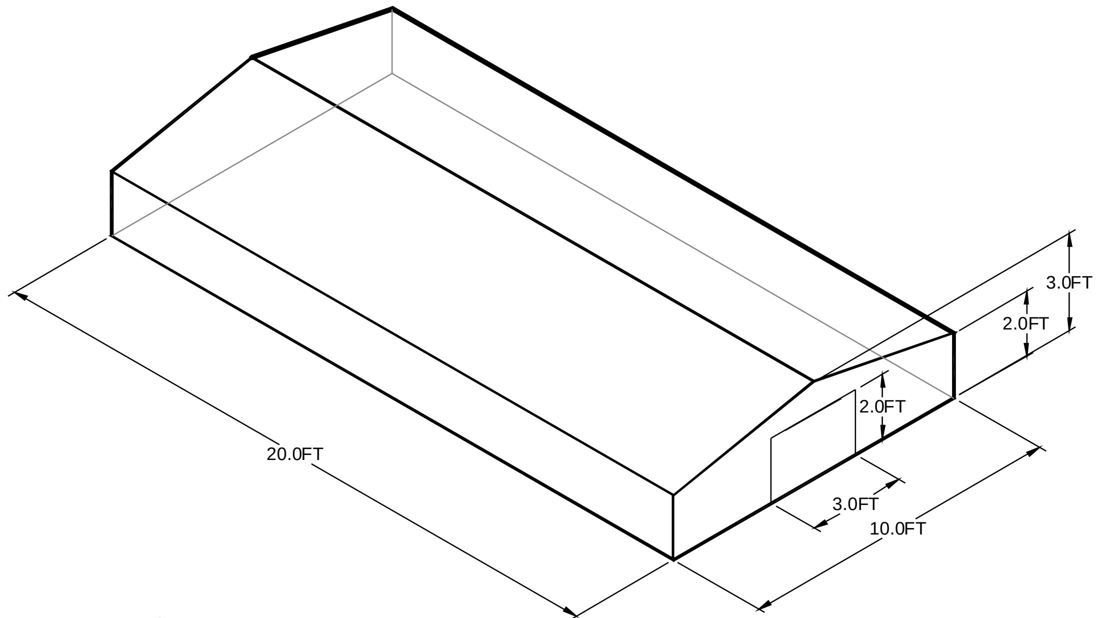
The goal of the Task 5 monitoring is to assess field heat loss performance of the E-Form. We plan to use the monitoring data to validate our TRNSED slab heat loss model. The validation effort may be prove difficult given variations in soil properties and moisture levels that complicate the comparisons between field and model results.

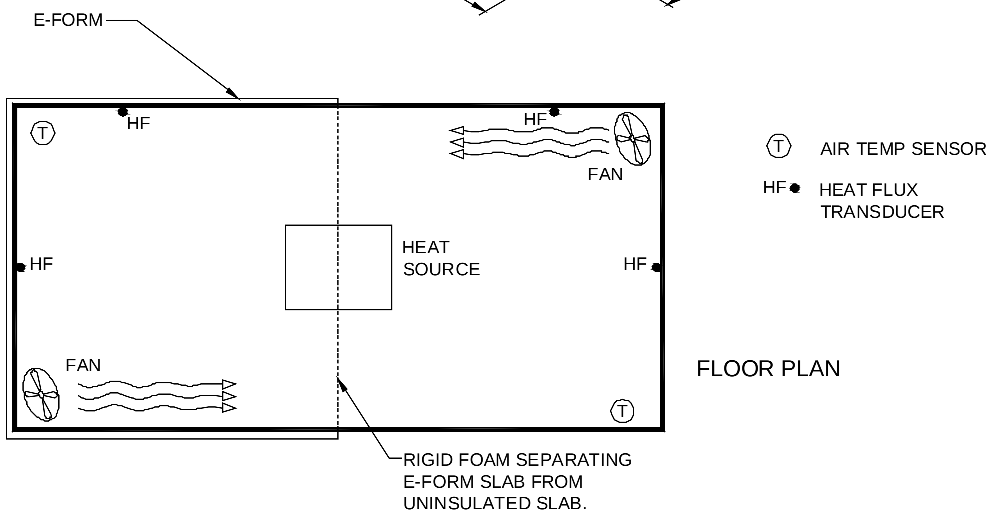
Methodology

In Phase 2, we will construct a conventional 10' x 20' slab with one 10' x 10' end uninsulated and the other insulated with E-Form. The long axis of the slab will be oriented East-West. A piece of rigid Styrofoam insulation will be installed at the mid-point line separating the two insulated and uninsulated slab sections. A short insulated framed wall (~2 ft tall) will be constructed on the slab perimeter. An insulated roof assembly will be added to complete the thermal envelope. The slab floor will be insulated to ~R-2 to approximate carpeting. An electric heater will installed in the center of the structure and will be controlled to maintain indoor temperature at typical heating setpoints. Two mixing fans located at opposed corners will circulate the air for temperature uniformity. Figure 1 below shows the proposed configuration and location of key components. The isometric view shows a 2' x 3' door on one end, allowing access to the datalogger.

The enclosure will be instrumented with a DT50 datalogger, a minimum of two indoor temperature sensors (at diagonal corners), and four heat flux transducers (two on the uninsulated slab edge and two on the insulated edge). The DT50 will be set up to log temperatures, monitor heat fluxes, and control the electric heater to maintain temperatures at 68°F ±0.5°F. Sensors will be scanned at 15-second intervals allowing for precise indoor temperature control. 15-second data will be averaged and logged on 15-minute intervals. The test will begin with a 72 hours equilibrium test to bring the ground under the slab up to temperature. The test will last three to five days.

Additional sensors will be added to monitor outdoor temperature and slab perimeter soil temperatures. The exact number of soil temperature sensors will be determined based on available data channels.


3.0FT
2.0FT
2.0FT
20.0FT
3.0FT
10.0FT


E-FORM
HF
HF
FAN
HEAT
SOURCE
HF
HF
FAN
AIR TEMP SENSOR
HF
HEAT FLUX
TRANSDUCER
RIGID FOAM SEPARATING
E-FORM SLAB FROM
UNINSULATED SLAB.

FLOOR PLAN

Appendix C:

Formsulate Installation Instructions

Cutting Formsulate: A sliding miter saw with a fine toothed trim or plastic cutting blade is ideal for cutting Formsulate although many common tools can also be used. It is best to cut slowly to avoid chipping.

Using pre-formed corners and splices: Inline splices and 90 degree inside and outside corners can be assembled easily by using pre-formed couplers which are attached by sliding the tabs on the couplers into the grooves on the form boards which can then be held in place by screws in each tab. Additional screws may be used on the front face of the couplers for more rigidity if necessary. The void at the corner (photo at right) can be filled with either tapered pieces of rigid insulation or polyurethane foam.

Staking Formsulate: Formsulate is set just like wooden form boards. Stakes may need to be slightly closer together than normal to prevent flexing (Approx. 3ft on center), and stakes must be screwed to boards, not nailed. Fine thread drywall screws work well.

<u>Creating custom corners with Formsulate:</u> Currently only in-line splices and 90 degree inside and outside corner couplers are available although other angles can be custom fabricated. In this example, 45 degree inside and outside corners will be shown.

45 degree outside corner:

Step 1: Using a depth stop cut a "V" shaped groove using 22.5 degree cuts and taking care not to cut through front face of form board.

Step 2: Bend ends of board together and hold in place with screws through metal tabs bent at appropriate angle. (135 degrees in this case)

Step 3: (Optional) A heat gun works well to give the bend a finished look.

Step 4: Finished corner. Seam at top edge should be sealed with caulking if desired.

45 degree inside corner:

Step 1: Cut through form board at appropriate angle. (22.5 degrees in this example)

Step 2: Slide angled flashing between front face of form board and insulation and attach with screws (stainless steel or other rust resistant screws recommended.)

Step 3: Attach metal clips on back side of form board.

Step 4: Finished corner. Seam should be sealed with caulking if desired.