INSULATING CONCRETE FORMS FOR RESIDENTIAL CONSTRUCTION:

DEMONSTRATION HOMES

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and

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NOTICE

Foreword

Recent material advances, technical developments, supply concerns, and economic uncertainty have prompted homebuilders to examine innovative framing materials and methods. Although such systems have existed for some time, builders often are hesitant to explore approaches that differ from their conventional practice. In many instances, their reluctance can be attributed to a lack of information about other systems.

In response to heightened interest, the U.S. Department of Housing and Urban Development (HUD) commissioned a review of structural materials available for homebuilding. The results, *Alternatives to Lumber and Plywood in Home Construction*, were published in 1993 and included the identification of several promising materials. Publications released in 1994 and 1995--*Alternative Framing Materials in Residential Construction: Three Case Studies*, and *Steel Framed Residential Construction: Demonstration Homes*--provided insight into the installed cost of several of these systems.

HUD is continuing to research alternative structural materials. This report, *Insulated Concrete Forms for Residential Construction: Demonstration Homes,* provides builders with practical information based on actual experiences with these materials. The information presented here accurately describes the Insulated Concrete Form (ICF) framing process and the way these construction systems are incorporated into homebuilding. *Insulated Concrete Forms* plays a vital role in the Department' cooperative effort with the homebuilding and concrete industries to develop cost-effective, prescriptive methods of constructing ICF framed homes.

We believe the report will guide builders in the use of this new technique, which promises to enhance housing affordability, and promote healthy competition through optimal use of all of our natural resources.

Paul A. Leonard
Deputy Assistant Secretary for
Policy Development

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This report was co-authored by Donald Carr, William Farkas, P.E., Matthew Pesce and Theresa Rosette. Technical support was provided by Geoffrey Gilg, James Lyons, Shawn McKee, and Albert van Overeem. Mark Nowak provided technical review. Julie Kostro provided administrative assistance.

NAHB Research Center would like to thank the following builders for their participation in demonstrating the use of insulating concrete forms in their homes:

Dominion Building Group	Virginia Beach, VA
John Weaver Custom Homes	Austin, TX
Gary Niles Homes	Sioux City, IA
Romak & Associates	Chestertown, MD

NAHB Research Center would like to thank the following Insulating Concrete Form manufacturers for their contributions to this project:

American Polysteel	Albuquerque, NM
I.C.E. Block? Building Systems, Inc.	New Carlisle, OH
Lite-Form, Inc.	Sioux City, IA
Reddi-Form, Inc.	Oakland, NJ

TABLE OF CONTENTS

SECTION I
Purpose, Scope and Overview of Insulating Concrete Forms

SECTION II
Demonstration Home Construction Process

SECTION III
Conclusions and References

APPENDICES

LIST OF FIGURES, TABLES, AND PHOTOS

Figures

SECTION I

SECTION II

Tables

SECTION I

SECTION II

Photos

EXECUTIVE SUMMARY

With sponsorship provided by the US Department of Housing and Urban Development (HUD) and the Portland Cement Association (PCA), the NAHB Research Center coordinated four demonstration projects to evaluate the use of Insulating Concrete Forms (ICF) in residential construction. The demonstration homes are located in Virginia Beach, Virginia; Austin, Texas; Sioux City, Iowa and Chestertown, Maryland. This report presents observations and experiences from these sites.

The Research Center staff and the demonstration home builders and/or general contractors were in communication throughout the home construction process. Research Center staff visited each site several times. Initial observations documented the construction details of the homes and recorded the construction via photographs. Site visits were made after construction to perform thermal testing and interview homeowners and builders concerning their satisfaction with the homes. Thermal testing consisted of collecting air infiltration data and thermographic imaging, which displays heat transfer through wall frame members in a color video format. Homeowners were interviewed concerning their impressions of the design, construction, thermal comfort, sound comfort, and overall satisfaction with their homes. Builders, or general contractors where appropriate, were interviewed concerning the construction process and construction costs. Insights about concrete handling (mix, pour); form placement and bracing; code requirements and other construction details were discussed. Costs of construction are compared to typical framing in the specific geographical location.

These homes show the advantages for homeowners and the implications for builders of residential use of ICF construction. The homeowners are pleased with their houses. Advantages of ICFs cited by homeowners include reduced transmission of "street noise" to the indoors and an appreciation for new technology. Builders did not have difficulty in selling these homes, and plan to continue using this construction.

Although installed costs of the ICF walls were higher (1-5% of final sales price) than the builders typical practice, they found the cost premiums to be worth the benefit of this construction method. Several observations and suggestions are presented to reduce this cost premium for future ICF projects.

Testing showed the solid concrete wall (clear wall) has less cold spots than frame construction. However, construction details of the openings, architectural penetrations and foundations influence greatly the level of energy efficiency. Winter infiltration rates for the demonstration homes, calculated using data from fan depressurization (i.e. blower door), ranged from 0.15 to 0.55 air changes per hour.

SECTION I

SECTION I

INTRODUCTION

The goal of this project was to evaluate the design, building code, construction and marketing issues faced by a builder considering the use of Insulating Concrete Forms (ICF) for a project within the United States. This study examines construction methods, builder perceptions, homeowner perceptions, costs, thermal performance, and energy efficiency, as these issues are impacted by the decision to use an ICF product. There are, of course, other issues and implications for this construction method that were not directly faced by the four builders in this demonstration project. In addition, this study does not examine all of the ICF products on the market, but is limited to the four systems used in the demonstrations.

Demonstration Home #1 was built by The Dominion Building Group and is located in Virginia Beach, Virginia. It is a custom, one-story home constructed using the American Polysteel system.

Demonstration Home #2 was built by John Weaver Custom Homes and is located in Austin, Texas. It is a custom, one-story home constructed using the I.C.E. Block™ System.

Demonstration Home #3 was built by Gary Niles Homes and is located in Sioux City, Iowa. It is a two-story home constructed with the Lite-Form product line (Lite-Form and Fold-Form).

Demonstration Home #4 was built by Romak & Associates and is located in Chestertown, Maryland. It is a one-story home constructed using the Reddi-Form system.

INSULATING CONCRETE FORMS

General

Insulating Concrete Forms most commonly consist of concrete between polystyrene foam, although other form materials such as polyurethane, recycled wood and cement mixtures exist. The foam is usually either expanded polystyrene (EPS, average R-value of 3.8 per inch) or extruded polystyrene (XPS, average R-value of 5 per inch). If ties are needed to hold the forms together, they are either plastic or metal. The forms, in general, fit together with interlocking tongue and groove joints and stack together accordingly. The forms themselves come in many shapes and sizes among the different manufacturers.

ICF forms have two obvious variables. These are the form size when looking at the exterior of the form and the cavity shape that the concrete fills. The exterior shapes of the forms are panel, plank, or block. Panel shaped forms are available in sizes from approximately 1"-3" x 8"-9" up to 4" x 12" and resemble traditional plywood forms. Plank shaped forms range in height from 8" to 12" and are either 4" or 8" long. Plank systems differ from block systems in that they can be shipped flat, either because the ties can bend or the ties are inserted as the wall is constructed. Blocks resemble a typical concrete masonry unit (CMU), although the dimensions may vary from the typical CMU. Blocks arrive on-site ready to stack with their ties in place.

Differences in the interior cavities determine the shape of the poured concrete. The most common cavities are flat, grid, and post and beam. Concrete poured in flat cavities has a uniform cross-sectional thickness. Concrete in grid systems have varying cross-sectional thickness, with vertical columns and horizontal beams formed 12" to 16" o.c. The space between the columns and beams may or may not be filled with concrete. These spaces, when filled with concrete, are referred to as webs, and are approximately 2" in thickness. Post and beam cavities have vertical columns spaced approximately 48" o.c. and horizontal beams typically either 4" or 8" o.c., without any concrete webbing between the posts and beams.

At this point, the terminology used to describe ICF systems can be confusing. Both the Research Center and the industry are working to define standard terms to describe and categorize the forms. The following definitions are consistent with the definitions that are being proposed as prescriptive code language for ICF systems.

Flat ICF Wall System: This system has a solid concrete wall of uniform thickness. This system has a nominal concrete thickness of 4, 6, 8, or 10 inches. The actual thickness of the concrete wall is typically nominal thickness reduced by 1/2 inch. Bracing for the forms and steel reinforcing (rebar) for the concrete is as required by the design engineer or the manufacturer's technical data.

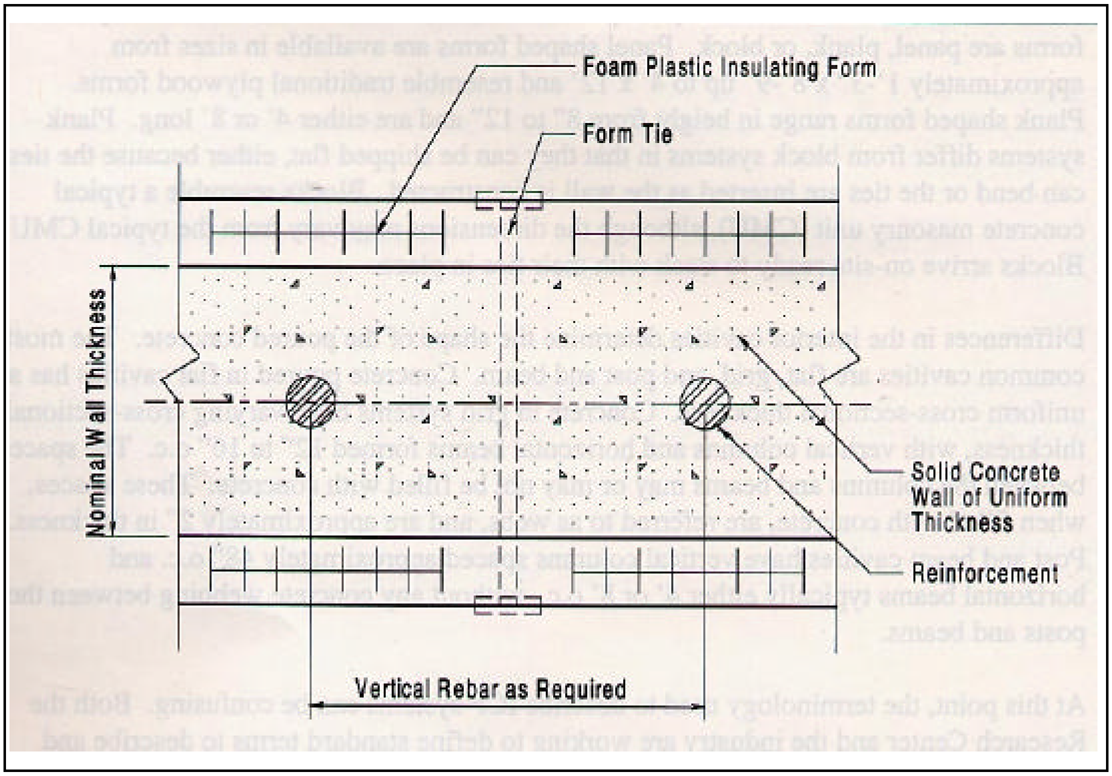


Figure 1: Flat ICF Wall System

Waffle-Grid ICF Wall System: This system has a solid concrete wall of varying thickness. It has a nominal concrete thickness of 6 or 8 inches for horizontal and vertical concrete cores. Maximum spacing of vertical cores is 12" o.c.. Maximum spacing of horizontal cores is 16" o.c.. Webs inbetween the cores have a minimum thickness of 2". Bracing for the forms and steel reinforcing (rebar) for the concrete is as required by the design engineer or the manufacturer's technical data.

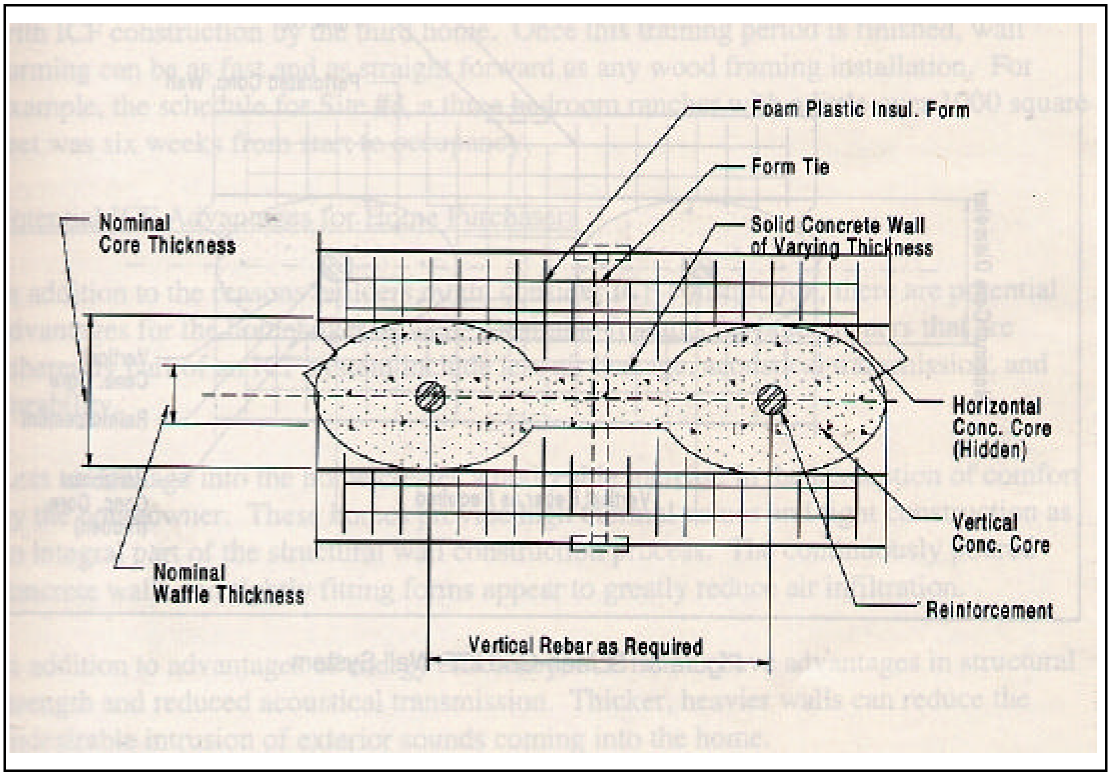
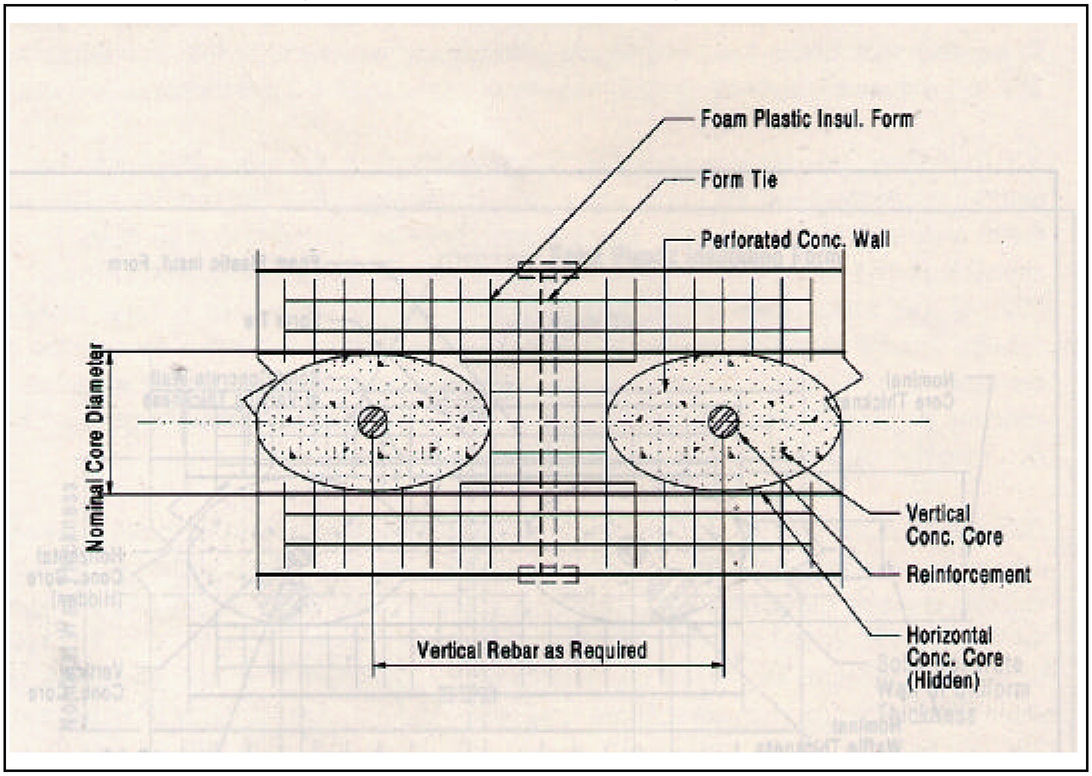


Figure 2: Waffle-Grid ICF Wall System

Screen-Grid ICF Wall System: This system is often termed "post and beam". It has a perforated concrete wall of varying thickness. This system has a nominal concrete thickness of 6 or 8 inches for the horizontal and vertical concrete members. Maximum spacing of vertical cores and horizontal cores is 12" o.c.. Unlike waffle-grid ICFs, the screen-grid systems do not have webs. Bracing for the forms and steel reinforcing (rebar) for the concrete is as required by the design engineer or the manufacturer's technical data.

Figure 3: Screen-Grid ICF Wall System



Builder Issues for ICF Construction

From a builder perspective, there are many reasons to consider ICF construction. Costs, availability of labor, and familiarity with construction methods are some of the factors when choosing a framing material. Perhaps the most important is cost. A detailed presentation of the cost experience of the four builders involved in this demonstration is presented later in this report. Costs are fairly easy to define from accounting records and receipts. Benefits are harder to quantify, since the purchaser's decision to buy is often the end result of many subjective factors. Unless the benefits of the ICF material clearly outweigh the costs, most builders will be hesitant to switch construction methods.

Site labor, either in the form of competent subcontractors or trained hourly employees, will impact a builder's decision to consider ICFs as a framing method. Regardless of how cost competitive an alternative is to wood framing, if the builder has limited choices for field installation, the risk of committing to ICFs as his or her framing method may be too great. It is important that sufficient crews and trained installers are available to meet production schedules, as well as to allow competitive bidding between more than one subcontractor. Like conventional wood framing, many ICF homes can be built with a small crew of moderately skilled people. In fact, traditional carpentry contractors may be the most likely subcontractors to have the appropriate tools and skills to install ICF, since an ICF home often has a conventional trussed or rafter type roof, and standard wood or metal interior partitions.

Based upon responses from the demonstration home builders, crews become comfortable with ICF construction by the third home. Once this training period is finished, wall forming can be as fast and as straight forward as any wood framing installation. For example, the schedule for Site #4, a three bedroom rancher with a little over 1000 square feet was six weeks from start to occupancy.

Potential ICF Advantages for Home Purchasers

In addition to the reasons builders might consider ICF construction, there are potential advantages for the homebuyer as well. Desirable features for homeowners that are inherently part of an ICF system include less air leakage, acoustical transmission, and durability.

Less air leakage into the home creates a noticeable increase in the perception of comfort by the homeowner. These homes provide high thermal values and tight construction as an integral part of the structural wall construction process. The continuously poured concrete walls and tightly fitting forms appear to greatly reduce air infiltration.

In addition to advantages of energy efficiency, ICF homes have advantages in structural strength and reduced acoustical transmission. Thicker, heavier walls can reduce the undesirable intrusion of exterior sounds coming into the home.

Concrete construction provides a fire resistant, durable structure requiring less maintenance. The homeowners of the demonstration homes reported appreciating the solid look and feel of their homes. The homes also have a "more-finished" look than typical framed homes, since ICFs are covered with 1/2" gypsum board in the attic and, if applicable, the basement.

Each of the above mentioned builder and homeowner issues are discussed herein. The experiences of the four participating builders are quite different, and provide an overview of the processes and the issues faced in their local markets.

BUILDING CODES

General

The use of Insulating Concrete Forms for above or below grade walls is not addressed specifically in the model building codes. As a result, engineered designs (usually with sealed sets of plans) are frequently necessary in order to obtain building permits. However, most ICF manufacturers have taken steps of their own to have their proprietary systems approved by the BOCA, SBBCI, and ICBO code organizations. Engineering reports, or evaluations by the code bodies, are available from those manufacturers. If the technical manual of the ICF manufacturer is accepted by the local code official, an engineered design may not be required for typical installations covered by the specific manufacturers instructions.

The American Concrete Institute publication, "Building Code Requirements for Structural Concrete" (ACI 318-95) and Commentary (ACI 318R-95) provides minimum requirements for concrete structures. The code does not replace sound engineering judgment and is not recognized as a building code document unless adopted by the local jurisdiction regulating construction. The difficulty with the ACI design code is that it's design requirements are based on tests involving much larger and more complex structures than typical homes. Applying the requirements of ACI 318-95 to low-rise one- and two-family dwellings results in over-design thereby increasing construction costs. More specifically, the main concern in residential applications is that the prescribed minimum steel reinforcing requirements in ACI 318-95 are conservative for the low loading conditions of one- and two-family residences.

Some examples of the specific minimum reinforcing steel requirements that are specified in the ACI Design Code are noted here. Flexural beams (lintels) are sized using equations in section 10.5 of the ACI code. Additional reinforcing steel, a minimum of two #5 bars on each side of the opening is required around the windows and doors, extending past the corners at least 24" (Section 14.3.7 of the ACI code). Maximum spacing for vertical and horizontal steel reinforcement in walls is 18" o.c., or three times the wall thickness, whichever is smaller (Section 14.3.5 of the ACI code). Section 14.2.7 of the ACI code does have a provision allowing the designer to waive the minimum reinforcement requirements under certain conditions. An additional design option is included in Chapter 22, for unreinforced concrete walls. During 1996-1997, the minimum reinforcing requirements for ICF walls are being examined by the NAHB Research Center, PCA, and HUD.

There are also changes that may be rationally supported in the areas of minimum wall thickness and concrete design mix that can result in acceptably strong and durable structures at a more economical cost. Design and specification issues such as these need to be addressed to allow residential structures with ICF walls to better compete on a cost basis with more traditional light framed structures.

It is expected that prescriptive requirements will be incorporated into code change proposals for residential applications of ICF systems with flat, waffle, and screen grid concrete systems, and will be submitted to the model code groups in upcoming code change cycles.

Fire Code Considerations

The fire separation and flammability requirements of building codes vary from jurisdiction to jurisdiction and between the different model codes. Multi-family dwelling code requirements are the most stringent because of the danger of fire spreading among adjacent units. Many codes require a minimum 15 minute fire barrier (assembly rating) over any exposed foam in occupied areas. For ICF structures, this would mean hanging drywall or other 15 minute rated material in basements and occupiable attics to protect the form of the ICFs. Penetrations in party walls are also a concern, therefore penetrations should be sealed on both sides to prevent flame spread. Building officials have clearly expressed some concern about how floor joists are integrated with ICFs. Joists that are embedded in the concrete of a wall may require a firecut, allowing the burning joist to fall clear of the wall structure without inducing stresses on the wall itself. Another method of floor joist attachment to the wall is to use a ledger. The ledger is bolted into the concrete and the foam behind each ledger bolt is completely cut away. The header is braced and bolts tied in place prior to the pour. Some code officials have indicated they will not approve of foam cut away only at the bolt due to a concern of fire stopping requirements. In this case, the ledger must be secured to the concrete directly, not to the foam surface.

Termite Protection Issues

Termite protection requirements are especially important to structures that intend to use ICF products below the ground surface. The Standard Building Code, developed and maintained by Southern Building Code Congress International (SBCCI), approved code change number B-153 on October 30, 1996. This change to the model code prohibits the use of foam insulation below grade in heavy termite infestation areas. ICF houses built on slabs, conventional concrete or masonry crawl space walls, or conventional concrete basement walls would not be affected by this code change.

It is difficult to assess the impact of this code change to ICF construction at this point since many homes in the heavy infestation areas are built on slabs or crawl spaces. The concern with termite infestations is that termites have an opportunity to nest in unprotected foam.

The ICF industry has responded with a series of effective ways to comply with the intent of the Standard Building Codes' termite protection requirements without prohibiting the use of all foams below grade. The Insulated Concrete Form Association (ICFA), published a list of 12 proposals to overcome the termite protection concerns of code officials and termite protection companies. These solutions range from chemical sprays and barriers on the foam itself, to treatments of the surrounding soil to prevent termites from reaching the ICF foam material. Colony elimination systems are being thoroughly investigated. This type of system consists of traps in which poison is transported back to the colony to kill the infestation. The ICFA continues to revise the list as more information and possible solutions become available. The list was updated as recently as March 1996. The ICFA is also working with the University of Georgia to study ICF homes in Georgia and South Carolina to assess the extent of infestation, mediation, and recommendations for new construction practices.

The approach of the ICF industry is to address the concerns of protecting buildings from termite infestation without unreasonable requirements imposed on a particular product or building method. Copies of the termite control proposals are available from ICFA. In any new construction, traditional pest control, such as termite barriers and treated soil are recommended by the ICFA for any ICF construction not restricted by the SBCCI code change.

Moisture Control

Moisture control for ICF wall systems is similar to other types of wall systems. Concrete and masonry basements and crawlspaces are either waterproofed or dampproofed below grade.

The CABO One- and Two-Family Dwelling Code requires foundations to be dampproofed or waterproofed from the top of the footing to the finished grade (CABO 1995, Section 406). The decision to waterproof or dampproof depends upon the amount of water in the soil of the construction site.

The moisture barrier used over an ICF form must be compatible with the form material. Most ICF forms are either expanded or extruded polystyrene. The moisture barrier should be non-petroleum based so that it will not deteriorate the foam.

The form manufacturer's product literature may list waterproofing and dampproofing products that have been used with their forms in the past. The sealant manufacturer's product and warranty literature should be reviewed to determine compatibility with the form and to insure that the recommended installation procedures followed.

Seismic Resistance

ICF structures can be designed for all seismic zones, due to the standard ICF combination of concrete and reinforcing steel. The industry is only now starting to consider shear wall testing of ICF wall systems. Empirical results from such tests are needed to quantify the methods of compliance of ICF home designs in earthquake-prone areas.

Wind Resistance

A properly constructed ICF home should be exceptionally resistant to loads caused by high winds. In both coastal hurricane areas, and in other high wind areas where building codes require an analysis of wind resistance, ICF wall systems can be demonstrated to be substantially in excess of current code requirements. With appropriate anchors to the concrete footings and foundation, and secure connections between the roof system and the ICF wall system, a builder will have a highly wind-resistant structure. Cost comparisons between wood frame structures and ICF structures should indicate less of a premium for the ICF wall system in high wind areas. A typical wood frame structure requires more costly upgrades for compliance in a high wind area, whereas the minimum ICF residence will require little if any upgrading to comply with the same high wind requirements.

TYPICAL CONSTRUCTION PRACTICES

General

This section discusses Insulating Concrete Form construction, conventional concrete requirements, and typical wood construction. Some of the differences between typical ICF and conventional concrete construction are highlighted. ICF is compared with typical wood frame construction to provide a contrast with the most widely used framing method throughout the United States

Concrete Design Requirements

Comparisons made to typical concrete construction focus on the concrete mix and the control of the pour. Typical mixtures for residential concrete have a compressive strength of 3000 psi, aggregate size of 3/4" and a slump of 4". The typical ICF mixtures have a compressive strength of 2500-3000 psi, aggregate size of 3/8" - 3/4" and a slump of 4" - 6". "Pump Mix" is also generally specified. This is a high flow concrete mix that will move well through a 2" pump. A free-flowing mix is paramount to allow concrete to flow into all interior spaces of the form. Potential voids or honeycombing will weaken the wall. Unintentional voids created in post and beam and screen grid systems are of particular concern due to the voids inherent in their system already. The presence of any unintended voids may compromise the expected strength of the ICF wall.

Variations Due to Climate

The ACI (American Concrete Institute) has code guidelines for concrete pours in extreme weather. In addition to the building code guidelines in ACI Code 318, there are ACI Code 306 - "Cold Weather Concreting" and ACI Code 305 - "Hot Weather Concreting." The codes in ACI 318 call for concrete, except high early strength concrete, to be kept above 50 F and in a moist condition for 7 days" (ACI Code Section 5.11) after a pour in cold weather. In hot weather, the concrete has to be "protected against excessive concrete temperature or water evaporation." (ACI Code Section 5.13).

Insulating forms make it easier to protect the concrete and assure proper curing in extreme weather. In cold weather, only the top of the form needs to be protected with insulating blankets, for temperatures down to 10 F. In extremely hot weather, in which evaporation is a concern, the top of the form is covered with a plastic moisture barrier.

Foundations

There are several possible approaches to the use of ICF products for foundations. For houses with crawl spaces or slab foundations, the ICF system can start at the top of the conventionally poured footing and continue up to the eaves of the home. This is similar to the method employed by the Demonstration Builders in both Chestertown, Maryland, and in Virginia Beach, Virginia. The interior slab is then poured completely inside the exterior ICF wall. The use of this approach provides full thickness insulation all the way down to the footing and prevents the possibility of interior heat radiating through the exterior wall to the outside. Such a radiating effect would be very visible in thermograph imagery taken from the exterior of the home during the heating season.

An alternative approach is to start the ICF system on the edge of a thickened slab, similar to typical pressure-treated-wood plate and wood-framed wall construction. This approach can be used for homes in warmer climates where foundation insulation is not typical practice and where monolithic type slab foundations are common. There is an energy implication involved in choosing this approach. This approach also provides a solution to the possible code prohibition of the use of foam products below grade, for termite infestation reasons. This is the approach chosen by the Austin, Texas Demonstration Builder, using the I.C.E. Block™ system.

For basement foundation situations, the use of ICF systems is adaptable to residential construction. Again, in areas where termite resistant construction is required, or in areas where foam products are prohibited by code to be used below grade, an alternative must be chosen or the foam form removed after the concrete cure. If these restrictions do not apply, the use of ICF products results in a fully insulated foundation wall, that can be cost effectively finished for additional living space. The Demonstration Builder in Sioux City, Iowa included a full basement, using the Lite-Form product, and has successfully marketed the potential of easily finished additional living space.

Comparisons to Wood Framing

Wood framing is very familiar to residential builders and therefore is a good point of reference to compare to ICF construction. With ICFs, some special precautions are required that are not usually issues with wood framing. These are summarized below in pre-construction planning, utility penetrations, window and door placement, floor joists and bracing, corner details and finishing details. The *Reference* Section of this report provides additional sources of information on these details and issues.

Pre-Construction Planning

Planning is crucial in ICF construction because the features that make ICF homes attractive to buyers are the same ones that make field adjustments to the structure difficult. This phase is particularly important if the blueprints were originally designed for wood framing. Since the exterior walls of ICF are thicker, the overall dimensions of a wood-framed design would be increased to avoid shrinking the interior floor plan. Also pre-determine the location of utility penetrations, exterior and interior finishes, and appropriate attachment details for the roof, floors and interior partition wall framing. Changes made after the concrete has set will result in greater labor costs.

The demonstration homes used wood framing where appropriate for various architectural details. The construction process photographs show these details in the demonstration homes. Site #1, in Virginia Beach, has wood framing around the curved top windows. The gable wall framing at the garage and in the attic are also wood. Site #4, in Chestertown, also uses wood for the gable walls enclosing the attic. Site #3, in Sioux City, has wood exterior walls on three sides of the second floor. This was done to allow these walls to be offset from the corresponding first floor walls. In general, ICF walls must be placed directly over ICF walls or foundations unless designed by an engineer.

Utilities

Utility penetrations for ICF construction should be determined in advance. Unlike a wood-framed wall, making a hole through a full thickness concrete wall requires tools not readily available on the typical job site. It is generally recommended to sleeve penetrations with PVC pipe before the concrete is poured and install the utilities later. Some users of the waffle grid wall systems prefer to hammer drill through the 2" web for penetrations less than 1 1/2" in diameter. This choice depends upon the type of system used, builder requirements and trade preference. A detailed discussion on this topic is included in the Site #1 Construction section. Larger chases, such as for vent stacks, or duct work may need an engineer's structural analysis, especially if significant concrete is displaced by the chase. Temporary bracing during the pour may also be required if too much foam is cut away.

Openings for Doors and Windows

Openings for doors and windows also need pre-planning. A permanent pressure treated window frame is frequently installed to provide an attachment surface for the window or the door frame. Sizing this permanent frame is key to efficient installation of the windows and doors. Whether the windows have "masonry style" window frames, or frames with nailing flanges, the permanent window frame should be sized appropriately to accommodate the actual size of the window. Strong, temporary bracing of all openings in an ICF wall is important to keep the opening square during the concrete pour and to support the weight of the concrete until it achieves its desired strength.

The thickness of the wall is rarely a concern with wood framing when hanging a door, however, for ICF walls, like other masonry walls, the depth should be considered. The door should be installed so the hinges are located at the outside of the opening. The door will not open all the way if it is improperly mounted. For example, an inward opening door will not open if it is flush to the exterior wall surface; and an outswinging door will not open if it is installed flush to the interior of the wall.

Windows can be set at any depth in the ICF wall. Windows that are flush mounted with the exterior face will have deep interior window sills and few problems with exterior moisture. Extended jambs may be needed on the inside of windows and doors because of the thickness of the ICF walls. These may not be available from the window manufacturer and may require extra work by the installer or finish carpenter. Deep interior window sills are perceived as a benefit to many home buyers who like window seats or window display areas.

Corner Details

There are several different types of ICF form corners. Each demonstration home has a different corner detail. Site #1, and Site #2 use pre-formed foam corners that turn a 90 degree (right) angle. If pre-formed corners are not available, two standard forms can be miter-cut and glued together to form the corner piece. Site #3 uses proprietary corner ties to secure wall sections intersecting in the corner. Site #4, also incorporates special corner blocks. Each ICF manufacturer has specific recommendations for the corner assembly of their product. However, in most systems, the corner blocks should be placed to stagger leg lengths for every other course. This allows the foam edges to be offset so that there is not a continuous vertical seam at the corner.

Floor Joists and Bracing

Floor joists are either hung from ledgers or are embedded in the concrete. The ledger and anchor bolts are embedded or secured into the ICF forms before the concrete is placed. Joist hangers secure the joists once the concrete has set. Embedded joists are firecut and require cutting out the foam and inserting wood spacers before the pour to create a pocket in which to seat the joist.

Temporary bracing is needed at corners, window and door openings, periodically along the length of walls, and at the top of the forms. Top braces square the forms and provide a surface to check wall height and cut uneven blocks.

When beginning the layout of forms, the first course is laid flush with metal angles, wood cleats, or wood studs placed along the length of the foundation to secure the forms. Blocks can be set in green concrete foundations. The courses should, in general, have staggered vertical joints. Foam sealant can be used along joints to secure blocks until concrete is poured. This is especially handy during windy conditions. Excessive sealant (gluing horizontal and vertical seams) will make it difficult to plumb the forms prior to pouring the concrete. Some ICF systems have interlocking edges to reduce or eliminate the need for gluing. Sealant, if used along the horizontal and vertical seams, will reduce cold spots at the joints.

Finished Surfaces

Attaching wall sidings requires adjustments when using ICF construction. The changes depend on the type of system used. Some manufacturers use plastic or metal ties built into the ICF blocks and panels into which siding material can be directly screwed. If the spacing of the ties is not suitable for the siding material, (i.e., when using either wood or vinyl siding) furring strips may be attached to the ties. Some ICF systems do not have ties and the furring must be secured directly to the concrete.

On the interior, drywall is either screwed to furring strips or screwed to the ties and glued to the foam. Metal angles can be placed around the interior perimeter to screw in trim. Cabinets will require additional bearing support to remain attached to the wall. Plywood or 2 x 4 studs can be nailed into the green concrete and then used to hang cabinetry. Electrical boxes and wiring chases are cut into the foam. The foam is cut away using a hot wire cutter or a router. The boxes and cable sit into the foam and are taped or sealed into place. The finished electrical outlets and switches sit flush against the drywall. Because insulation is removed, thermal losses increase when foam is cut away. This can be seen on the thermography testing of the demonstration homes. Foam cut away for electrical boxes and wiring should be minimized. Sealants and tapes can be added around electrical boxes and wiring to reduce thermal losses.

THERMAL OVERVIEW AND ANALYSIS

<u>Cost Comparisons</u>

Cost issues figure predominantly in the builders decision to change to other framing materials such as ICF construction, although other factors such as price stability, scheduling problems, or labor issues may have considerable impact on a builders decision to try a new material.

<u>Thermal Resistance</u>

Thermal Resistance, in reference to wall construction is the ability of the wall structure (or cavity material) to refrain from transmitting heat through the depth of the wall. Thermal Resistivity is denoted as R-value, and expressed in the units F - ft5 - h / Btu - in. It is also referred to as the inverse of the conductivity of a material. "High R-value" and a "low conductivity" have the same meaning. Walls with a high R-value will keep heat within the structure and provide greater thermal comfort and less energy waste. Wood has a lower resistance to heat flow than fiberglass, polyurethane foam, or expanded polystyrene. In conventional framing, this means that studs have a lower resistance or R-value than the surrounding insulation and reduce the overall thermal performance of the wall. This thermal reduction, or framing factor, increases heat transfer, reduces comfort, and increases utility bills. The thermal effects are magnified at the corners, where there are more wood studs. Insulating concrete form walls have no framing and are expected to have better overall thermal performance than stud walls.

In evaluating wall performance, walls are considered in sections so that the framing factor of the constituent parts of the wall can be determined. The wall can be broken into several components.

- *Material R-value:* This is the resistance to heat transfer of common materials such as fiberglass, wood, concrete, or foam per inch of material. Manufacturers of insulation typically state this value on their label.

Cavity R-value: This is the maximum R-value of the materials through the cavity of a frame wall. For this example, the cavity R-value is the sum of the R-values of the fiberglass, the plywood, and the drywall.

- *Clear Wall R-value:* This is the resistance of a wall section with no windows, doors, or corners. For wood framing this is vertical studs, top and bottom plates, and one bay of insulation. For ICF construction, the wall section is a section of repeating geometry, consisting of the foam forms and the concrete.

- *Assembly R-value:* Assembly R-value is the resistance of a combination of framing details that go into a specific assembly, such as a window or door. For a window supported in wood framing this includes the header, sill plate, jack studs, king studs, and support studs. For a window supported in ICF construction, the assembly includes the window framing material (wood or plastic), the concrete and the foam form.

- *Overall or Whole-Wall R-value:* This is the combined resistance of clear walls, window and door assemblies, and corners.

Clear Wall and Assembly R-values for a conventional 2 x 4 framed wall and an ICF wall are calculated and compared in Table 1.

Three methods have been used to calculate average R-values: parallel flow; isothermal planes; and 2-D finite element analysis. The parallel flow and isothermal planes methods are used to determine stud clear wall, stud window framing, and ICF window-wall R-values. These methods are based on 1-D resistance equations as discussed in ASHRAE Fundamentals. The parallel flow approach assumes that heat moves on a perpendicular path through a combination of materials and not laterally through the material. The isothermal planes method assumes that heat will move both normally (perpendicular) and laterally through the materials and uses a different averaging method to account for this. The actual heat flow through combinations of materials usually lies between the two methods.

A 2-D finite element analysis is used to calculate the 3-stud corner and ICF corner R-values. The method solves the 2-D heat conduction equation at discrete points, or nodes, placed in the geometry. The more nodes the better the resolution and accuracy. Film coefficients are not used on the inside and outside surfaces for any of the calculations. The air space between the studs in the 3-stud corner uses a film coefficient for a vertical, planar air space as specified in ASHRAE Fundamentals.

Figure 4 shows a standard framed wall with cut away views of the corner and clear wall sections. Figure 5 shows a standard ICF wall with the same section drawings. Windows are modeled with two single 2"-8" x 6"-2" windows separated by a nailing stud. The header is a pair of 2 x 6"s. In the corner detail, a three stud corner is compared to a panel ICF corner. The corner does not include the effects of top and bottom plates. Material resistance are specified in Table 2. The results do not include air films on inside and outside surfaces. The ICF model does not account for lower resistance at the form ties.

Table 1 clearly shows the impact of the framing members of the wood walls when the R-value of the cavity is modified by taking into account the studs, and the studs with plates. The ICF wall has no interior framing to diminish the average wall R-value.

The effect is also apparent at the corners. Though there is a diminished R-value from the corner effect on the ICF wall, the corner framing effect on the wood frame wall is even more dramatic. Even with ICF walls, there is a corner impact when the geometry of the corner is considered. The R-value reduction from the ICF Clear Wall to the ICF corner is 24%. Without insulation in the three stud corner there is a 41% reduction in the R-value, and even if insulation is added to the three stud corner, there is still a 31% R-value reduction.

Wall Type	ICF Framing	Stud Framing	Per Cent Reduction
ICF clear wall*	16.2		-
Cavity		14.1	-
plates		12.1	14%
Studs with plates		11.4	19%
ICF corner*	12.3		24%
3 stud corner with air cavity		8.3	41%
3 stud corner with insulation		9.9	30%
Wall with window openings			
With window	3.0	2.8	
Without window	15.6	6.6	

* includes concrete and drywall

Table 1: Wall Assembly R-values

	R-value per inch of Material	R-value as Specified
Expanded polystyrene foam, 4 inches	3.8	15.2
Fiberglass insulation, 3.5 inches	3.71	13.0
Plywood, 1/2 inch	1.25	0.62
SPF studs, 3.5 inches	1.23	4.30
Double pane, vinyl window (2826)	**	2.17
Drywall, 1/2 inch	0.90	0.45
Concrete, 8 inches	0.0625	0.50

Table 2: Material R-values

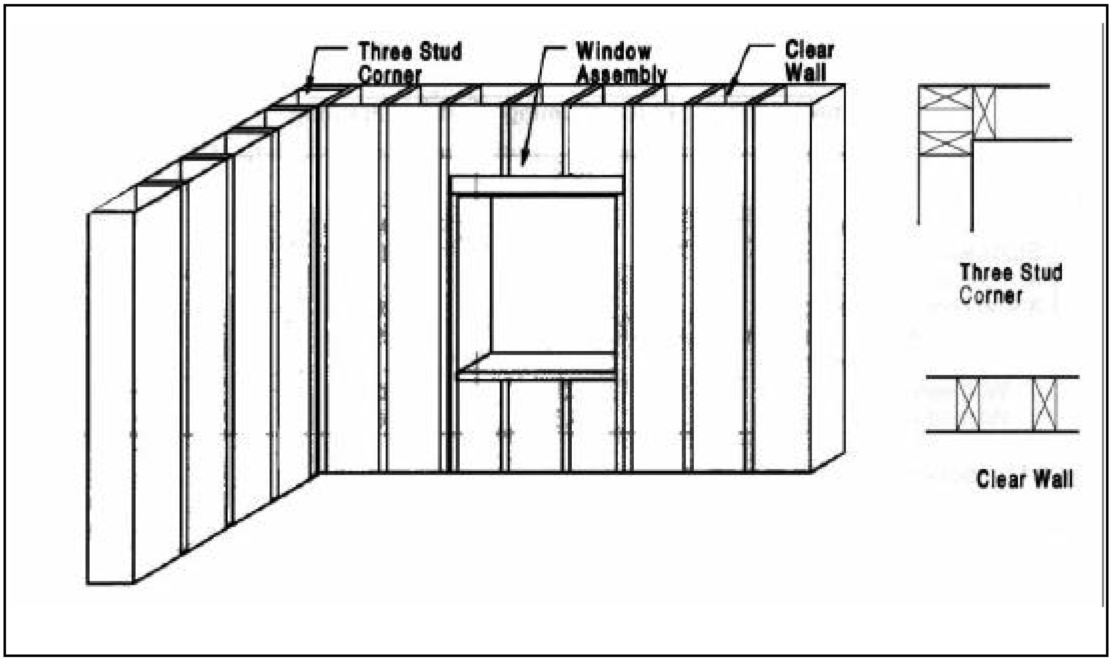


Figure 4: Conventional Framed Wall

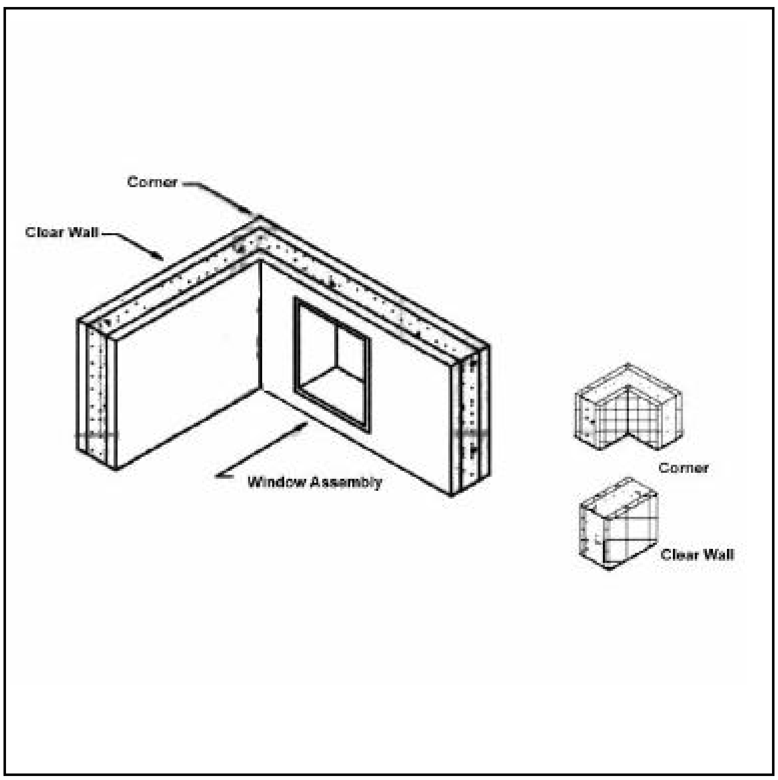


Figure 5: ICF Wall

Infiltration

Building infiltration is measured using ASTM test procedure E779-1987, "Standard Test Method for Determining Air Leakage Rate by Fan Pressurization." E779 tests are performed by placing a fan in a door or window and drawing air from the home. House to outdoor pressure differences are taken between 12.5 Pascal and 75 Pascal, and the air flow through the fan is measured at each point. The data are fit to a power law equation of the form $Q = c P^n$, where Q is flow, P is measured pressure, and c and n are constants. If only one point is taken, n is set to 0.65. Air leakage is normalized by the house volume to get air changes per hour (ACH). A standard comparative number is the air leakage at 50 Pascal or ACH50. Fifty Pascal is equivalent to 0.0072519 psi or 0.20065 inches of water column.

Once the air leakage and power law coefficients are known, methods specified in ASHRAE Fundamentals are applied. Leakage at 4 Pascal is calculated and corrected for seasonal or peak outdoor and indoor temperatures and wind speed. Seasonal natural infiltration is calculated using average monthly temperatures and wind speed from NRC Canada's Hot2000 program database. Months where the temperature difference between outdoor and house are nearly zero are not used to calculate the seasonal average. Peak natural infiltration is calculated using design temperatures from ACCA's Manual J building load standard and the maximum heating or cooling season wind speed from the Hot2000 database. An average year infiltration can be calculated using both seasonal values. The 1995 CABO "Model Energy Code," 2nd Printing, uses a standard design air change rate of 0.50 ACH.

Infrared Thermography-Resolution and Physics

Infrared images can be taken alone or in combination with a blower door. When taken alone, the infrared images indicate thermal bridges or shorts. When taken in combination with a blower door, the infrared pictures identify sources of air leakage. Images can be taken in color or black and white. The images in this report are shown in gray scale. For these images, the direction of thermal conduction, and the color displaying the area of leakage depends upon the orientation of the camera. Images taken from the outside of the house will have white areas showing hot spots of heat leakage out of the home. Images taken from the interior of the house will have dark areas showing cold spots. Areas around windows show the heat conduction very prominently if there are any leakage paths. For this report, representative images have been selected for each demonstration house. The individual demonstration house discussions contain an analysis of infrared images.

Peak and Annual Energy Consumption Analysis

Peak and seasonal energy use are calculated using REM/DESIGN, a commercially available energy software. The software employs a Modified Bin analysis. In a Modified Bin calculation, outdoor temperatures are separated into bins of 5°F increments, and the number of hours for each temperature bin are counted. The seasonal loads are the sum of instantaneous loads at each Bin temperature. Off-design performance of HVAC equipment and solar loads are coupled to the Bin temperatures to provide more accuracy than in a standard Bin analysis. The software calculates peak loads using ASHRAE design temperatures and solar data.

Building take-off lengths, areas, and volumes are calculated from the drawings. Each component area or perimeter and its associated R-value are input to the software. These are shown in Table 3. Framing factor is accounted for in the code using an ASHRAE parallel path calculation. In this report, calculations for stud walls use 15% of the net wall area for studs and 85% of the area for stud cavities. ICF walls are calculated without a framing factor. Windows are treated in the software as mostly shaded or screened unless under a porch roof where they are treated as fully shaded. Measured infiltration is input into the software as air changes per hour at 50 Pascal.

The thermal mass of an ICF system is accounted for in the annual heating and cooling load calculations. In heating climates, the extra thermal inertia provided by the 'heavier" walls moderates the indoor temperature swings and may reduce winter energy consumption for the structure acting as a whole system. During the cooling season, the mass of the ICF wall system may also provide an advantage, especially in climates where summer humidity is not a dominant factor.

	Wall Component R-values
Virginia Beach	
Outside air film	0.17
Stucco, 3/8 inch	0.06
: inch expanded polystyrene	2.89
Polysteel block plus concrete[a]	17.48
Drywall	0.45
Inside air film	0.68
Total	21.73
Austin	
Outside air film	0.17
Stucco, 3/8 inch	0.06
2 inch expanded polystyrene	1.90
I.C.E. Block **J** plus concrete[a]	17.48
Drywall	0.45
Inside air film	0.68
Total	20.74
Sioux City	
Outside air film	0.17
Vinyl siding	0.0
Fold Form plus concrete[b]	15.2
Drywall	0.45
Inside air film	0.68
Total	16.50
Chestertown	
Outside air film	0.17
Vinyl siding	0.00
Reddi-Form plus concrete[c]	18.27
Drywall	0.45
Inside air film	0.68
Total	19.57

<u>Note</u>: [a] *Physical measurements taken and calculated with ASHRAE parallel path method; no reduction considered for metal wall tie*
[b] *Four inches of expanded polystyrene*
[c] *Tested under ASTM C-236; report*

Table 3: Calculated Wall R-values of Demonstration Houses

SECTION II

SECTION II

DEMONSTRATION HOME CONSTRUCTION PROCESS

INTRODUCTION

This section documents the on-site construction processes of the demonstration homes. Since each builder uses a different ICF product, each site is treated separately. Builder and product information, cost comparisons, homeowner comments, and energy summaries are included in this section.

Builder profiles include information on the builder, the typical construction for the area, type of home built, and form used. Summaries of the foam product used to construct the house are in this section. This information is taken from the manufacturer product literature.

The construction process for the homes is shown in photographs. The sites were visited to document the construction details discussed in previous sections, such as placing forms, bracing, rebar placement and pouring concrete. Photos of the finished homes are at the beginning of each site section.

An analysis was performed to compare the cost of constructing an ICF wall with a wood-framed wall. Cost information from the four builders was obtained and classified into the following four categories:

- labor cost
- cost of ICF materials (form and ties)
- cost of concrete
- miscellaneous costs

Comparison models of costs for typical wood-framed walls at the four locations were developed. When several different constructions were common in an area, the model uses the type which corresponds to the demonstration home (e.g., custom, affordable).

In general, the local home builders associations were contacted to determine typical construction practice in their area. In each case a referral was made to an associate member in the building supply business who provided construction and cost details of a typical exterior wall. Note in most cases the level of energy efficiency for the typical comparison construction is less than that achieved with ICF construction. An equivalent energy cost comparison may need to be performed for the builders who market high efficiency homes.

R.S. Means 1996 *Residential Cost Data* adjusted for regional variations was used to determine the wood-framed wall costs. A take-off of each site's house plan provided the information to apply the Means cost factors. The Means framing estimates include a separate framing cost for door and window headers based on the size of the header lumber and the width of the header. Header sizes were determined using the 1995 CABO *One and Two Family Dwelling Code* requirements contained in Table 602.6.

The specific wood-framed construction cost information for each demonstration site is divided into two categories, wood-framing and energy features. Wood-framing includes the studs, top and bottom plates, let-in bracing, and wood sheathing. The applicable energy features include cavity insulation, foam sheathing, plastic moisture barrier, and housewrap.

This cost table is presented both as costs per square foot of floor area and cost per square foot of wall area. Summary cost information is presented in two ways, for each of the four demonstration sites. A direct side-by-side comparison between the ICF wall construction and the frame wall that is considered typical in the local area.

Another way of evaluation costs of ICF systems in residential projects is to consider the extra cost on the total finished sale price of the home, In this way the incremental costs of the ICF system can be compared to the benefits that accrue to the purchaser of the home. This comparison is shown in the <u>*Costs*</u> *Conclusion* Section of this report.

Homeowners were interviewed about their perceptions of their home. The homeowners were asked about sound levels in the house, thermal comfort, utility costs and their overall satisfaction with the home.

The report section then turns to thermal and energy efficiency data. Each home was thermograph tested. The thermograph measures heat movement and displays this data in a video format. The corners, windows, doors, and wall-to-floor connections are examined. Results are shown. Each home was also tested for air infiltration, or leakage. These results are also shown. The energy usage is compared to computer modeling results.

SITE PROFILES

The following chart summarizes the builder, location, ICF system and type of home.

SITE	Site #1	Site #2	Site #3	Site #4
BUILDER	Dominion Building Group	John Weaver Custom Homes	Gary Niles Homes	Roger McKnight, Romak & Assoc.
CUSTOM/PROD	Custom	Custom	Custom/spec	Prod/affordable
HOUSE LOCATION	Virginia Beach, Virginia	Austin, Texas	Sioux City, Iowa	Chestertown, Maryland
HOUSING COMMUNITY	South Shore Estates	Las Entrades	Niles Addition	Knight's Landing
CLIMATE TYPE	Cooling	Cooling	Heating	Heating
COOLING HRS / HTG DEG. DAYS[1]	1150 Cooling Degree Hours	1860 Cooling Degree Hours	6960 Heating Degree Days	4600 Heating Degree Days
ICF MANUF.	American Polysteel	I.C.E. BLOCK J , Inc.	Lite-Form, Inc.	Reddi-Form, Inc.
LOCATION	Albuquerque, NM	New Carlisle, OH	Sioux City, IA	Oakland, NJ
PHONE	800/977-3676	800/423-2557	712/252-3704	800/334-4303
SYSTEM TYPE	Waffle Grid	Waffle Grid	Flat Wall	Screen Grid
FORM TYPE	Block	Block	Plank	Block
HOUSE STYLE	Custom	Custom	Affordable/Spec.	Affordable/Prod.
# STORIES	One	One	Two	One
# BDR/#BATH	3 / 2.5	4 / 4.5	4 / 2.5	3 / 2
GARAGE	Two Car	Two Car	Two Car Integrated	None
EXTERIOR FINISH	EIFS	Adobe Finish Stucco	Vinyl Siding	Vinyl Siding
FOUNDATION	ICF footing w/ floating slab	Conventional slab	FPSF w/ basement	ICF footing w/ floating slab
SQ. FOOTAGE	2775	3894	2505	1008
GROSS WALL AREA (ft^2)	2694	5105	2231	1191

Table 4: Builder, Product, and House Profile

[1] Definition from ASHRAE Standard 90.2-1993 *Energy-Efficient Design of New Low-Rise Residential Buildings:* Cooling Degree Hours/Heating Degree Days - Unit, based upon temperature difference and time, used in estimating cooling loads of residences in the summer. For any hour when the dry-bulb temperature is greater than a reference temperature (base 74^oF for this standard) there are as many cooling - degree hours as degrees Farenheit difference in temperature between the average hour temperature and the referenced temperature.

Heating degree days is similarly defined as unit, based upon temperature difference and time, used in estimating heating loads of residences in the winter. For any day when the dry-bulb temperature is less than a reference temperature (base 65 F for this standard), there are as many heating-degree days as degrees Farenheit difference in temperature between the average daily temperature and the referenced temperature.

DEMONSTRATION HOME #1 - VIRGINIA BEACH, VIRGINIA

The home is constructed by Mr. Reid Pocock, P.E. of the Dominion Building Group. Mr. Pocock is both a builder and American Polysteel Form distributor.

This home is constructed by the Dominion Building Group as a Homerama, or builder's showcase home. The house is a custom one story slab-on-grade home, with three bedrooms, two and a half baths, and 2775 square feet of living space. The exterior finish is synthetic stucco. The floor plan for the home is shown in Figure 6.

Photo 1: Site #1 - Front Elevation

Photo 2: Site #1 - Rear Elevation

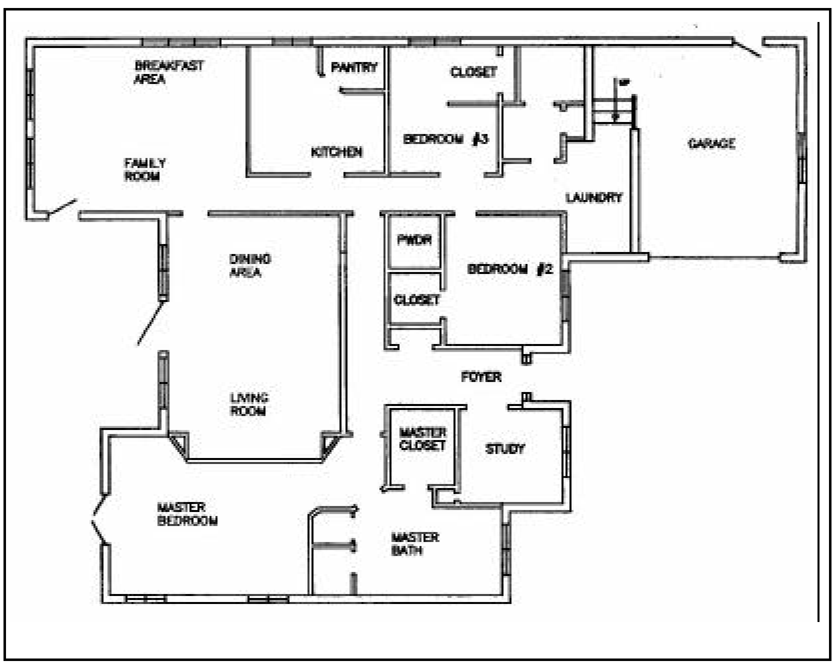


Figure 6: Site #1 - Floor Plan

ICF Product Summary

The house is constructed from American Polysteel Form *forms*. The form has a block shape and an interior cavity that produces a waffle-grid concrete wall. The builder used the 6" core Polysteel form. The forms are 48" long and 16" tall. The concrete width in the core varies from 2" in the waffle section to 6" in the post and beam sections. The outer dimension of the form is 9 1/4". The vertical columns are spaced 12" o.c. and the horizontal beams are spaced 16" o.c.. The horizontal beams are formed as the blocks are stacked, and the vertical posts are in-between the webs. Polysteel forms have steel webbing that runs through the thickness of the form and connects the outer furring strips together. The integrated galvanized steel furring strips allow the interior and exterior finishes to be attached without the construction crew having to take an extra step to add furring strips themselves. The American Polysteel Form product literature states an R-value of the EPS (foam) as 4.17/inch, thermal mass (6" core) 56 lb./ft^2 and an air infiltration rate of 0.09-0.1 air changes per hour. An illustration of the form is shown below.

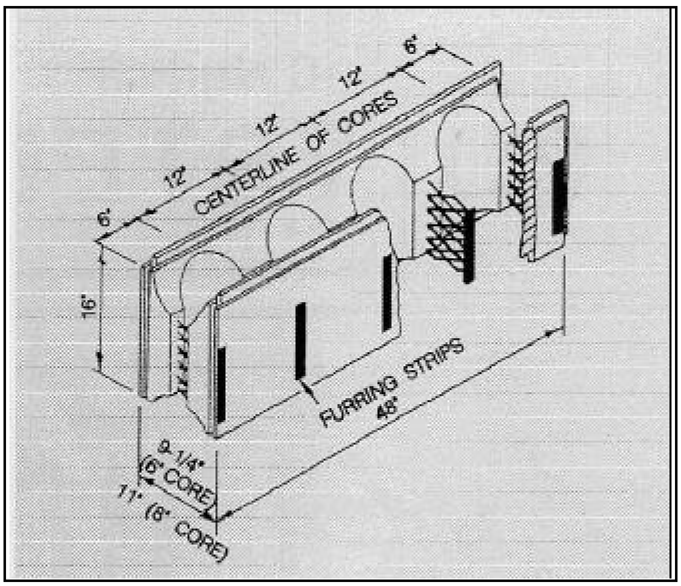


Figure 7: American Polysteel Form
(Figure Used With Permission)

Polysteel recommends a concrete mix with a minimum compressive strength of 2500 psi, a 5" slump, and a 3/8" (pea gravel) aggregate. They offer pre-formed corner forms and rebar stirrups to lessen construction time. The manual includes procedures and recommendations for form layout, corner, wall and window bracing, rebar placement, and utility penetrations. The builder reports the Polysteel technical staff knowledgeable and helpful. The builder used the Polysteel manual, videos and attended a training seminar.

Construction Summary

The site construction summary is based on builder responses and staff observations of construction. The photos are of field installations both at the demonstration site, and other sites where this builder has used ICF.

The concrete mix used had a compressive strength of 3500 psi, a 5" slump, and 3/4" aggregate. The mix was designed by the builder and ready mix contractor to use a 3/4" aggregate because the 3/8" mix is cost prohibitive in this area. Fly ash is in the mix to improve workability. Grade 60 rebar is used. #4 rebar is placed 24" o.c. vertically and 48" o.c. horizontally. Two #5 rebar are used on either side of the windows and doors. The vertical bars were placed through tie wire. The rebar is placed after forms are erected. The builder currently uses the rebar saddles offered by the manufacturer to place the vertical and horizontal rebar. Both methods save construction time, because the rebar is dropped into the forms instead of threading the forms over the rebar.

Photo 3 shows the rebar placement at the corner of the block. The horizontal rebar is turning the corner around the vertical rebar. The builder has found that placing the vertical rebar after the blocks are set saves time in construction. The builder uses Polysteel support saddles that support the horizontal rebar and provide a path for the vertical rebar to be placed.

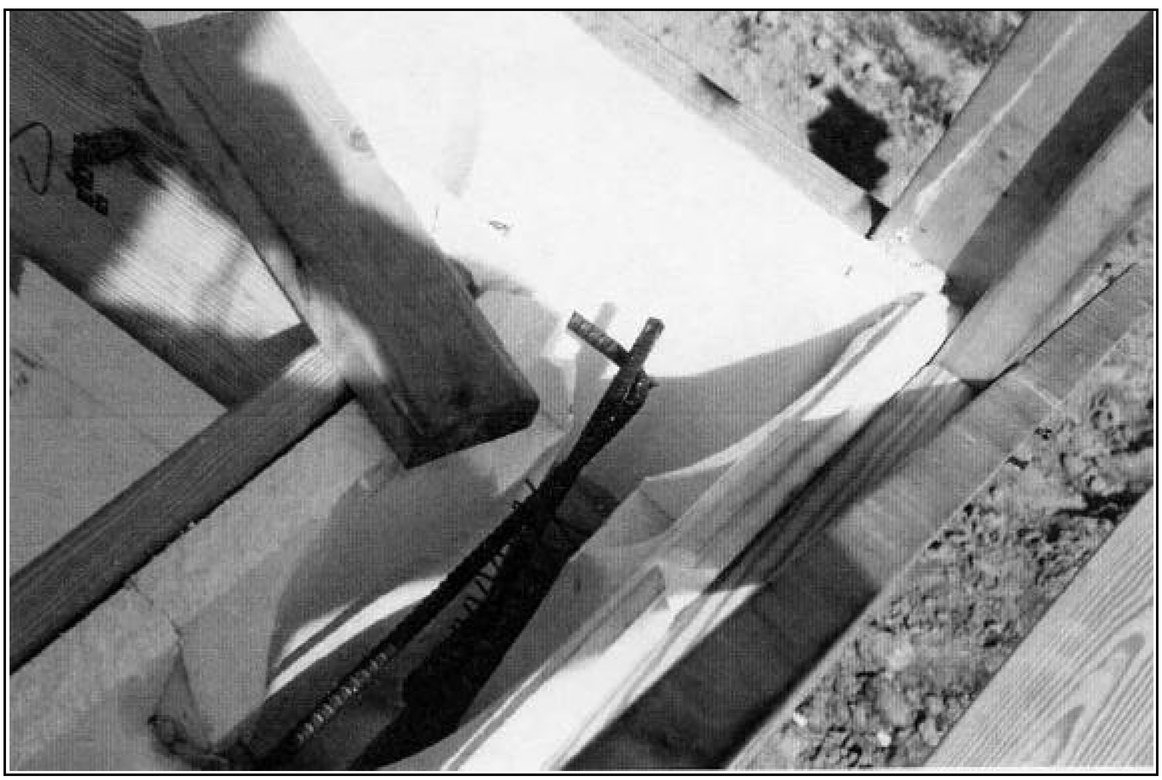


Photo 3: Site #1 - Rebar at Corner

Photo 4 shows the corner detail at the first course of Polysteel. The builder uses the Polysteel pre-formed corner forms for improved construction efficiency. Although corners can be cut on site if desired, it is faster to use the pre-formed corners. The vertical joints of the blocks are staggered. Wood 2 x 4 studs are used to temporarily brace the corner. Two 2 x 4s are used at the exterior corner dimension line and fastened to the bottom of the wall. Some corner braces are braced with diagonal 2 x 4s. Others have a horizontal brace from the exterior corner brace to the window frame bracing. Two 2 x 4 vertical braces are in the interior corners. They are tied to the exterior brace every other course. Wood strips are used to align the course along the wall length. The builder plans to switch to metal angle to align the first course in the future as it does not warp and can be reused more often than wood. Either wood or metal alignment methods with this system are temporary and are removed after the wall is poured.

Photo 4: Site #1 - Corner Detail

Photo 5 shows the rest of the temporary corner bracing running the height of the wall. The 2 x 4 studs in the corners tie into the horizontal bracing at the top of the forms. The Polysteel forms are staggered so that there is not a continuous vertical seam. The metal furring strips line up for easier placement of interior and exterior finishes.

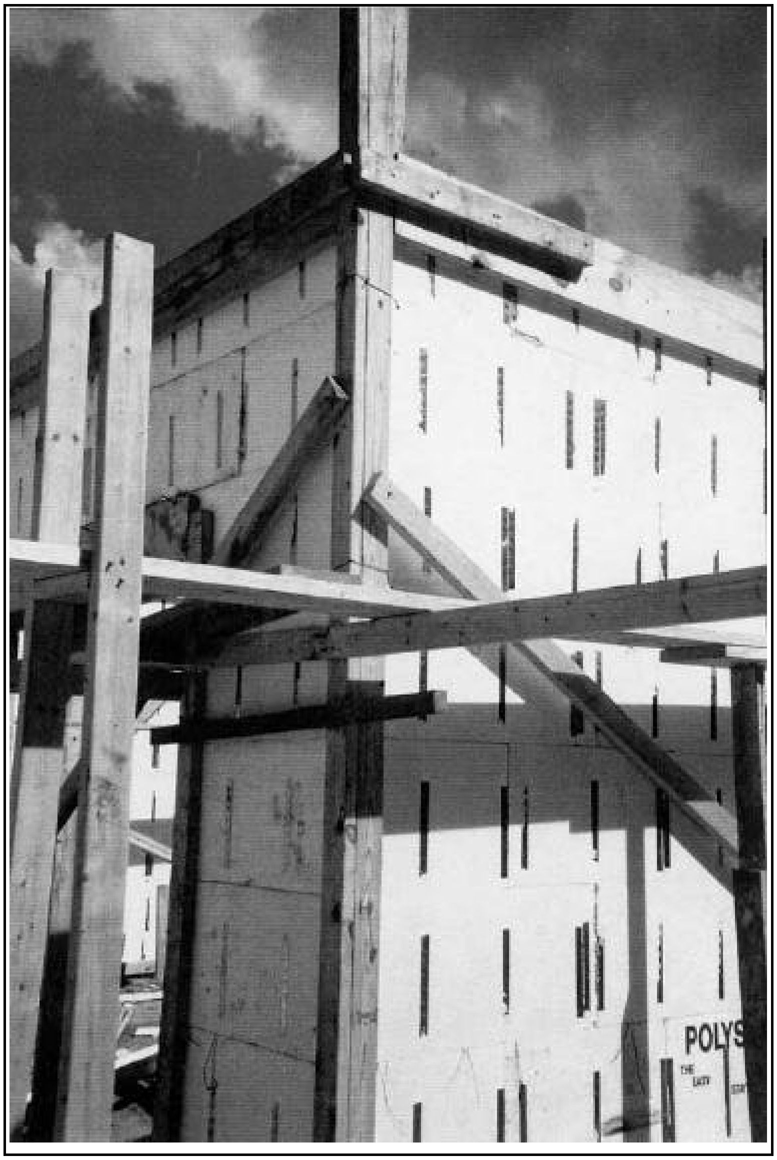


Photo 5: Site #1 - Corner Detail

Photo 6 shows the temporary bracing along the length of the wall. The wall courses have vertical seams staggered. The horizontal seams are glued. Vertical joints are not glued so that the walls can be straightened. 2 x 10s are attached to the tops of the walls approximately 4" - 6"to brace, straighten and level the wall. 2 x 4s are used for intermediate wall bracing.

The window frame is flanged to maintain proper placement in the wall. The frame has horizontal, vertical and diagonal bracing to keep the opening square until the concrete is poured. Window frames are pressure treated 2 x 10s constructed on-site and inserted as courses are placed. Twenty penny nails are nailed into the window frames to bond to the poured concrete. 2 x 4s are attached to the interior and exterior of window openings to hold window frames in place and prevent blowouts.

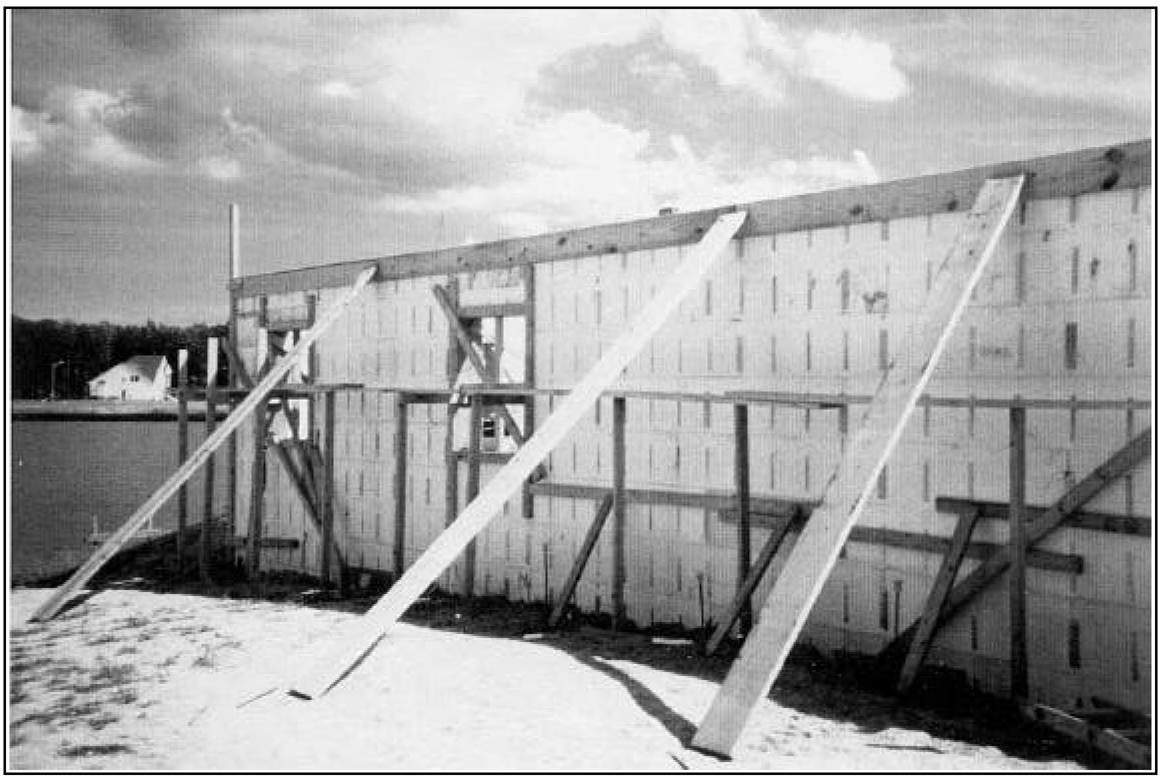


Photo 6: Site #1 - Wall Bracing

Photo 7 shows the floor joist ledger attachment. The open web floor joists sit in metal joist hangers attached to wood ledgers. Electrical cables are run through the joists, near the header and out of the way. This photo was taken at a different Dominion Building Group site, at the construction of a two-story house.

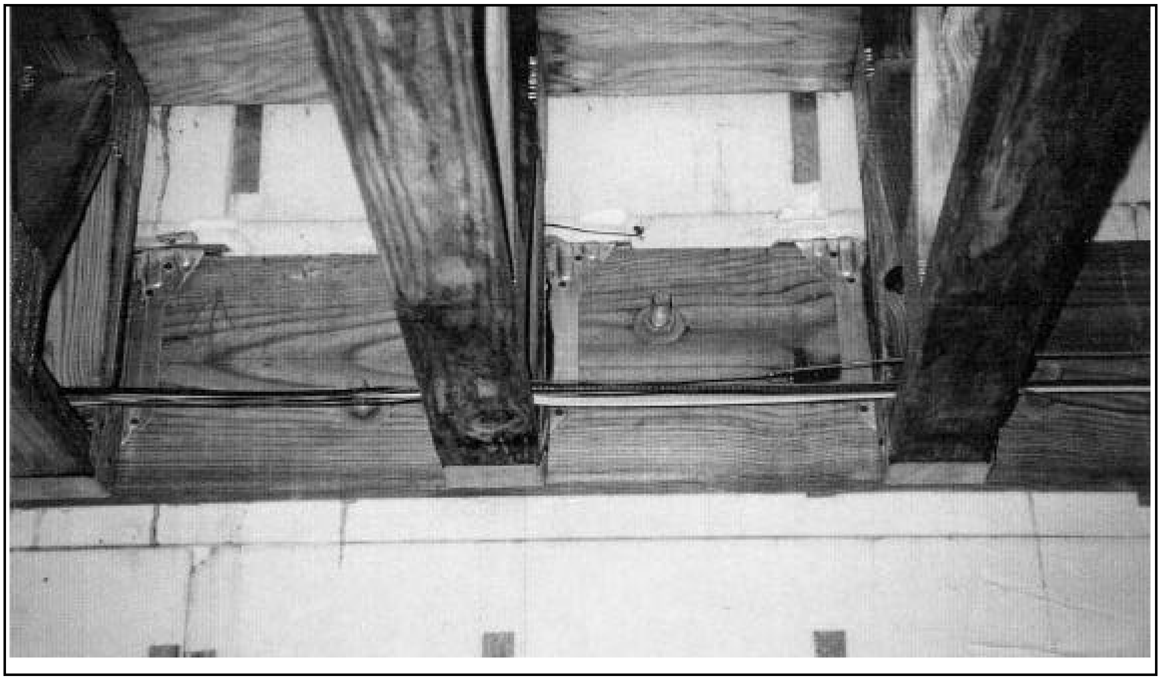


Photo 7: Dominion Building Group Site - Floor Joist Header

Photos 8 and 9 show two different methods for placing curved windows in the forms. Photo 8 is in the demonstration home. The curved window is boxed in with wood framing. This keeps all of the Polysteel forms rectangular in shape. The window in Photo 9 has Polysteel forms cut to the curved window frame. Sealant is used to secure the forms. Note also in Photo 8 that the doors open to the exterior and are mounted toward the exterior side of the wall. This allows clearance for the door/window opening.

Photo 8: Site #1 - Curved Window Detail

Photo 9: Dominion Building Group Site -
Curved Window Detail - Cut Forms

Dominion Building Group, uses utility sleeving for penetrations greater than 1 1/2" before the pour. For this home, the plumber inserted a 4" PVC sewer sleeve before the pour. The electrician "hammer-drilled" through the concrete after the pour for his service line. The builder prefers that the trades drill through the 2? concrete web after the pour because it saves coordination time. The trades tend to prefer to drill after the fact so that they do not have to come to the site both before and after the pour.

Photos 10 and 11 show kitchen cabinetry details. These details are from the same house as Photo 9. Electrical wiring is run first. Plywood is used to attach the cabinetry. The plywood is screwed into the furring strips. Note the conduit under the plywood was marked with red paint. The electric boxes are sealed with tape. Drywall is placed after the plywood and butts to the plywood (Photo 10). The 1/2" plywood and 1/2" drywall are flush. The electric receptacle covers are flush against the drywall when completed.

Photo 10: Dominion Building Group Site -
Kitchen Cabinetry Rough-In

Photo 11: Dominion Building Group Site -
Kitchen Cabinet Placement

At the time of this report, the builder has completed several Polysteel homes and continues to build with the forms. Recommendations he makes include:

- **?** Use metal angles for bracing as they can be reused more often than wood.
- **?** Controlling the rate of concrete pour is very important. He has switched to a flex hose for his concrete pumping operation. For the demonstration home, he used a rigid supply pipe with a 5" to 3" reducer that was prone to clogging during the pour.
- ? Construction time can be saved by using Polysteel corners and saddles.
- ? Straighten forms at the last minute, just before concrete is poured.

Cost Summary

The typical wood-framed construction model was developed from information provided by a leading building material supplier who is an active member in the Tidewater Builder's Association. The Table 5 summarizes typical conditions found in custom home construction:

Layer	Virginia Beach, VA
Internal vapor barrier	4 mill polyethylene
Framing	2 x 4, 16@ o.c.
Cavity insulation	R13
Exterior sheathing	7/16@ OSB
Exterior insulation	none
Exterior air barrier	yes

Table 5: Typical Conditions

Engineering judgment was applied to the Virginia Beach header design to adjust for higher design wind conditions associated with a coastal location. Specific ICF cost information was not available for the Virginia Beach site. The home was built for the local builders association home show and used donated or discounted materials. The builder supplied cost information on a comparable custom home. The comparable home is larger so all quantities are scaled to the ratio of ICF blocks for the homes.

ICF Wall Construction Costs	
ICF material	$7,084
Concrete	$3,766
Misc. materials	$1,228
Installation	$5,837
Total	$17,916
Wood-framed Wall Construction	
Framing Cost	
Material	$1,999
Installation	$2,319
Total	$4,318
Energy Features Cost	
Material	$1,048
Installation	$372
Total	$1,421
Total Wall Cost	
Material	$3,048
Installation	$2,691
Total	$5,739

Table 6: Site #1 - ICF and Wood-Framed Wall Construction Costs

Based on the cost analysis the builder is paying a substantial premium for ICF wall construction compared to conventional practice for the area. Table 7 provides cost information normalized to overall wall and floor area.

	Installed Cost per Floor Area (sf)	Installed Cost per Wall Area (sf)
ICF Construction	$6.46	$6.65
Wood-framed Construction	$2.08	$2.14

Table 7: Site #1 - Normalized Wall Costs

This home was marketed and sold based on its exemplary design features, its waterfront location, and its many features, including the Polysteel wall system. Participation in the builder's local home show provided a large amount of publicity and exposure for the builder and the home. Clearly minimizing the costs of the exterior wall system was not a high priority of the builder. Even factoring in the wall system cost premium, there was only a 4.7% impact on the sales price of the home.

Builder Comments

The home was constructed by Mr. Reid Pocock, P.E. of The Dominion Building Group. Mr. Pocock is both a builder and American Polysteel Form Distributor.

This builder previously built three other homes (two custom), along with a small commercial structure, and a basement. It took him two houses to overcome "the learning curve" for ICF, although he has experienced continual learning and refinement since then. His subcontractors had to adjust their practice in varying degrees to accommodate ICF construction, although reportedly only the vinyl siding installer slightly increased his cost. The demonstration home did not use any vinyl siding, an EIFS exterior finish was used for this home only, consequently there were not any price increases associated with the subcontractors.

The following lists the changes in decreasing impact on the subcontractors work the trades had to make.

? *Plumber* - The 2" vent and drain lines on external walls required chipping away excess concrete since no furring was used for the interior finish material. Although preplanning, makes it possible to allow a "space" or a "recess" for such an exterior wall vertical plumbing vent and eliminate the need for expensive concrete chipping, the plumber chooses this method since it eliminates an extra site visit.

? *Siding Contractor* - There were no problems with the EIFS finish on this home, however most of his homes use vinyl siding and the installers need screws instead of nails.

? *Drywall Contractor* - They had to use screws in place of nails to secure the gypsum wallboard. The drywall installers need to be aware to notify the builder of any of wall bulges prior to installing the wallboard. Bulges can be quickly remedied by shaving or rasping the interior surface of the foam insulation to provide a flat surface for the board to set against.

? *Framer* - Their only problem occurred when connecting the interior walls to the ICF wall. They had to devise an attachment method to secure the wood studs to the ICF walls. Several ICF manufacturers provide suggested methods for securely fastening interior walls to the exterior ICF wall. Careful attention to the future locations of interior frame wall connections during the placement of the ICF system can eliminate any lost time or extra cost later during the interior wall construction process.

? *Electrician* - A hot-knife was used to create a "foam trench" in which to install the wiring and electrical boxes. Otherwise the electricians experienced no changes in tools required. Boxes and straps are secured to the concrete with screws.

? *Mechanical Contractor* - No problems were encountered in the field. The only problem involved correct sizing of the HVAC equipment for ICF construction.

The builder reported no cost impact with code acceptance, permit fees, builder warranty, and customer service. There was a slight increase for the engineering of the house. The builder is a structural engineer and normally does his own engineering but he had an outside structural engineer involved with this particular home. He estimates ICF construction adds two to four weeks to the construction schedule, because of all of the form work such as shipping, setting and bracing before the concrete pour. He finds the trade-off well worth it for this kind of construction.

For this builder, the increased cost of ICF construction versus wood-framed construction has no effect on his decision to use the product. ICF is less expensive than concrete masonry construction if the same finish and insulation materials are used. The "non-existent labor pool increases cost", but this difference should decrease as more installers understand the system, allowing for price competition. He subcontracted out his first ICF home and found there was considerable material waste and he had little control over the crew. Since that first ICF home, he has installed the ICF with his own employees, resulting in less material waste (currently estimated by the builder at 4%) and 20% lower labor costs. The amount of waste block appears to be a direct function of the installer's knowledge of ICF construction.

The builder specifically mentioned that his houses are seen by his customers as being "quite different" because of the ICF, and that is the biggest reason for his success. He reports his customers purchase his homes because of their increased energy efficiency strength and durability. The builder feels that ICF construction combines strength and energy efficiency in a new home system that his customers can appreciate.

Homeowner Comments

The homeowners are a retired couple who have lived in twenty different homes and have owned four previously. They viewed the home while under construction and were impressed by its appearance. After visiting with the builder they decided to purchase the home. Selling features they liked included:

? open areas with large windows,
? waterfront lot,
? energy efficiency (a strong selling point); and,
? ICF construction (it was a new concept but impressed them in its technology).

The homeowners continue to like their home and appreciate it more the longer they live in it. They consider their home to be energy efficient and soundly constructed, with ICF construction having a look of "solidness" to it. The wide window sills contribute to this feeling and provide a nice area for decorating. A marketable benefit to the "solidness" is a reduction of outside noise being transmitted inside. This will be an asset when the home is sold due to its close proximity to Oceana Naval Air Station.

The efficiency of the home is measured by the low utility bills and the comfort levels. The homeowners report no drafts in their home. They also appreciate the synthetic stucco exterior finish, which has a nice appearance and provides a contrast to the neighboring homes built with brick facades. The homeowners are pleased with their home and indicated they would buy another ICF home.

Energy Analysis

Infiltration

The Virginia Beach house was built to Virginia Power's Energy Saver Plus standard which required an air seal package to reduce natural infiltration below 0.2 air changes per hour. Electrical penetrations to the attic were foamed, the windows were caulked, and the ducts were sealed with mastic. Table 8 presents the home's tested infiltration data. Winter seasonal infiltration includes October through April; summer seasonal infiltration covers June through September. A heat recovery ventilator was installed to bring the home back to recommended air changes.

Site	Air Changes
ACH50	3.0
Winter ACH	0.150
Summer ACH	0.086
Peak Winter ACH	0.184
Peak Summer ACH	0.115

Table 8: Virginia Beach Tested Infiltration Rates

Infrared Scans

The infrared camera identified thermal shorts for ICF corners, framing top plates, framed knee walls in cathedral areas, and framed tray ceilings. Framing shorts around the windows were nearly invisible and air leakage through the rough opening had been tightly controlled with foam sealant. The steel wall ties were visible through the drywall.

Peak and Annual Energy Consumption Analysis

Peak and seasonal energy use were calculated using REM/DESIGN. The results are presented in Table 9. Figure 8 shows both winter and summer loads in a bar chart format. Figures 9 and 10 present just the component loads in a pie chart format and neglect the internal gains. The above grade (AG) walls lose 6.6 and 1.0 MMBtu/yr and take 17% and 4% of the winter and summer component loads, respectively. The window loads are larger, nearly 34% and 67%. The Virginia Beach house had nearly 17.4% of the floor area in windows. The slab load is small. The ICF walls extended to the footings and increased the slab edge R-value. Finally, the natural infiltration load (based on the above noted tests) is small–a winter air change rate of 0.15 and a summer air change rate of 0.09. When mechanical ventilation is used, however, additional energy will be displaced and electric consumption will increase.

	Peak (Btu/hr)	Season (MMBtu/yr)
Heating	23.5	31.3
Cooling	34.2	24.9

Table 9: Virginia Beach Estimated Seasonal Loads Using ICF Construction

Figure 8: Virginia Beach Estimated Seasonal Loads Using ICF Construction

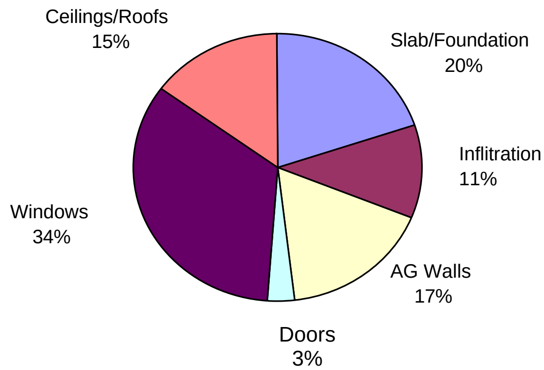


Figure 9: Virginia Beach Estimated Heating Loads (Only)
Using ICF Construction

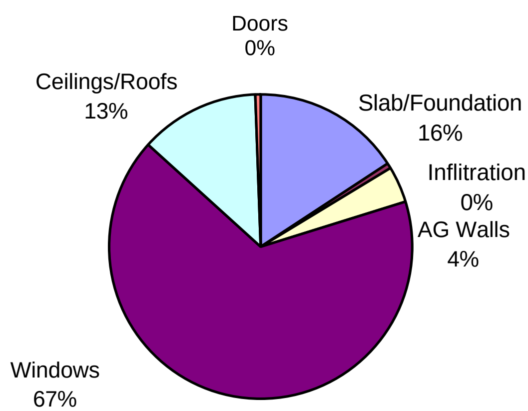


Figure 10: Virginia Beach Estimated Cooling Loads (Only)
Using ICF Construction

Using the same software program and switching to a 2 x 4 wood-framed exterior wall design increases the winter above grade (AG) walls component load from 6.6 million Btu per year to 9.2 million Btu per year (about 50%) and increases the summer AG walls component from 1.0 million Btu per year to 1.5 million Btu per year (also about 50%). For the wood frame comparison, the stud framing is assumed to have plywood sheathing plus 3/4 inches of expanded polystyrene foam. An assumed rate of 0.50 (MEC 1995) for this type of construction would increase winter natural infiltration load from 4.3 to 14.5 million Btu per year. The summer infiltration load would not change appreciably due to this infiltration assumption.

DEMONSTRATION HOME #2 - AUSTIN, TEXAS

This home is constructed by John Weaver Custom Homes. The home is a custom design built on a conventional slab on-grade foundation. The landscaping is central to the house design. The rear elevation is made of glass doors and full length windows to give views of the pool, grounds, gardens, and lake. There are covered patios on three sides of the home. Log beams run from the front to the rear in the upper story of the central part of the house. The floor plan for the home is shown in Figure 11.

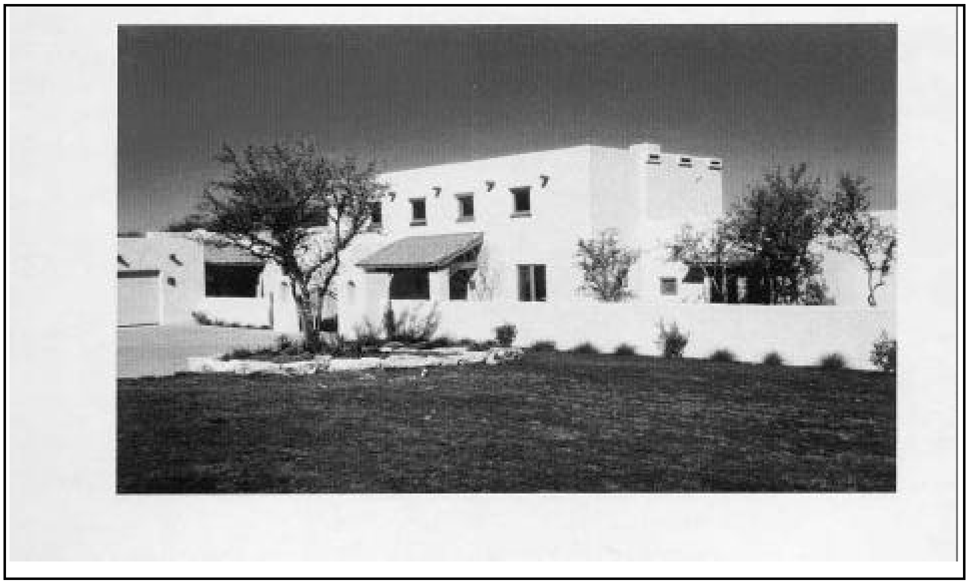


Photo 12: Site #2 - Front Elevation

Photo 13: Site #2 - Rear Elevation

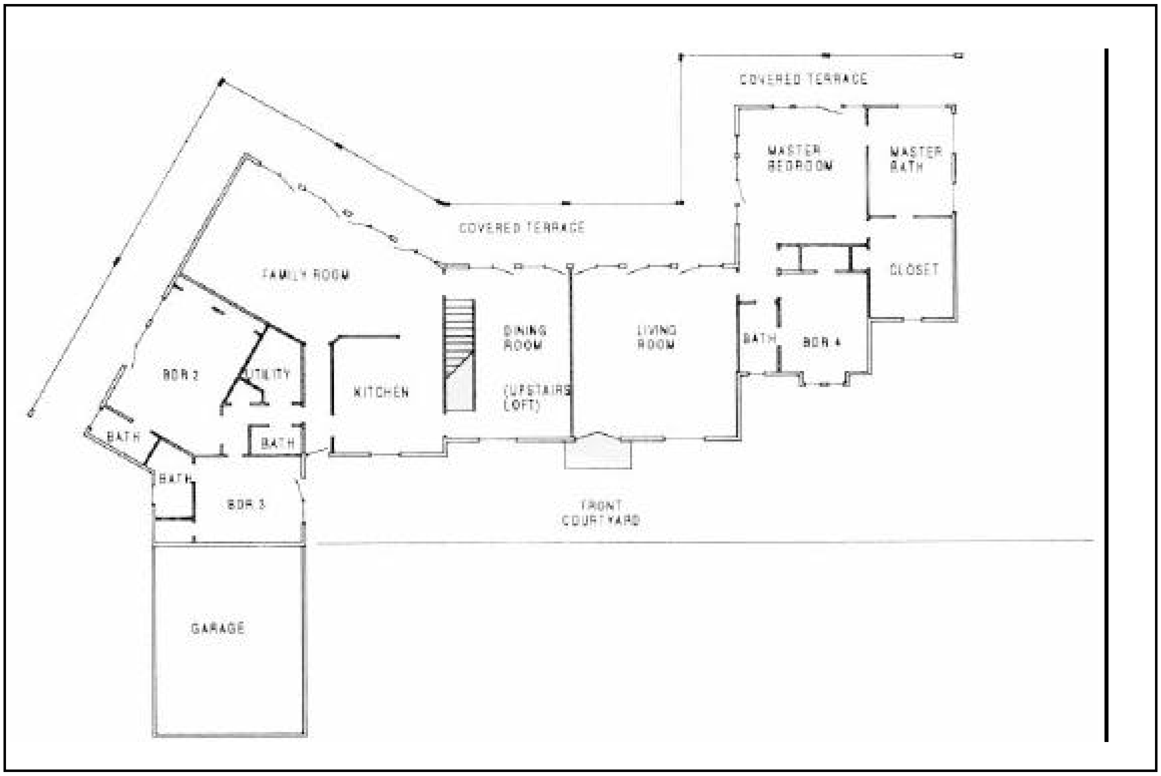


Figure 11: Site #2 - Floor Plan

<u>ICF Product Summary</u>

The house is constructed using the I.C.E. Block™ Forms. The I.C.E. Block™ form has a block shape and an interior cavity that produces a waffle-grid concrete wall. The forms are 48" long and 16" tall. There are two available widths of I.C.E. Block™, one with a 6" core (9 1/4" o.d.) and the other an 8" core (11" o.d.). The web in between the cores is 2 1/4". The vertical cores are spaced 12" o.c. The horizontal cores are spaced 16" o.c. The I.C.E. Block™ forms have 0.0225" galvanized steel webbing 12" o.c. through the thickness of the expanded polystyrene form and are embedded in both sides of the form. These strips are used to attach interior and exterior finishes. The product literature states that the forms have a "text book" R-value of 22+, and goes on to state R-value by thermograph testing to be R-28 to R-32.

The I.C.E. Block™ manual includes design tables, load capacities and calculation methods for structural capacities of walls and lintels. The recommended minimum rebar reinforcement is one #4 bar, 24" o.c. vertically and one #4 bar, 48"o.c. horizontally. Minimum lintel reinforcement for openings less than 4' wide is stated as minimum 8" concrete depth with two #4 bars horizontally with a 3/4" clear concrete cover above and below the opening, together with two #4 bars on each side of the opening. An illustration of the I.C.E. Block™ Form is shown in Figure 12.. The product does have corner blocks to reduce construction time.

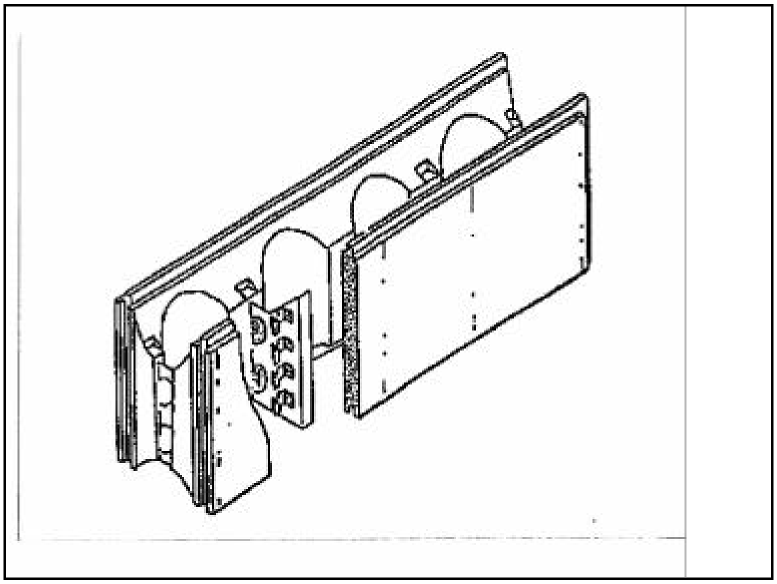


Figure 12: I.C.E. Block **J** Form
(Figured Used With Permission)

Construction Summary

The construction summary is based on staff observations and contractor comments. Mr. Juan Batch, ICF general contractor for the home, provided both technical information and the I.C.E. Block™ used to construct the home.

This house is built with 6" core blocks. The concrete mix has a 5" slump, an aggregate size of 3/8", and compressive strength of 3000 psi. Initially the 2" pump was used, but the small line quickly clogged up. The pump successfully used has a 10' length of 5" flexible hose with two 90 degree angles and a short 5" to 3" reducer. Using this type of pump is one of the lessons learned from experience. The crew can pour 10 yards of concrete in 20 minutes. Based on information from the I.C.E. Block™ distributor, the concrete pour maximum lift is 9'4" (7 courses). The wall cavity is filled almost to the complete 9' - 4" height and flows down and across to prevent concrete voids.

The contractor does not practice wood framing and finds I.C.E. Block™ to be an easy construction method. Assistance from I.C.E. Block™ was available throughout the construction process. Engineering design and SBCCI engineering reports were provided by the manufacturer. The form placing, bracing, and leveling was done per the manufacturers specifications.

The contractor had the benefit of an I.C.E. Block™ technical representative on site to clarify the construction process and prevent errors.

The builder and contractor did not have any issues with the building and fire code officials. The building code officials had previous exposure to I.C.E. Block™ construction. Fire stop was not required. All exposed foam not covered with sheetrock is covered with a stucco system with a one hour fire rating.

Photo 14 shows the rebar placement within the I.C.E. Block™ forms. The horizontal and vertical rebar are tied together. The manufacturer literature refers to A.C.I. code for rebar placement. Minimum rebar placement is #4 - 24" o.c. for vertical rebar and #4 - 48" o.c. for horizontal rebar. For the tall walls (height > 20 ft.) #4 rebar is placed 12" o.c.. The I.C.E. Block™ forms were threaded down over the vertical rebar.

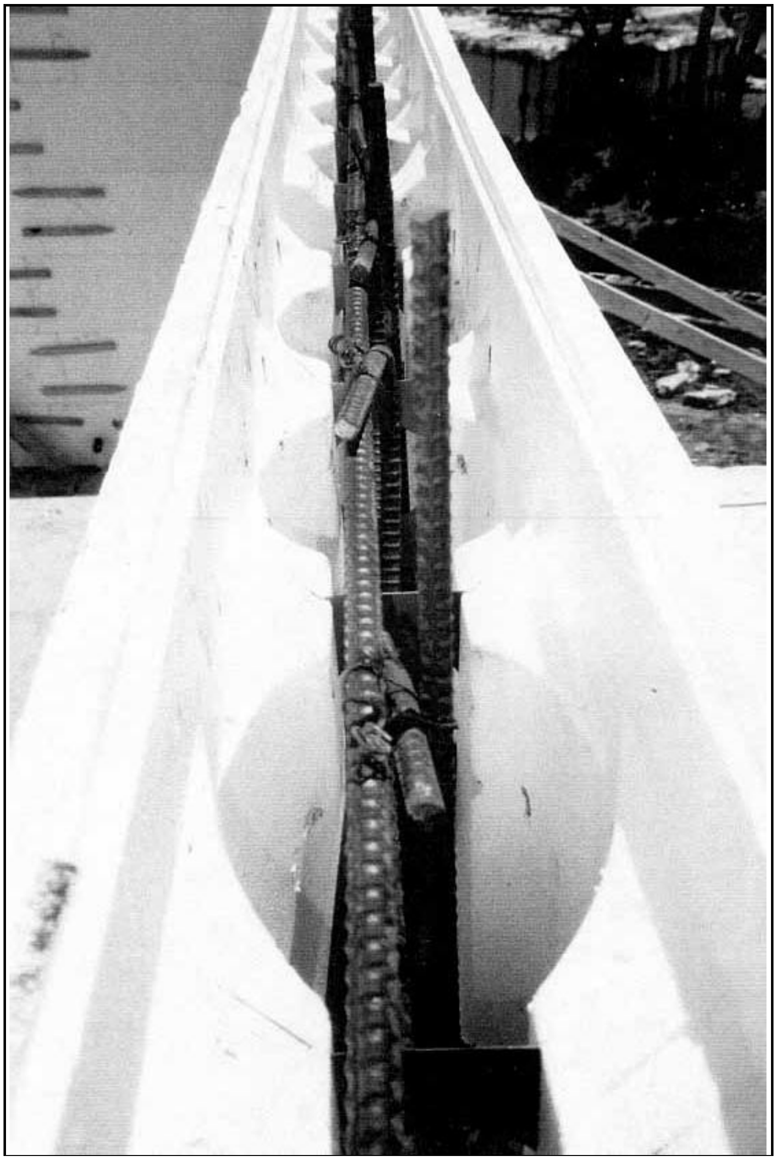


Photo 14: Site #2 - Rebar Within I.C.E. Block J Form

Photo 15 shows the construction of a window jamb and brace. The window openings are framed with pressure-treated 2 x 10 wood framing. The jambs extend the full width of the wall. 1 x 4 wood around the window provide nailing surfaces. The wood strips are used because of the stucco finish, and are not typical. The window framing does not have flanges to aid the stucco application for the exterior finish in this architectural style. Horizontal spreader bars secure the vertical wood frames. Window framing is permanently anchored into the concrete with barn spikes. Doors and windows have two #5 rebars on each side. Horizontal rebar reinforced above the windows and doors was chosen based upon span tables provided by I.C.E. Block™.

The vertical rebar is also visible in this photograph. The rebar is placed and tied into the horizontal rebar as it is placed. The forms are lifted over the rebar when the wall is stacked. The block joints are staggered.

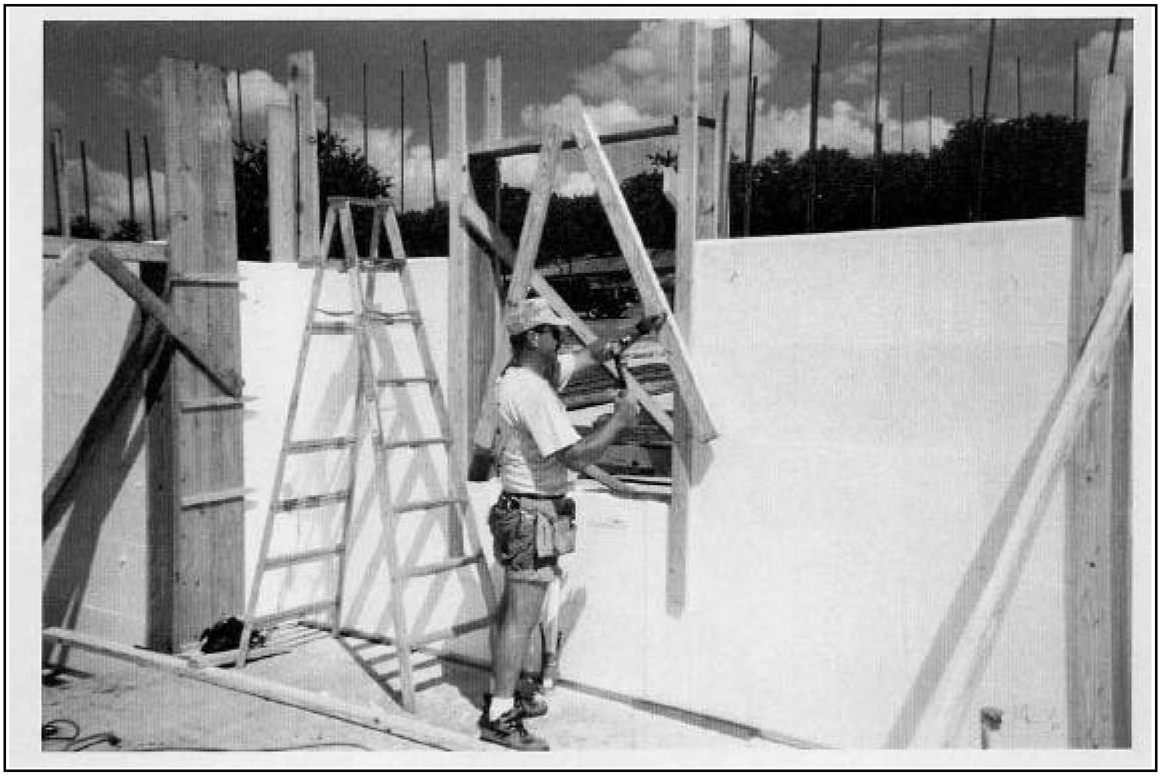


Photo 15: Site #2 - Window Jamb Construction

Photo 16 shows the corner bracing. I.C.E. Block™ corner forms were used. The corners of the structure are braced with 2 x 6s vertically and 2 x 4s diagonally at the corners. A reusable tension bracing system available from I.C.E. Block™ is also used by the contractor. The exterior hose bib penetration is in place and in use. The first course of I.C.E. Blocks™ are stacked on the finished slab and aligned to a metal angle set on the interior side of the block. This metal angel remains permanently in place and secures the interior finish and wood trim later. The door opening bracing is also visible. Note that in this house, the temporary bracing is on the exterior of the wall to allow unhindered access to the wall from the inside.

Photo 16: Site #2 - Corner Detail

Photo 17 shows the support for a wall containing eight large openings (doors and full length windows). The jambs are made from 2 x 10 lumber. Each opening is supported with a temporary 2 x 4 kicker on either side of the narrow I.C.E. Block™ column.

Photo 17: Site #2 - Bracing of Full Length Window and Door Openings

Photo 18 shows many of the construction details. In the forefront, the bracing of the door is shown. The vertical supports are on both sides of the opening. There is diagonal bracing as well, to keep the forms square. The small window and corner bracing are shown. The concrete is being pumped, the two 90-degree bends and the 5" to 3" reducer are visible. There is a crew of four pouring the concrete. Two men are on the scaffolding, pouring and vibrating the concrete. Two men are rolling the scaffolding along the interior as the concrete is poured. The pour starts from the corner and follows the perimeter of the structure. The walls are squared and aligned using a "ladder" of 2 x 4s that set on top of the forms. This keeps the forms from floating during the pour and keeps the forms straight.

Photo 18: Site #2 - Concrete Pour

Photo 19 shows a utility sleeve. The penetration is foam sealed to prevent air infiltration and to firestop this opening. Penetrations should be foam sealed by the time the exterior finish is placed so the exterior finish can be neatly finished to the penetration.

Architectural penetrations also must be sealed. For example, the wall penetrations for the 12 x 12 beams shown in the photographs of the exterior elevations (Photo 12). The beams are set in beam pockets. The depth of the ICF wall was an aid to the crew when they placed the beams.

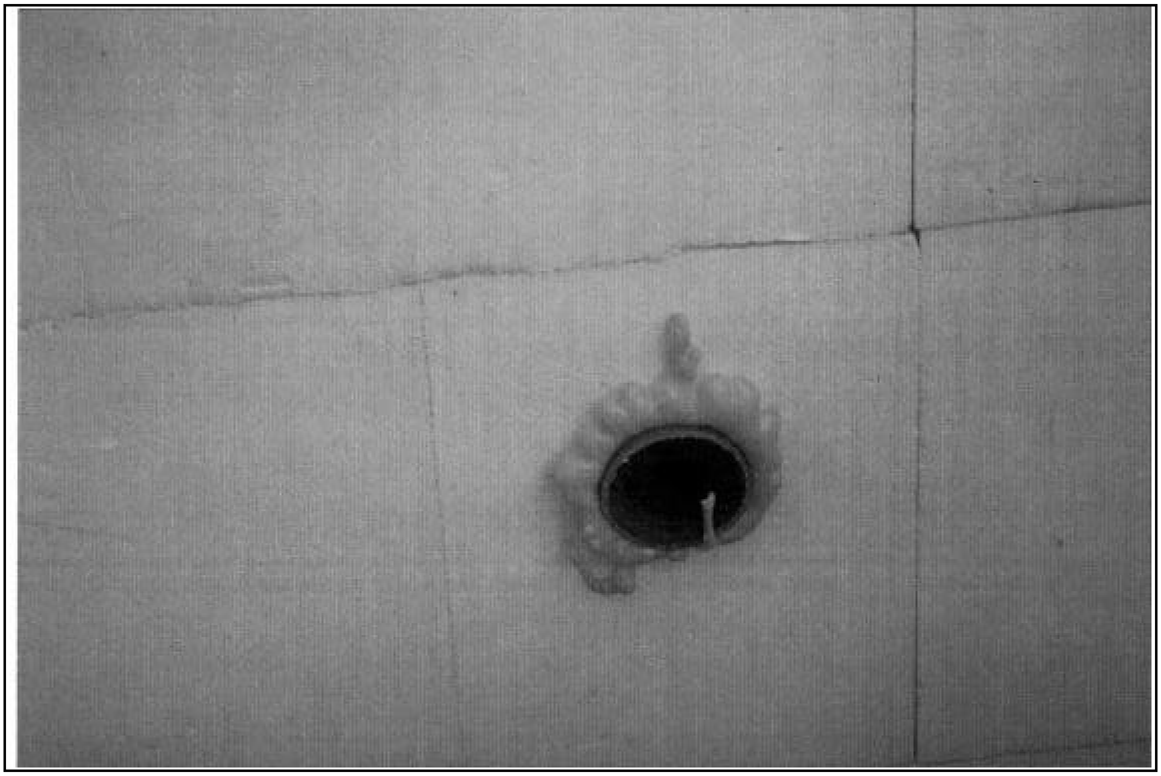


Photo 19: Site #2 - Utility Penetration

Cost Summary

The typical wood-framed construction model was developed from information provided by a leading building material supplier who is on the Board of Directors of the Texas Capitol Area Builder's Association. Table 10 summarizes typical conditions found in custom home construction. It is quite prevalent in custom homes to fully sheath the walls in OSB to meet shear wall requirements and to use a layer of foam insulation for energy efficiency.

Layer	Austin, TX
Internal vapor barrier	none
Framing	2x4, 16@ o.c.
Cavity insulation	R13
Exterior sheathing	7/16@ OSB
Exterior insulation	1/2@ extruded polystyrene
Exterior air barrier	yes

Table 10: Austin, Texas - Typical Wood-Framed Construction

Table 11 compares ICF and wood-framed construction. ICF cost information was obtained from the ICF distributor/installer.

ICF Wall Construction Costs	
ICF material	$12,496
Concrete	$4,288
Misc. materials	$1,638
Installation	$11,900
Total	$30,332
Wood-Framed Wall Construction	
Framing Costs	
Material	$3,688
Installation	$4,294
Total	$7,982
Energy Features Costs	
Material	$2,342
Installation	$1,156
Total	$3,497
Total Wall Costs	
Material	$6,030
Installation	$5,450
Total	$11,479

Table 11: Site #2 - ICF and Wood-Framed Wall Construction Costs

Based on the cost analysis the builder is paying a substantial premium for ICF construction. Table 12 provides cost information normalized to overall wall and floor area.

	Installed Cost per Floor Area (sf)	Installed Cost per Wall Area (sf)
ICF Construction	$7.79	$5.94
Wood-framed Construction	$2.95	$2.25

Table 12: Site #2 - Normalized Wall Costs

This home was constructed as the personal residence of a small volume custom home builder. The use of the ICF wall system delivered the traditional massive wall adobe appearance desired by the builder. The ICF wall system also resulted in a substantially higher steady-state R-value than is typically achieved in the Austin area. While the incremental cost of the ICF system was significant, it only impacted the estimated sales price of this custom home by 5.3%

Builder Comments

This is the second home done in I.C.E. Block™ by the builder John Weaver. He is pleased with the I.C.E. Block™ product, and feels it is the best ICF product in the market. He prefers the finished product of ICF construction to the finished product of wood-frame construction. He plans to continue to build with ICF construction since he feels it is the best house money can buy. Based upon his experience, "done slowly and properly, there isn't a better product…it is not cheap, not easy, and the subs [subcontractors] do not like it…when completed, it's like a fortress around you."

The new housing market is active in Austin, TX and the builder has found that there is a shortage of all the subcontracting trades. Each subcontractor had different concerns when working with this type of construction. For plumbing, it is important to do a thorough plan of the penetrations. Chases and utility sleeves should be in before the pour, as it is difficult to make corrections to a 12" thick wall of concrete. The electrician has the same utility penetration concerns as the plumber. He used a heat gun to cut a channel for the conduit to sit in the foam. The mechanical contractor did not have installation problems because chases were made for the duct work. Sizing the HVAC equipment was also not an issue for this house. The interior wall framing in the house is wood. The framing subcontractor would have preferred to do a whole house instead of part of a structure. He also felt he had the hardest part to do (the roof). There are two types of finish on the interior walls. Some of the walls are sheet rock, others are plaster. Plaster is used in the living room and dining room and has a metal lathe behind it. The remaining walls and ceilings are sheet rock. The sheet rock attachment was difficult because the metal furringstrips shifted as the height of the wall increased. He complained of differences in the strips of as much as 15" off center.

Positive factors that influence the builder to try ICF construction are product differentiation, energy efficiency product durability and lumber quality. He estimates that a custom home, comparable to this one, would cost $6.00 - $7.00/square foot "under the roof" which includes the finished house, garage and porches. The premium for the ICF product (estimated by the builder at 30%) did not deter him from using it. He finds the forms are expensive, and would like to see this addressed by the industry.

There were a few "lessons learned" on this house. On future houses, the builder will consider attaching 2 x 4 strips 30" o.c. to the interior side of the form. This will allow shallow electrical boxes to be attached and speed the drywall installation. As discussed and shown in other sections of this report the thermograph testing shows heat loss at the slab of this house. The utility bills are lower for this house than for others (see *Homeowner Comments* section) however, the builder will consider installing the I.C.E. Block™ forms two feet below the foundation in his next house to isolate the slab. Non-structural changes include the use of more hardwood flooring and less of the mexican floor tile.

Homeowner Comments

This house is the personal residence of the builder and his family. They chose this house because of the lake front location, the energy efficiency of ICF construction, and the architectural design. The homeowners enjoy the home, consider it a good value, and appreciate it the more they live in it.

One of the features the homeowners appreciate the most is the solid construction of their home. They are confident that this house can withstand the extreme winds that affect the lake area. The owner shared a story about a thunderstorm that came through, destroyed 100-year-old oak trees and left their house untouched.

Other features of the home that they appreciate include lack of sound transmission, lower utility bills, and the architectural details. Outside noises do not come through. They cannot hear the engines of the boats on the lake. They also find interior sounds are lessened in between rooms. The thermal insulation and energy efficiency is greater than previously owned homes. In this house, a winter heating bill is approximately $175/month. In previous homes, the heating bill was approximately $350/400 month. The ICF structure complements the southwest architectural style. The owner feels that this type of construction is ideal for a stucco finish. This home is finished with conventional stucco. The finish has been stylized with rounded corners and free-flowing curves.

For the owner, features that increase the re-sale value of the home include sound reduction, environmental comfort and utility costs. The owner would purchase another I.C.E. Block™ home.

Energy Analysis

Infiltration

The Austin house utilized a flat, vented roof and decorative, hand-hewn timbers. The timbers were attached directly to the ceiling trusses, and the drywall was butted to the timbers. The builder endeavored to reduce leakage with caulk and canned polyurethane foam but could not reduce the impact of this construction detail. The builder/home owner also indicated that noticable drafts were present during the winter as air passed through the roof vents and around the beams. Table 13 presents the home? s tested infiltration data. Winter seasonal infiltration includes November through March; summer seasonal infiltration covers May through September.

Site	Air Changes
ACH50	12.94
Winter ACH Summer ACH	0.555 0.417
Peak Winter ACH Peak Summer ACH	0.732 0.547

Table 13: Austin, Texas - Tested Infiltration Rates

Infrared Scans

As shown in the infrared scans, several architectural details in the Austin home impacted its energy performance. The most significant of these details was the installation of hand-hewn timbers. In all but one room, the non-structural timbers were fastened to the underside of the trusses, and the drywall was butted to the beams. The rough shape of the timbers prevented a tight air seal against the drywall, as confirmed by blower door data and infrared images (Photos 20 and 21).

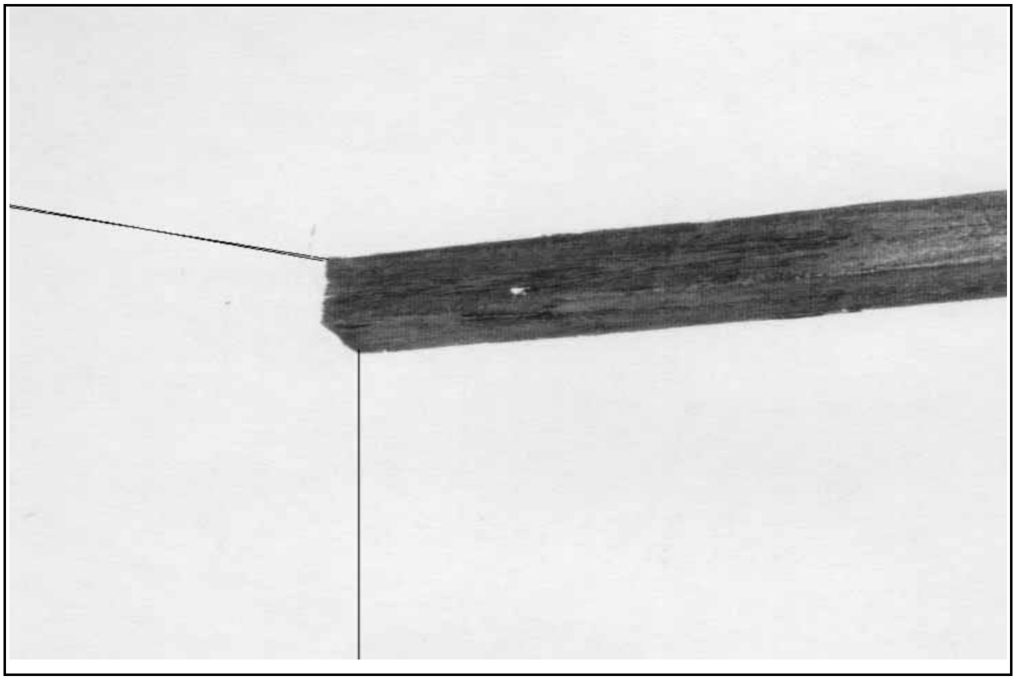


Photo 20: Site #2 - Rough-Hewn Timber Against Drywall

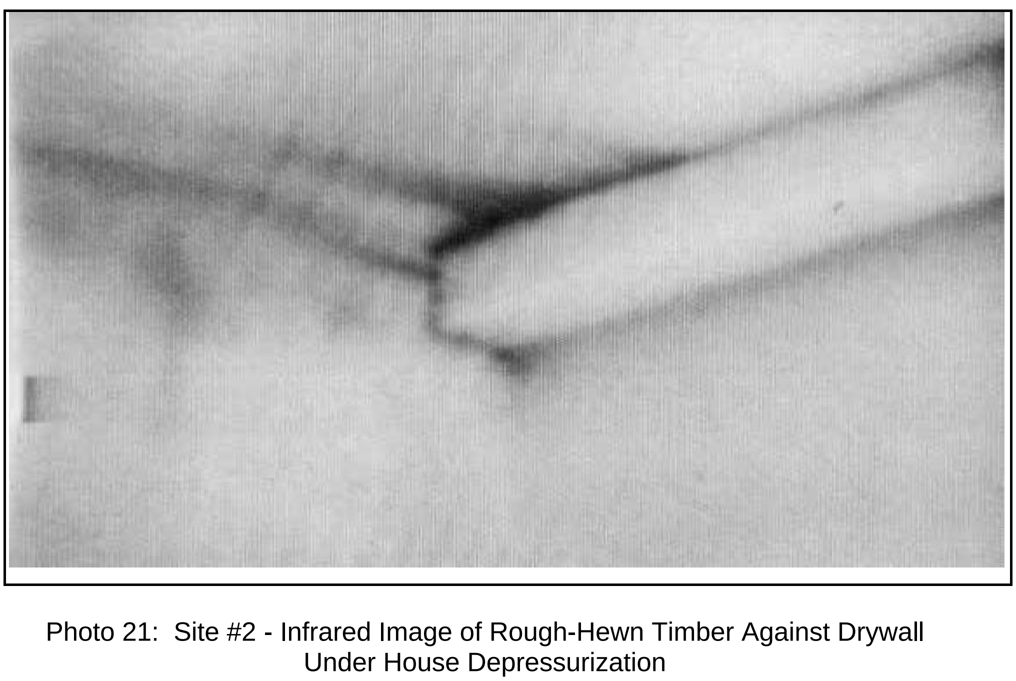


Photo 21: Site #2 - Infrared Image of Rough-Hewn Timber Against Drywall
Under House Depressurization

The timbers also passed through the outer shell of the home as beams and window sills. The reduced R-value and air leakage amplify these penetrations (Photos 22 and 23). The ICF wall in the back-drop has no visible thermal shorts and even has the same infrared spectrum as the parapet wall above the timbers. This parapet wall is built with conventional concrete blocks.

Photo 22: Site #2 - Timber Window Sills

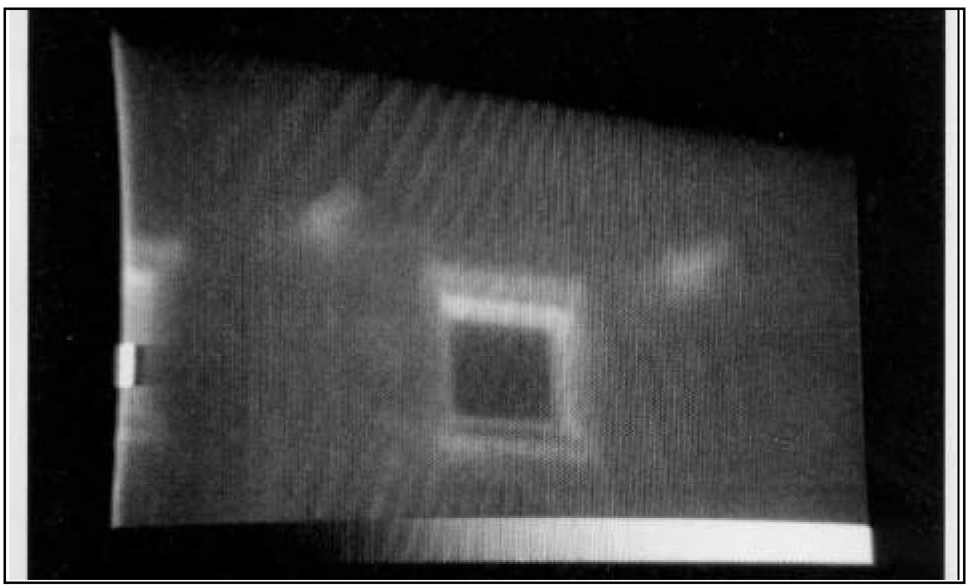


Photo 23: Site #2 - Infrared Image of Timber Window Sills From Outside Under Natural Conditions

Another detail that reduced building performance is that the house foundation slab and patios were poured as a continuous slab. As noted in the *Typical Construction Practices* section, this is a foundation treatment that does not allow for slab-edge insulation. This detail is shown in Photos 24 and 25.

Photo 24: Slab Edge From Outside
Under Natural Conditions

Photo 25: Site #2 - Infrared Image of Slab Edge as Viewed From Outside

Peak and Annual Energy Consumption Analysis

Peak and seasonal energy use were calculated using REM/DESIGN. The results are presented in Table 14. Figure 13 shows both winter and summer loads in a bar chart format. Figures 14 and 15 present just the component loads in a pie chart format and neglects the internal gains. As evident in the tables and charts, the ICF walls represent only a small portion of the building load. This is due to the high R-value of the material and the large loads in other parts of the structure. Three loads stand out over the above grade walls. First, the window loads are much larger. The Austin house had nearly 28% of the floor area in windows. Second, the slab load is very large. The home was single story, slab on grade and did not use slab insulation. The ICF walls were placed on top of the slab, which was usually at or above grade. Finally, the natural infiltration load is large–having a winter air change rate of 0.555 and a summer air change rate of 0.417.

	Peak (Btu/hr)	Season (MMBtu/yr)
Heating	55.6	57.2
Cooling	59.8	59.8

Table 14: Austin Seasonal Loads

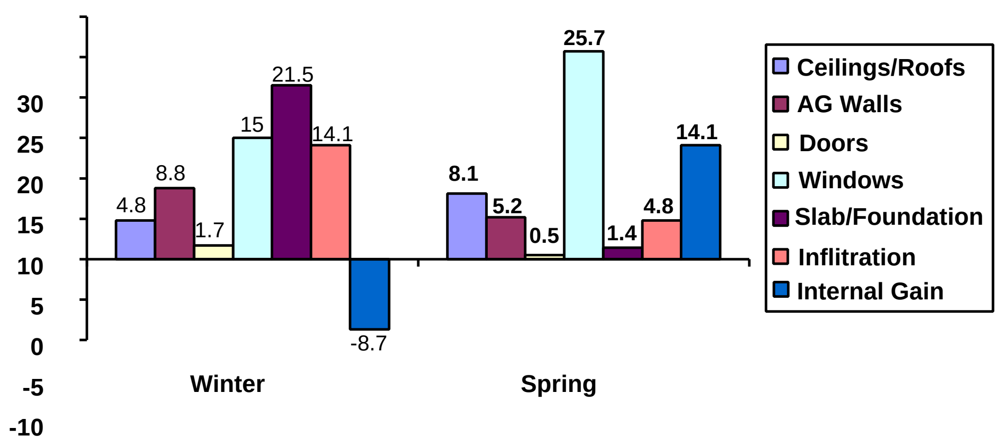


Figure 13: Austin Seasonal Loads

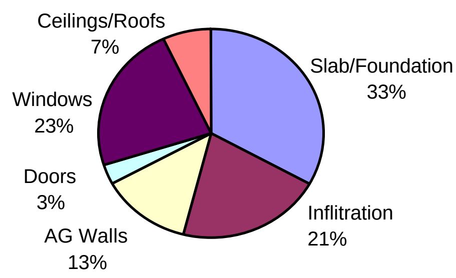


Figure 14: Austin Heating Loads (Only)

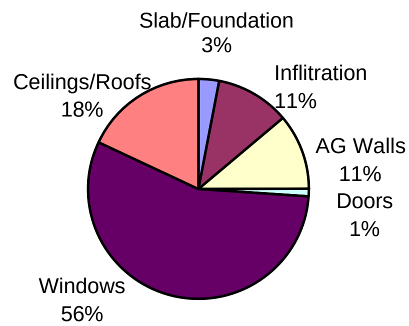


Figure 15: Austin Cooling Loads (Only)

Using the same software program and switching to a 2 x 4 framed exterior wall design increases the winter AG walls component load from 8.8 million Btu per year to 13.4 million Btu per year and increases the summer AG walls component from 5.2 million Btu per year to 7.9 million Btu per year. Installing the decorative timbers is expected to have the same effect on infiltration in stick-framed construction. The stud framing is assumed to have plywood sheathing and 1/2 inches of expanded polystyrene foam.

DEMONSTRATION HOME #3 - SIOUX CITY, IOWA

This home is constructed by Mr. Gary Niles of Gary Niles Homes as a spec house. It is a two-story home with four bedrooms, two and one-half baths built on a Frost Protected Shallow Foundation with basement. The floor plan is shown in Figures 16 and 17.

Photo 26: Site #3 - Front Elevation

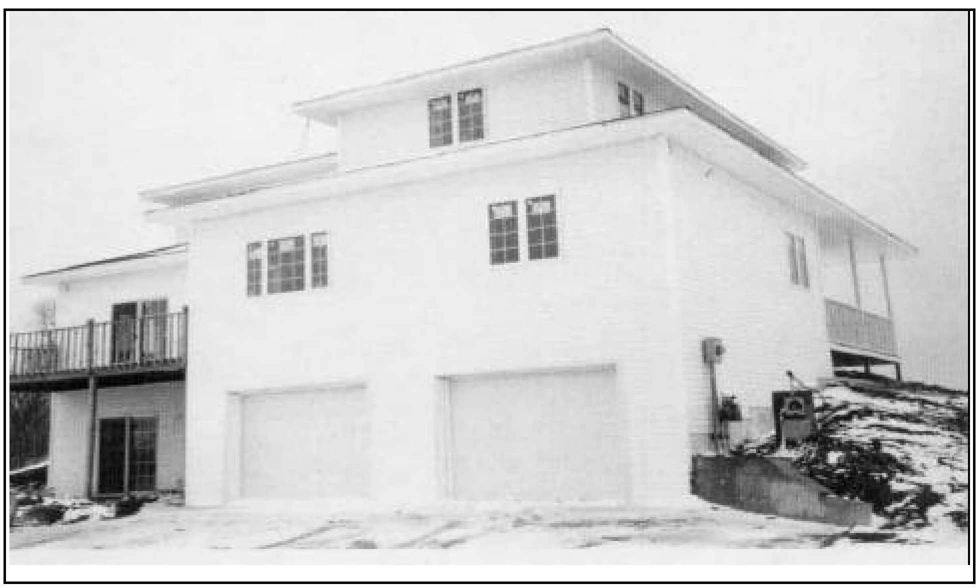


Photo 27: Site #3 - Rear Elevation

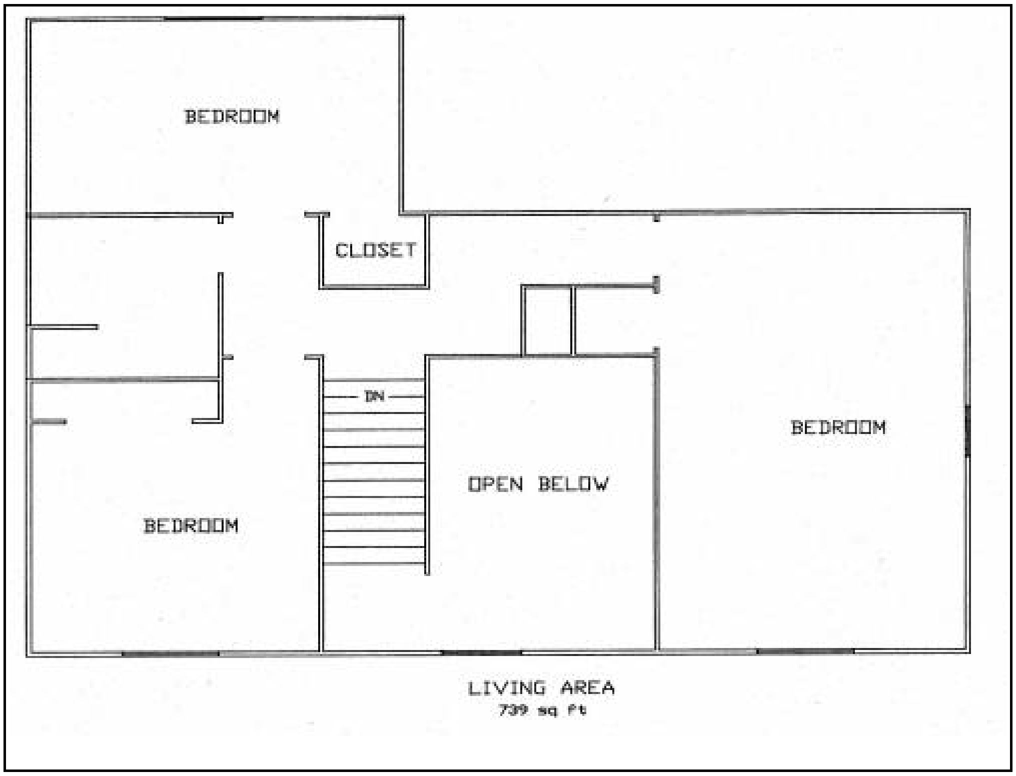


Figure 16: Site #3 - Floor Plan

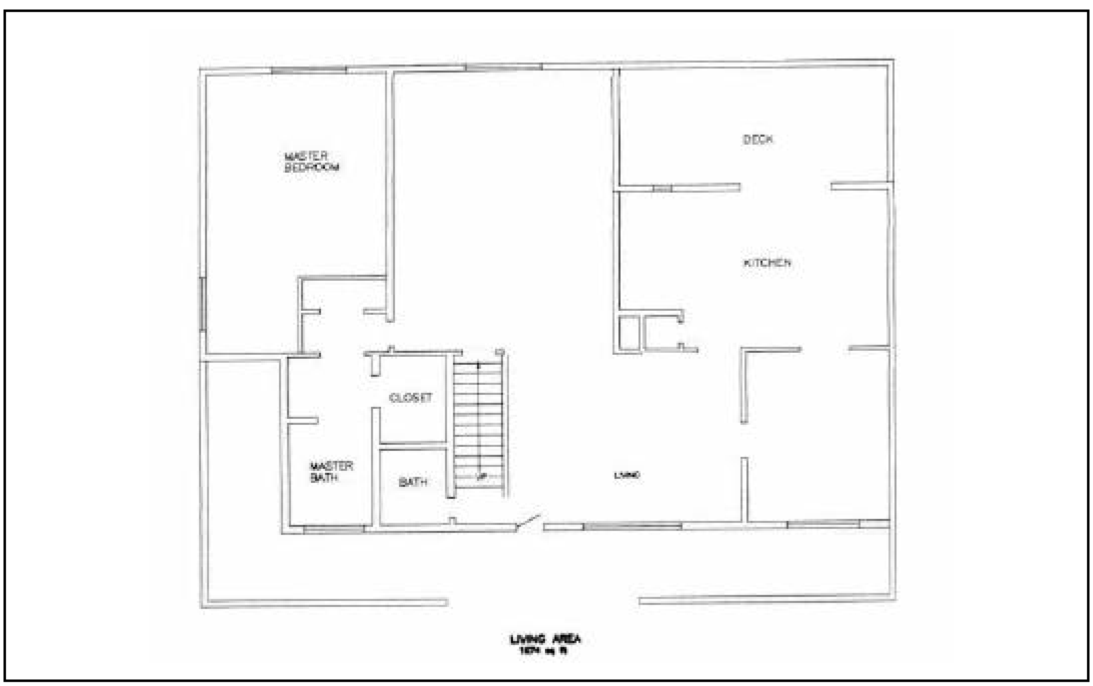


Figure 17: Site #3 - Floor Plan

ICF Product Summary

The house is constructed using the Fold-Form system, which is manufactured by the Lite-Form Company. The Fold-Form *form* shape is a plank. The interior cavity is smooth and produces a flat concrete wall. The forms are 12" x 48" and come in 4", 6", 8", 10", 12", 14", and 16" interior depths. The forms have plastic ties that are slipped into openings in the foam panels. The ties are hinged so that the forms can lay flat during transportation to site. The literature states a calculated R-value of 18.

For support of forms during placement and pour, the product uses corner ties and metal bracing located inside the wall. The product has pre-trimmed corner kits, used with corner ties, which should be placed at each 12" course. The "in wall" bracing system is a welded wire girder placed every 4" vertically and at the top of the wall. The girder is embedded in the concrete. The top girder is the width of the cavity and is used to straighten the form.

The Lite-Form manual shows vertical rebar set into a PVC collar as the suggested method of securing the bottom of the vertical rebar. Openings and walls are temporarily braced with wood. An illustration of the Fold-Form product is shown.

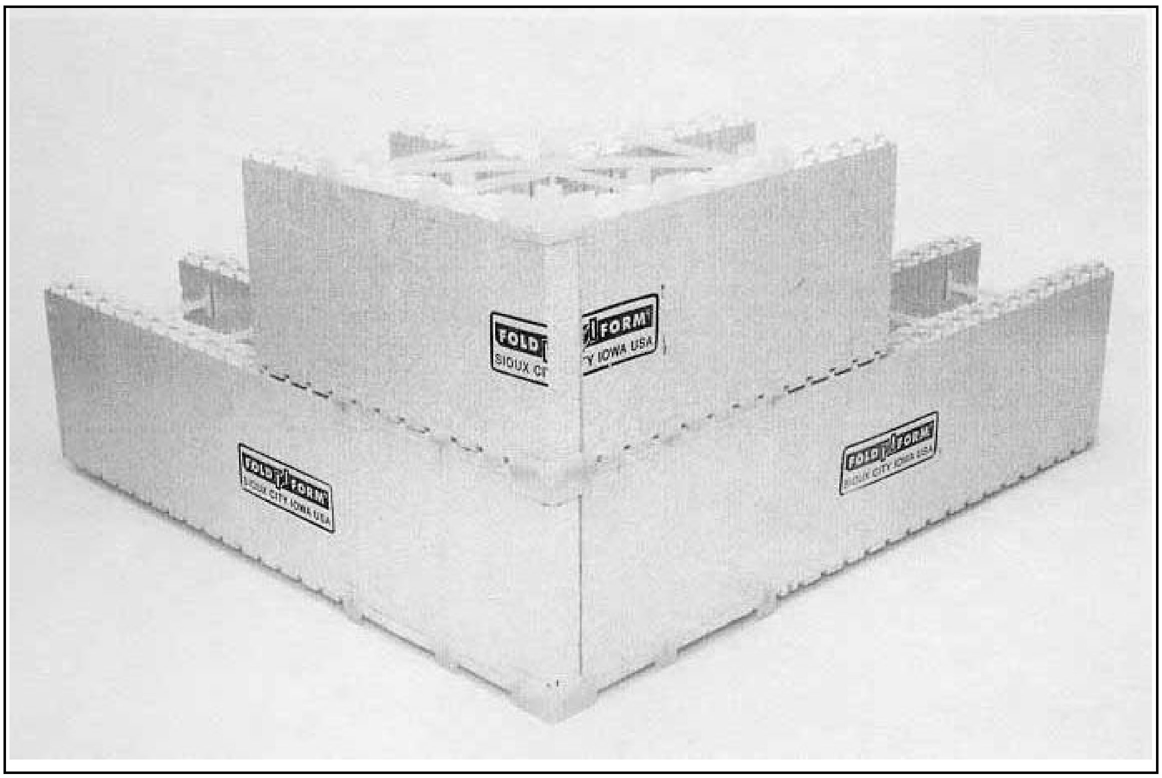


Photo 28: Fold-Form
(Photo Used With Permission)

Construction Summary

The site construction summary is based upon builder survey responses by the builder, Mr. Gary Niles, and staff observations. The photos are of field installation at the demonstration home site.

The concrete mix used had a compressive strength of 3500 psi, a 4 1/**2"** - 5" slump and a 3/8" aggregate size.

Photos 29 and 30 show the proprietary Fold-Form bracing inside the forms. The plastic ties sit in grooves. The steel in-wall bracing (mesh) keeps the forms equidistant. It does not replace structural rebar. There are two widths of the in-wall bracing. The bracing placed at the top of the form is the full width of the form and is used to keep the top of the forms straight, as reported by the manufacturer. The smaller in-wall bracing is placed at a height of 4" within the wall. It is completely embedded in the concrete. Note the corner detail. The two sides of the corners are mated, not one continuous form that turns (L shaped). The manufacturer explained that this design is used so that there are no left-handed or right-handed pieces. Finishes (interior/exterior) are attached with screws to the embedded ties.

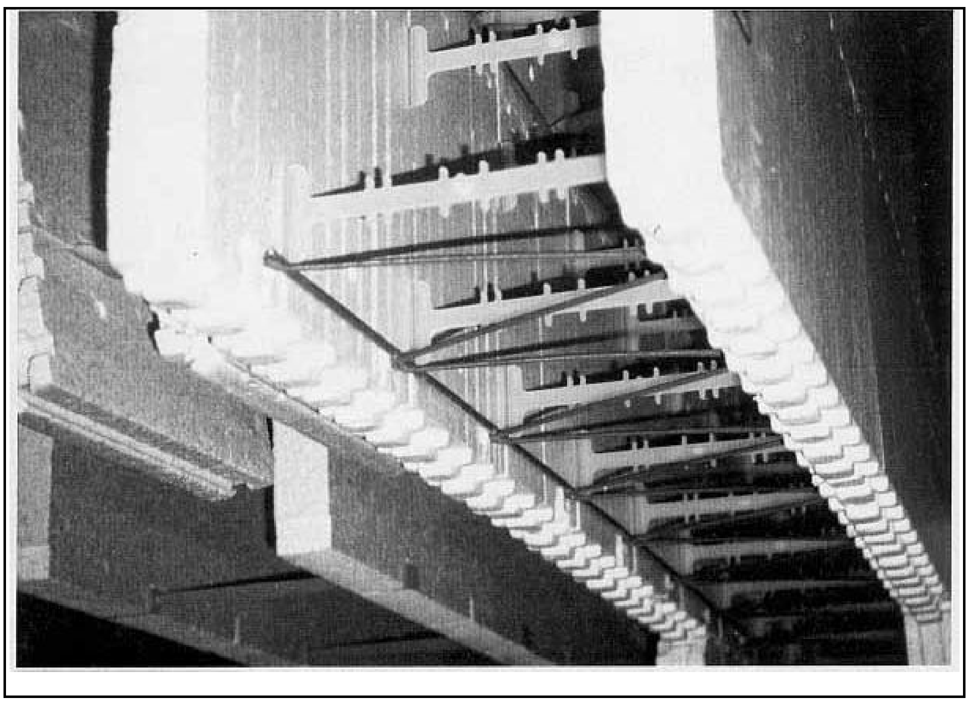


Photo 29: Site #3 - Interior Cavity of Fold-Form
with Proprietary Reinforcing

Photo 30: Site #3 - Corner Detail and Reinforcing

Photo 31 shows the exterior side of the corner. The 2x corner bracing used in other systems is not required when the "in wall" bracing is used and manufacturers instructions are followed. There is a plastic corner tie that is placed in the corner at every course.

Photo 32 shows the stacking of the second story wall forms. The interior framing is already installed, and scaffolding is in place for the concrete pour. The exterior wall in the background is wood-framed since there is no solid bearing below.

This demonstration house has walls of varying thickness. The basement walls are 11" tall and are constructed with 8" cavity Fold-Forms. The first floor walls are 10" tall and are constructed with 4" cavity Fold-Forms. The overall first floor wall thickness is 8", there are 2" of foam on either side of the concrete. The in-wall bracing system is placed at 3", 6" and 10" up the height of the first floor walls. Horizontal rebar is #4 placed at 4", 6" and 8" up the height of the first floor wall, vertical rebar is #4, 48" o.c..

Photo 31: Site #3 - Corner Detail and Plastic Tie

Photo 32: Site #3 - Second Story Wall

The second story walls are both concrete and wood-framed. The concrete is poured using the Lite-Form product with a 2" cavity. Photo 33 shows the partial wood-framed exterior on the second story. The second floor wall set-back condition meant that there was no ICF wall directly under the second floor exterior wall. The use of traditional wood framing is a good economical solution for this condition.

Photo 34 shows the concrete pour into the second story wall. The hose is bent along the length of the top of the form in order to control the flow of concrete. The pour begins in each corner and is poured toward the middle of the wall.

Photo 35 shows the concrete pour into the wall cavity beneath a window. Note that flangeless window frames were used and are recessed into the opening between the front and back foam wall panels. Bracing of the opening is minimal.

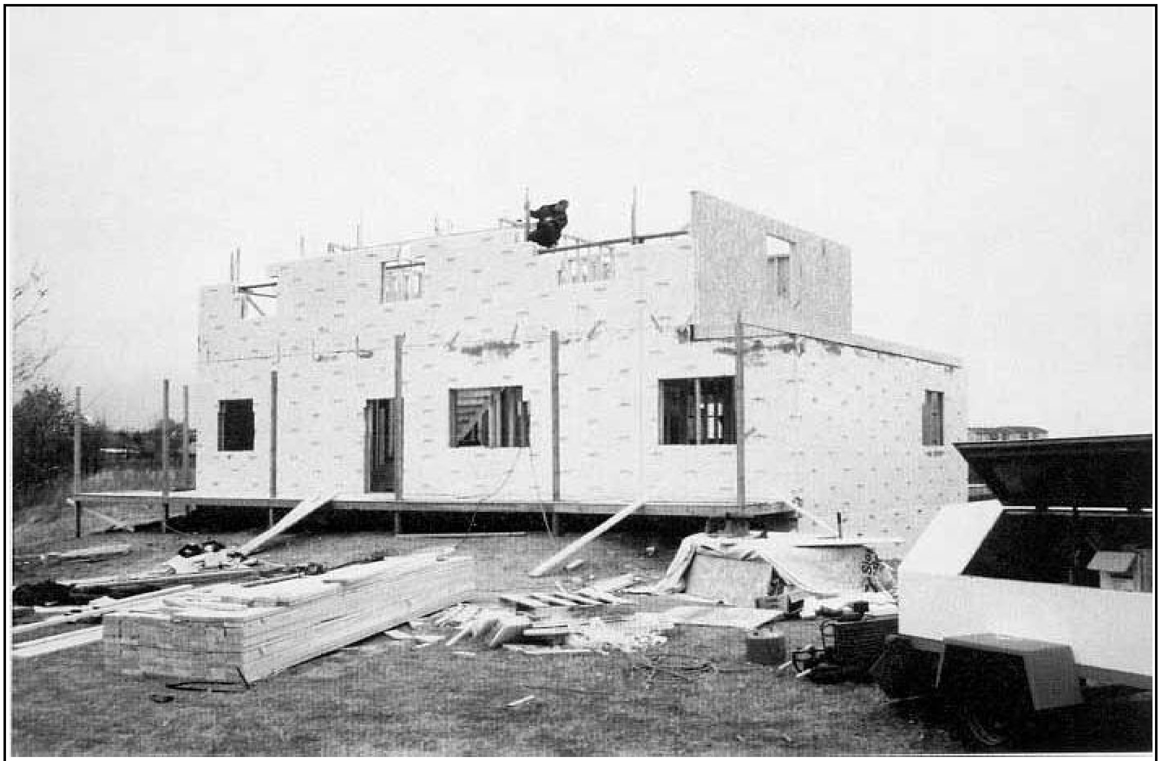


Photo 33: Site #3 - ICF and Wood-Framed Exterior Walls

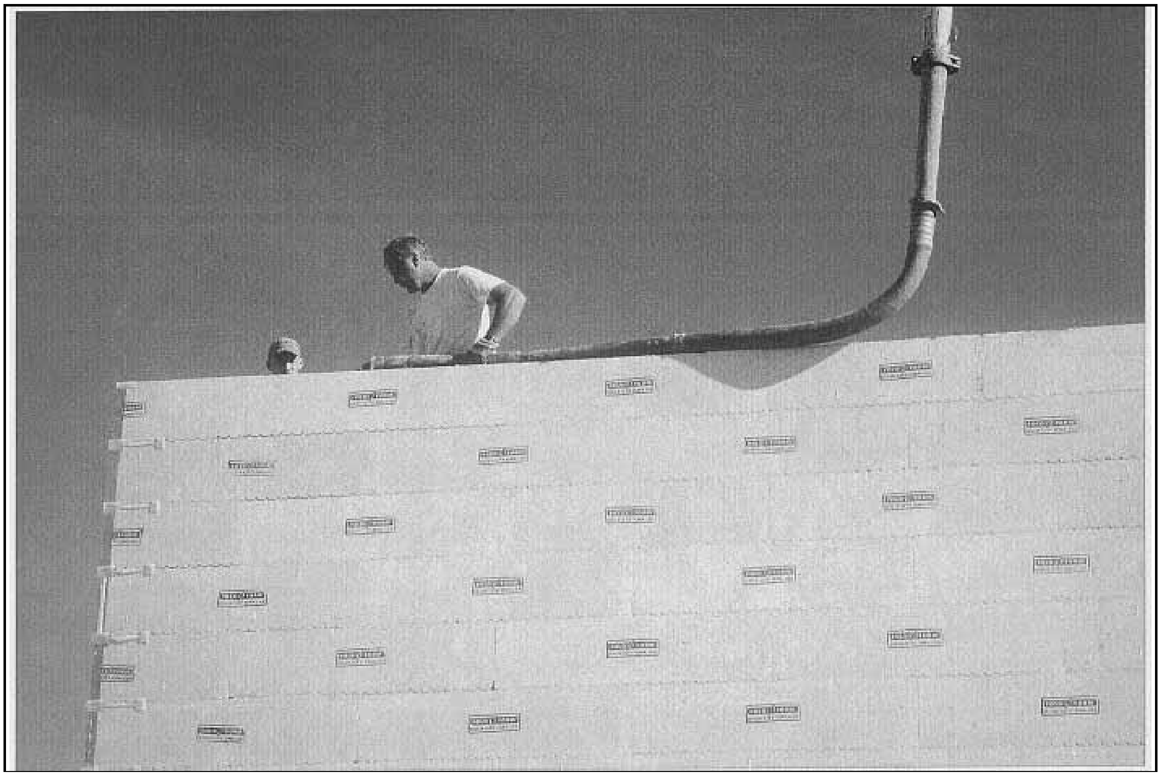


Photo 34: Site #3 - Concrete Pour Second Story

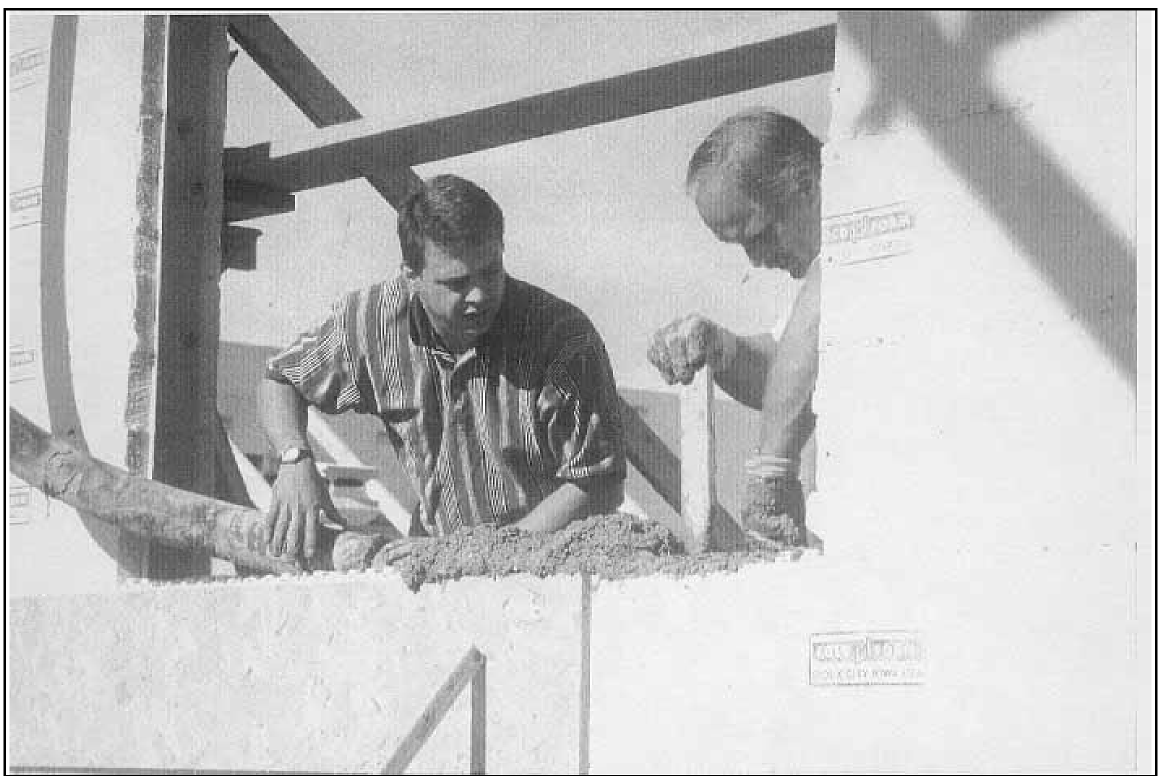


Photo 35: Site #3 - Concrete Pour at Window

Photo 36 shows the results of improper bracing. Form failures can occur from a watery mixture, which creates a high pressure against the form, pouring the concrete too quickly, or a lack of bracing. In this case, it appears to be a lack of bracing, as missing even one of the manufacturers required corner ties can cause a problem. Minor bulges and blowouts occur occasionally and can be remedied during the pour. Note also the grooved tabs broken on the corners of several of the forms. This may have weakened the forms and contributed to the problem. With careful installation of the ICF forms, and with proper bracing, these problems can be minimized.

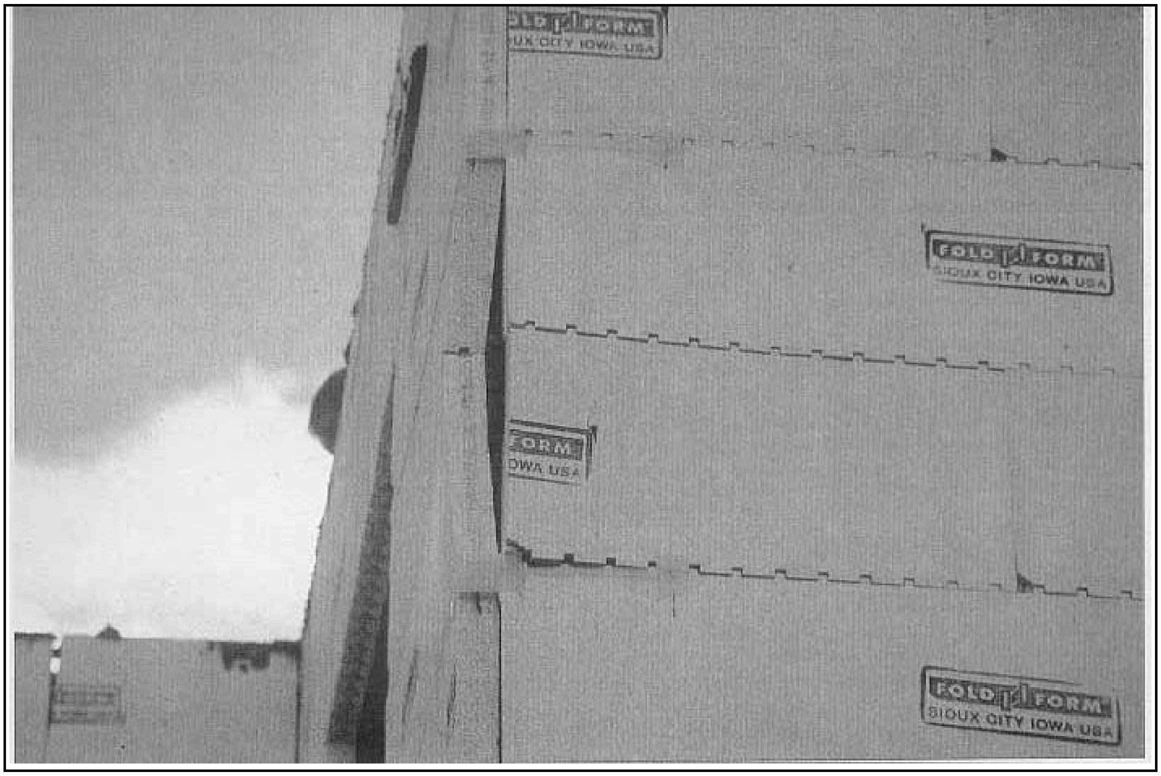


Photo 36: Site #3 - Improper Bracing

Photo 37 shows the joists supporting the first floor. The joists and I-beam are made of engineered wood. The beam supporting the joists is embedded into the ICF basement wall.

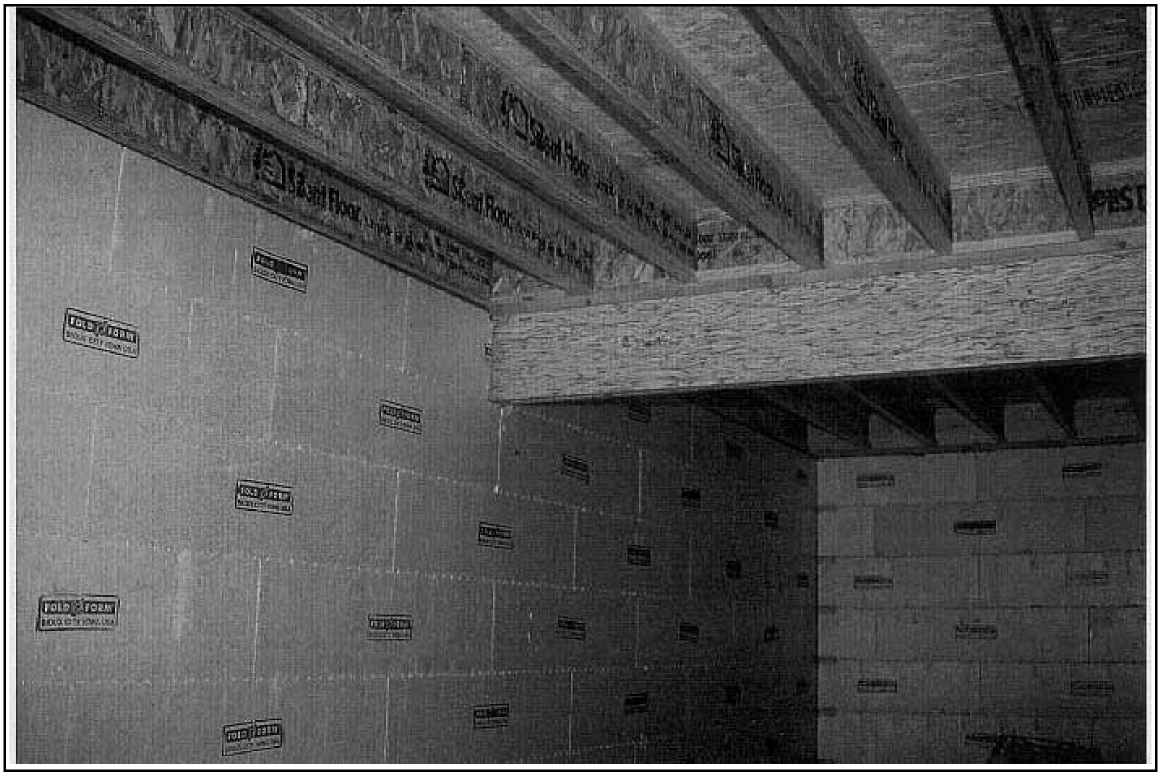


Photo 37: Site #3 - Floor Joists

Cost Summary

The typical wood-framed construction model was developed from information provided by a local ICF manufacturer and a leading building material supplier who is an associate member of the HBA of Greater Siouxland. The following table summarizes typical conditions found in conventional, affordable homes in the Sioux City area which is nearly 50% of all new housing in the Sioux City market:

Layer	Sioux City, IA
Internal vapor barrier	4 mil polyethylene
Framing	2x6, 24@ o.c.
Cavity insulation	R19
Exterior sheathing	7/16@ OSB
Exterior insulation	none
Exterior air barrier	yes

Table 15: Sioux City, IA - Typical Wood-Framed Construction

The second floor of this home was offset 6 feet on three sides, consequently three of the four walls on this level are wood-framed. Both the ICF and wood-framed costs in the following table do not include these three walls.

ICF Wall Construction Costs	
ICF material	$2,590
Concrete	$2,403
Misc. materials	$297
Installation	$1,695
Total	$6,985
Wood-Framed Wall Construction	
Framing Costs	
Material	$1,992
Installation	$1,887
Total	$3,879
Energy Features Costs	
Material	$1,261
Installation	$340
Total	$1,601
Total Wall Cost	
Material	$3,254
Installation	$2,227
Total	$5,480

Table 16: Site #3 - ICF and Wood-Framed Wall Construction Costs

Based on the cost analysis the builder is paying a 26.9% premium for ICF construction. The following table provides cost information normalized to overall wall and floor area. Note the unit cost per floor area is lower than what would be expected since three of the second floor walls were not included in the analysis. The unit cost per wall area is indicative of the actual or expected construction cost and can be directly compared to the other sites.

	Installed Cost per Floor Area (sf)	Installed Cost per Wall Area (sf)
ICF Construction	$2.79	$3.13
Wood-framed Construction	$2.20	$2.47

Table 17: Site #3 - Normalized Wall Costs

This home was constructed in an area where minimizing energy consumption is important to home purchasers. The two-story design, the integrated garage and the variety of ICF products used all combined to minimize the cost premium attributable to the ICF walls. Overall, the ICF's appear to have had a minimal impact on the overall cost of the home (1%) while providing an exceptionally high exterior wall R-value.

Builder Comments

Mr. Niles started using ICF construction in 1988, to date he has built over 20 homes with the product. He noted the product is fairly intimidating the first few times, though by the third or fourth time a builder should be reasonably comfortable with the requirements of ICF systems. With ICF there are continual learning requirements due to frequent product changes and improvements. All his subcontractors are experienced with the product with only the electrical contractor charging slightly more for working with ICF construction. The vinyl siding installer maintains the same price but takes slightly longer to complete the job. On this demonstration home installing the siding strips added 4 man-days.

In general there are not any extra costs for engineering of the house, code acceptance, permit fees, and builder warranty. The builder experiences a decrease in customer service costs due to fewer callbacks. The ICF manufacturer's literature provides sufficient information for all necessary design requirements. Problems with code acceptance have occurred in the past. For example, after using the product for 3 years, his local building department wanted the basements drywalled and taped. After complying with this fire issue, the electrical inspector was going to red-tag the house due to insufficient outlets in the basement. The problem was resolved, however problems like these can occur until inspectors are familiar with the product.

This builder estimates a 30% cost premium of ICF vs. wood-framed construction, at a cost of approximately $3.75 to $4.00 per square foot. The builder has his own crew install the ICF block and rents the concrete pump truck. Using his own crew decreases the material requirements, there were no extra blocks at the end of the job and approximately 20 to 25 blocks of waste out of 918 blocks ordered (2.7 %).

The builder continues using ICF construction to minimize production delays and provide "flexibility for scheduling". He reported drywall installers and masons are the hardest to get on site. ICF construction eliminates scheduling problems since the masons do not have to install the basement. ICF construction also eliminates concerns with ground water seeping into the basement, a prevalent problem with block walls. Product differentiation is not an issue, the "customers don't really care, [and] are more concerned with amenities."

Homeowner Comments

The demonstration home was not completed at the writing of this report so no comments are available on this particular home. The builder has been utilizing ICF construction for ten years and we spoke to another customer of his.

The homeowner interviewed has been living in a home with an ICF basement for over a year. The ICF basement provides a significant comfort increase as compared to a conventional block or concrete basement. The homeowner reports an extremely stable basement temperature and reported they do not have to wear a sweater, which was their experience in previous homes. Their basement is drier with no musty, moldy feeling associated with it.

Energy Analysis

Infiltration

The Sioux City home had little air leakage through exterior walls and windows but had noticeable air leakage through interior walls and ceilings connected to exterior spaces. Table 18 represents the home's tested infiltration data. Winter seasonal infiltration includes October through May; summer seasonal infiltration covers June through August.

Site	Air Changes
ACH50	4.06
Winter ACH	0.268
Summer ACH	0.146
Peak Winter ACH	0.406
Peak Summer ACH	0.228

Table 18: Sioux City Tested Infiltration Rates

Infrared Scans

The Sioux City home was a mixture of 2 x 6 framing and ICF construction, and infrared scans were used to identify differences in thermal bridging and air leakage between the two structural systems. Photo 38 shows an infrared image of an outside corner. Two-by-six stud framing was used on the left wall, and ICF was installed on the right wall. Air leakage induced with a blower door is visible from the corner connection and top plates. Photos 39 and 40 show the effect of framing and air leakage at two window corners. The first window is located in a 2 x 6 stud wall, and the second window is in an ICF wall. Framing and air leakage are visible in the 2 x 6 wall image. Wall ties are visible in the ICF wall. Photo 41 shows an electric outlet on a clear ICF wall. There is no air leakage behind the drywall. Photos 42 and 43 show a switch box next to a sliding glass door. Air leakage at the door frame and traveling down an electrical wire toward the switch box is visible. Photo 44 shows air leakage moving past an interior partition wall. Dark shading indicates air washing of drywall. Light vertical lines are the interior studs.

photograph not available

Photo 38: Infrared Image of Mixed Stud Framing and ICF Walls
Under House Depressurization

photograph not available

Photo 39: Infrared Image of Window Corner In Stud Framed Wall
Under House Depressurization

photograph not available

Photo 40: Infrared Image of Window Corner in ICF Wall
Under House Depressurization

photograph not available

Photo 41: Infrared Image of Outlet in ICF Wall
Under House Depressurization

photograph not available

Photo 42: Infrared Image of Air Leakage From Attic Toward Light Switch
in ICF Walls Under House Depressurization

photograph not available

Photo 43: Infrared Image of Air Leakage From Attic Toward Light Switch
in ICF Walls Under House Depressurization (continued)

photograph not available

Photo 44: Infrared Image of Air Leakage From Interior Stud Walls
Under House Depressurization

Peak and Annual Energy Consumption Analysis

Peak and seasonal energy use were calculated using REM/DESIGN. The results are presented in Table 19. Figure 18 shows both winter and summer loads in a bar chart format. Figures 19 and 20 present just the component loads in a pie chart format and neglect the internal gains; negative summer loads are made positive to compare magnitude. Air infiltration is the third largest winter load, only slightly behind above grade walls and foundation walls. Winter and summer seasonal air infiltration are 0.268 ACH and 0.146 ACH, respectively, both values are below the ASHRAE 62-1989 recommended level of 0.35 ACH. This indicates that the magnitude of the infiltration load is very low and that by comparison the wall loads are also very small. The window area is only 11.85% of the floor area which results in modest winter and summer loads compared to several of the other demonstration homes.

	Peak (Btu/hr)	Season (MMBtu/yr)
Heating	58.5	100.2
Cooling	37.9	20.0

Table 19: Sioux City Seasonal Loads

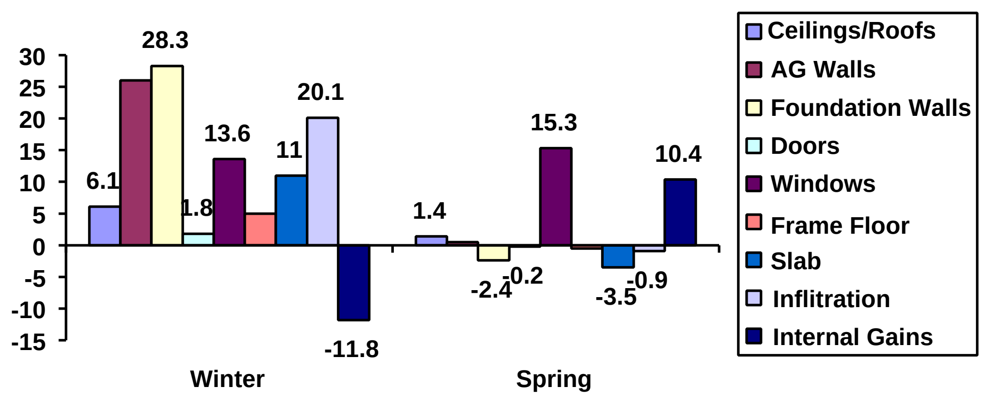


Figure 18: Sioux City Seasonal Loads

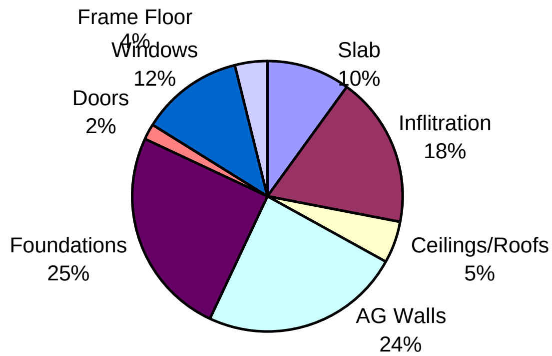


Figure 19: Sioux City Heating Loads (Only)

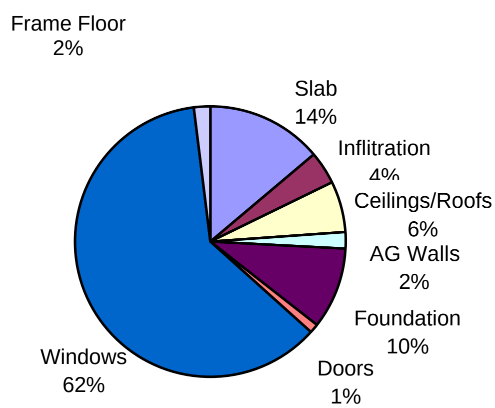


Figure 20: Sioux City Cooling Loads (Only)

DEMONSTRATION HOME #4 - CHESTERTOWN, MARYLAND

This home is constructed by Mr. Roger McKnight of Romak & Associates. The home is part of an affordable housing community. The builder wanted to construct attractive homes that homeowners could afford the house payment and the utility bills. For this reason, he chose to build with ICF. The home is a ranch style with three bedrooms, two baths and vinyl siding. The floor plan is shown in Figure 21.

Photo 45: Site #4 - Front Elevation

Photo 46: Site 4 - Rear Elevation

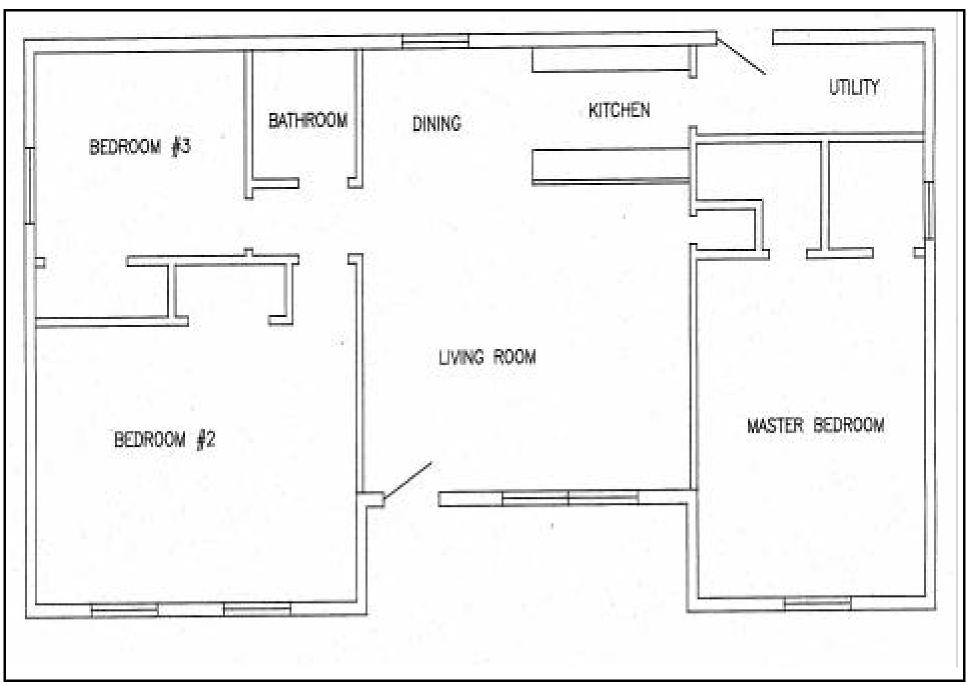


Figure 21: Site #4 - Floor Plan

ICF Product Summary

The house is constructed of Reddi-Form Blocks. The Reddi-Form *form* shape is block. The interior cavity is molded to produce a screen-grid concrete wall. The forms are 48" long, 12" tall and 9'-6" wide. The form consists of 5 vertical columns. As the forms are stacked, the horizontal beams are formed. The columns are 9 5/8" o.c. and the beams are 12? o.c.. There is no web of concrete between the columns and beams like the I.C.E. Block™ or the Polysteel Form. Reddi-Form Blocks do not have integrated furring strips. There are optional plastic strips that can be added in between courses of block to provide connection points for interior and exterior finishes.

Reddi-Form recommends concrete with a minimum compressive strength of 3000 psi, a slump 4" - 6" and a maximum aggregate size of 1/2". They recommend starting the pour in a corner and pouring against the form web of the form to control the flow. The concrete should flow in an inverted 'V' as it is poured. Air exchanger or a heat recovery ventilation system in the house is recommended by Reddi-Form. The literature also discusses corner and wall bracing and opening details.

The builder reports the manufacturer provides clear and detailed instructions. Manufacturer's engineering reports were needed by the builder for rebar placement. An illustration of Reddi-Form is shown.

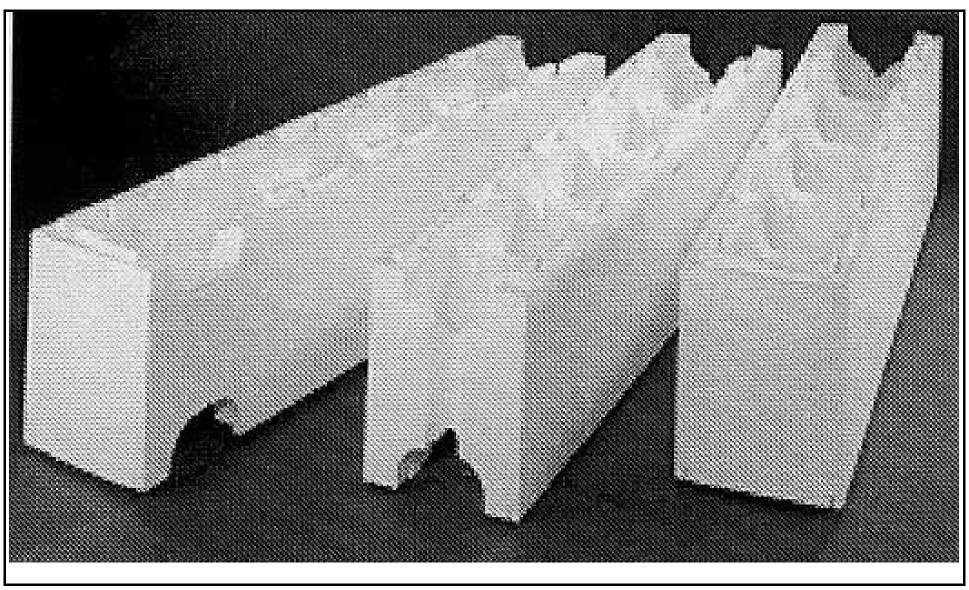


Photo 47: Reddi-Form
(Photo Used With Permission)

Construction Summary

The site construction summary is based upon survey responses provided by Mr. Roger McKnight and staff observations. (The photos are of field installation of the ICF wall system at the demonstration home.)

Photo 48 shows the bracing of the Reddi-Form walls. The first course was set with wood cleats directly on the footing. Walls are temporarily supported with diagonal wood 2 x 4s along the length of the wall, and extra support at the windowframing. The corner is framed with two 2 x 4s to support the weight of the wet concrete and keep the corner plumb during the pour.

Photo 48: Site #4 - Bracing of Reddi-Form Wall

Photo 49 shows the window bracing in detail. The windows have both horizontal and vertical supports at several points within the window frame. The windows use extended jambs. The door jambs are also extended. The manufacturer recommends 2 x 10 material to frame the windows. However, the builder prefers to make the window frames with 3/4" plywood. Nails are spaced within the jamb on all sides to become embedded permanently into the concrete.

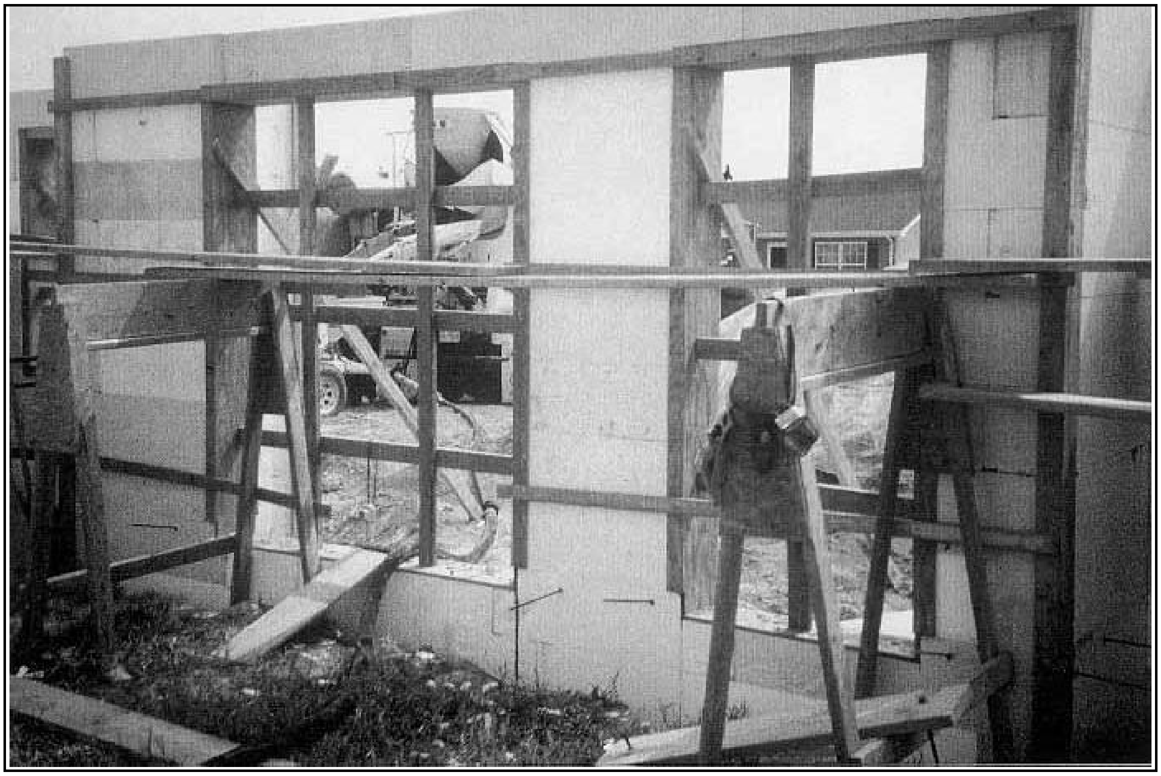


Photo 49: Site #4 - Window Detail

Photo 50 shows the window and corner bracing in more detail. Corners and window openings have a 2 x 4 brace. Window and door frames are fabricated from 3/4" plywood and 1 x 4 wood strips.

Rebar placement is 24" o.c. horizontally. The vertical rebar is placed 18" o.c. vertically after the wall was stacked. No-tie Rebar chairs are available from Reddi-Form. Openings are supported with two #4 rebars above (lintels) and one #4 on either side.

Photo 50: Site #4 - Window and Corner Detail

Photo 51 shows the utility penetrations into the interior of the home. These penetrations are sleeved.

Drywall is attached with glue along length of wall and nailed only into jambs around windows and to the top plate.

The cabinetry for this demonstration house is attached by recessing 2 x 4s into the foam surface while concrete is green. These furring strips were carefully located to match the planned locations of both upper and lower kitchen cabinets. Then the cabinet contractor has flexibility to secure the cabinets directly to the furring strips.

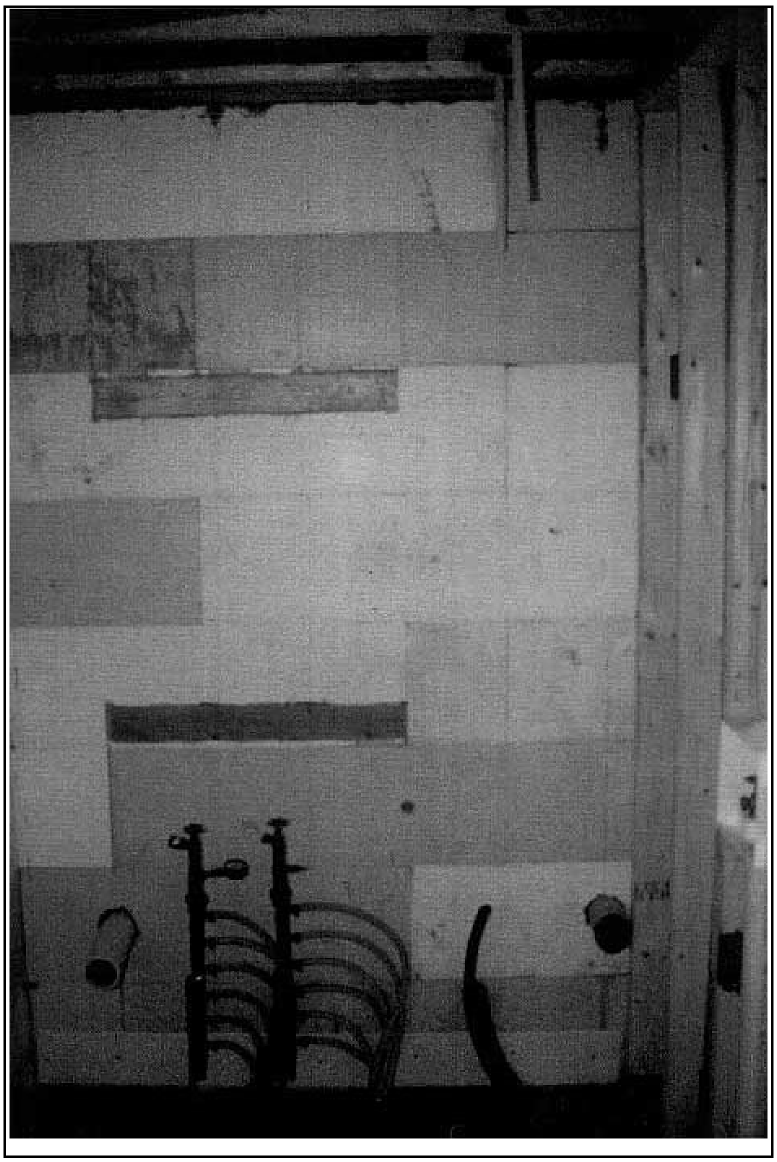


Photo 51: Site #4 - Utility Penetrations

Photo 52 shows the concrete pour. The concrete mix has a compressive strength of 3500 psi and a 3/8" aggregate. The portable 2" pump is owned by the builder's subcontractor. An overhead boom truck pumper was tried at first, but the portable 2" pump works best for this subcontractor. The concrete is poured by standing on scaffolding set in the interior space of the home. Concrete is poured from the corner to the middle of the wall. The concrete is controlled by one man on the scaffolding. The other is checking the stability of the forms.

Photo 52: Site #4 - Concrete Pour

Photo 53 shows the concrete pour into the wall under the window. Concrete is then pumped into the 2 1/2" holes until the sill area is completely filled. Plywood is used for flanges around the window. A nail that sets into the concrete is visible.

Photo 53: Site #4 - Concrete Pour at Window

Photo 54 shows the house in between the concrete pour and the exterior finishing. The gable-end sheathing is plywood. The rafters and ceiling joists are wood. Wood furring strips are added to the exterior of the forms while the concrete is still green in order to attach the vinyl siding. Putting the furring in while the concrete is green allows hand nailing of the strips with regular nails.

Photo 54: Site #4 - Unfinished Exterior and Roof Details

Cost Summary

The typical wood-framed construction was developed from information provided by a production supervisor for the 1993 National Housing Quality Award winner in the Large Volume Builder category. This supervisor has extensive knowledge of typical practice and building experience in the area. Table 20 summarizes typical conditions found in affordable home construction:

Layer	Chestertown, MD
Internal vapor barrier	none
Framing	2x4, 16@ o.c.
Cavity insulation	R13
Exterior sheathing	7/16@ OSB
Exterior insulation	none
Exterior air barrier	yes

Table 20: Chestertown, Maryland -
Typical Wood-Framed Construction

The builder did not have precise cost information broken out for ICF construction. He did have general cost information which was used to calculate the cost of ICF construction. The results are contained in the following table.

ICF Wall Construction Costs	
ICF material	$2,091
Concrete	$898
Misc. materials	$142
Installation	$983
Total	$4,114
Wood-Framed Wall Construction Framing Costs	
Material	$722
Installation	$843
Total	$1,565
Energy Features Costs	
Material	$396
Installation	$104
Total	$500
Total Wall Cost	
Material	$1,118
Installation	$947
Total	$2,065

Table 21: Site #4 - ICF and Wood-Framed Wall Construction Costs

Based on the cost analysis the builder is paying a substantial premium for ICF construction. Most of the premium can be attributed to the relatively high cost of his ICF material. In fact, the ICF materials alone cost 190% more than wood frame materials for the same house. This compares with only a 26% ICF material premium in Iowa. The following table provides cost information normalized to overall wall and floor area.

	Installed Cost per Floor Area (sf)	**Installed Cost per Wall Area (sf)**
ICF Construction	$4.08	$3.45
Wood-Framed Construction	$2.05	$1.73

Table 22: Site #4 - Normalized Wall Costs

This home was constructed with attention to both the initial cost of construction and the longer term operating costs that the home owner will have to pay. The builder has done a good job of balancing these two issues in a small-sized, price driven marketplace. The overall first cost impact of the decision to use ICF walls was only 2.2% of the home price.

Builder Comments

Mr. McKnight has built 47 homes employing ICF construction. He originally considered ICF construction to qualify for a home owner financing assistance under a Farmers Home Administration demonstration homes project. He continues to use ICF since it provides better scheduling on his jobs. The material does not require as many trades or steps to complete exterior walls. For example, locally there is only one subcontractor who pours the footers and foundations. Utilizing ICF for the foundation wall eliminates one site visit from this installation crew. Other steps eliminated include installing cavity insulation, exterior sheathing and house wrap. Overall the builder reports no increase in the time required to build a home. The builder also mentioned potential time savings associated with the home building process. After his framing crew got familiar with concrete construction, they purchased a small bulldozer ("Bobcat") and began placing the footings. Since there is only one contractor in the Chestertown area who installs footing, the framing crew eliminated a potential delay in the construction process.

Most of his subcontractors had no problems working with ICF construction. The electrician had to make some adjustments and settled upon using a hot-wire for boxes and a router for wiring. The trim and cabinet installer had the most trouble in securing items, although they developed a workable installation method. In general, the first home trades are learning what needs to be done, the second home goes quicker, and the system is down by the third home. Most of the trades do not charge more for working on an ICF home. The framer charges more but the increase is offset by not requiring other trades. The electrician charges 5% to 6% more.

The builder has a framing crew he subcontracts with to do both ICF and wood-frame construction (interior partition walls and roofs). The framers like the ICF system. In Chestertown the concrete pumper trucks have to come from Annapolis or Wilmington Delaware. After experiencing high cost and delays in building their first ICF home, the framers asked if they could buy a portable concrete pumper to do their own pouring. The lower costs paid for pumper after first job it was used on. This has lowered the framing costs on subsequent homes along with providing better service.

Continued use of ICF construction is prompted by the builders' concern for energy efficiency. He builds in an economically-depressed area and reasons that if customers have trouble with a house payment they will have trouble paying utility bills. He will use ICF for his next personal home because of increased energy efficiency (insulation and air infiltration) along with the overall quietness of the home (little exterior transmitted noise).

Homeowner Comments

This home was the first one for the owner and he is pleased with it. He commented on its quietness and the appearance with the wide window sills. He felt these features should have a positive impact on the re-sale value of the home.

Energy Analysis

Infiltration

The Chestertown house had a simple floor plan with only a few interior walls. The windows were caulked to the trim, not during installation and the interior penetrations were not air- or fire-stopped. Table 23 presents the home's tested infiltration data. Winter seasonal infiltration includes October through May; summer seasonal infiltration covers June through August.

Site	Air Changes
ACH50	6.57
Winter ACH Summer ACH	0.310 0.176
Peak Winter ACH Peak Summer ACH	0.403 0.251

Table 23: Chestertown Tested Infiltration Rates

Infrared Scans

The outdoor and indoor air temperatures were 54°F and 71°F. The radiant slab heating system was not operating, even though the exterior temperature was well below the indoor temperature. Thermographic imaging was completed without the simultaneous use of the blower door, so some of the exaggerated temperature images at windows, recessed lights, and interior partitions seen in other houses were not evident. Even so, the thermal imaging provided some excellent qualitative insight into the thermal performance of the Reddi-Form ICF system.

photograph not available

Photo 55: Infrared Image of Ceiling and Wall Corner
Under Natural Conditions

The thermal bridging that occurs in a wood frame wall, even a well insulated wood frame wall does not occur in the ICF wall. As with the other demonstration homes, there were visible temperature differences (cool spots) at the intersection of the exterior walls and the ceiling and in the corners (Photo 55). The ceiling connection has reduced R-value due to the framing plate and the corner has a lower overall R-value than the rest of the wall, as presented in an earlier section.

There were also some temperature differences apparent in areas unrelated to the ICF wall system. The cooler ceiling area where the bottom chord of the truss contacts the ceiling drywall was clearly visible compared to the warmer area between the trusses where full height insulation was present. The areas of wood framing around the windows and doors was also visible as a cooler area, compared to the adjacent full thickness ICF wall section.

Even though the builder chose to fully isolate the interior concrete slab from the exterior environment by building the exterior ICF wall continuously from the footing to the eaves, the thermographic images still noted a cool area at the exterior wall-interior floor slab intersection. It is not clear why this situation is occurring in this house. There is no insulation under the slab and there may be a measurable temperature gradient between ground temperature and slab edge.

Peak and Annual Energy Consumption Analysis

Peak and seasonal energy use were calculated using REM/DESIGN. The results are presented in Table 24. Figure 22 shows both winter and summer loads in a bar chart format. Figures 23 and 24 present the component loads in a pie chart format and neglect the internal gains; negative summer loads are made positive to compare magnitude. Several things are evident from the table and charts. The ICF walls represent a large portion of the building load, second only to the winter slab load. This is due to a small to average window area, only 12.8% of the floor area, and low infiltration.

	Peak (Btu/hr)	Season (MMBtu/yr)
Heating	12.9	18.3
Cooling	14.4	10.5

Table 24: Chestertown Seasonal Loads

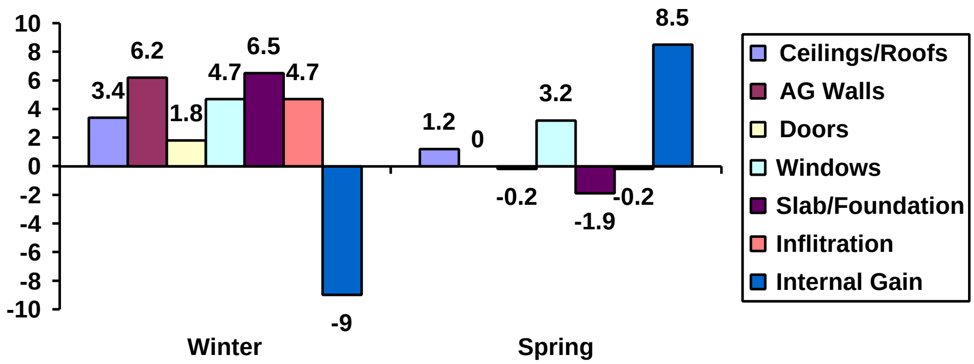


Figure 22: Chestertown Seasonal Loads

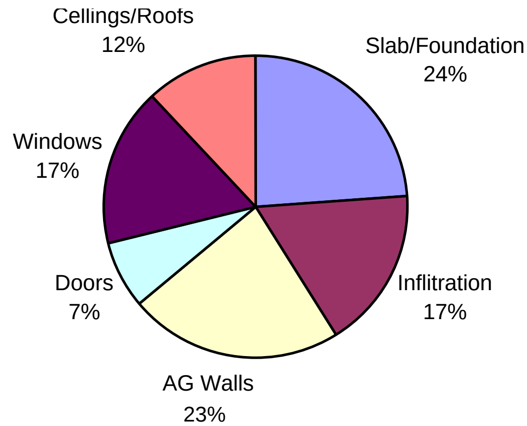


Figure 23: Chestertown Heating Loads (Only)

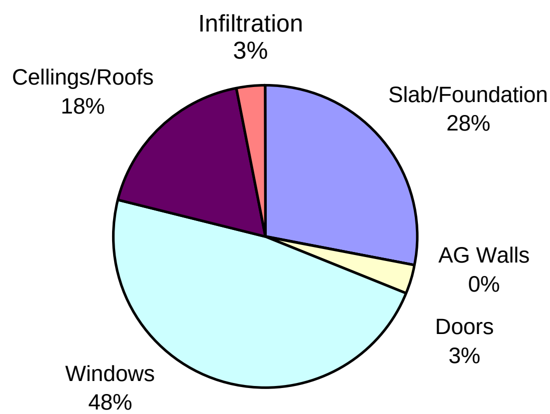


Figure 24: Chestertown Cooling Loads (Only)

Using the same software program and switching to a 2 x 4 framed exterior wall design increases the winter AG walls component load from 8.8 million Btu per year to 13.4 million Btu per year and increases the summer AG wall component from 5.2 million Btu per year to 7.9 million Btu per year. The stud framing is assumed to be sheathed in plywood and have vinyl siding. A typical infiltration rate of 0.50 (MEC 1995) would increase winter natural infiltration load from 4.7 to 7.l million Btu per year. The summer infiltration load does not change appreciably.

SECTION III

SECTION III

CONCLUSIONS/REFERENCES

CONCLUSIONS

INTRODUCTION

The conclusions for this demonstration report are presented as a series of separate issues. These issues are grouped in major sections that are all of interest to the builder. Included are separate discussions of field installation feasibility, costs, codes, equipment, R-values, infiltration rates, builders views, homeowners views, and needs for additional research. Taken together, these are all key components of most builder's decision making process. It should be noted that while there are many conclusions, there are not a large number of insurmountable issues uncovered by this demonstration project. The barriers to much more widespread use of ICFs, at least as the ICF products and builders represented here are concerned, are not very high. Prices must come down closer to other building alternatives, and builders and homeowners both must better understand the ICF issues and benefits, but these things will come through more and more use of the ICF technology.

<u>Field Installation Feasibility</u>

? Builder reported that with reasonable care during the construction process, concrete wall blowout problems can be avoided.
? A practical mix of ICF framing wood, and metal framing can be used to solve special structural problems and openings for non-standard openings.
? Preplanning can overcome utility penetration problems.
? Wood for temporary bracing is an expense that can be minimized through the use of more metal bracing, which is reusable more times.
? The added cost of pre-formed, or pre-packaged corners is justified by time-savings on the job site.
? In at least one case, virtually all interior nail pops in the drywall were eliminated due to the elimination of nearly all drywall nails or screws from the drywall installation process.

<u>Costs</u>

? ICF construction currently has a cost premium over wood framing alternatives (see Table 25). ICF builders need to understand and quantify the benefits of ICF construction to aid purchasers in fully understanding the ICF cost-benefit situation.

Location	Total Extra Cost\ ICF Forms	Final Sales Price	% of Final Sales Price
Virginia Beach	$12,177	$260,000	4.7%
Austin	$18,843	$350,000 (est.)	5.3%
Sioux City	$ 1,505	$150,000 (est.)	1%
Chestertown	$ 2,049	$ 91,000 (typ.)	2.2%

Table 25: Summary of ICF Cost Impact on Sales Price

The multiple durability, serviceability, acoustical, and energy conservation benefits of ICF systems can be emphasized by builders to offset higher initial costs at this time. In most local markets, good designs that are well implemented and responsive to the needs of the local market will be favorably received by prospective buyers.

There are some areas of emphasis that might produce future cost savings for ICF homes. The particular construction details of any ICF project are dependent on the selection of a specific manufacturer's product. Once a particular builder has chosen an ICF system, and has gone through the costly learning curve process with that product, there is a cost disincentive to switch to any other ICF product. This reduces the competition between ICF systems and potentially adds unnecessary costs. A reduction in the number of different ICF systems and standardization of construction details between competing ICF systems could result in a reduced premium for ICF homes compared to conventional wood frame construction.

Building code recognition of the use of ICF walls above grade could reduce the premium being paid or potentially being paid for a builder's choice of an ICF home. For those manufacturers that have obtained a code compliance report for their product, code modifications could reduce those manufacturer's costs of maintaining and revising those code compliance reports. For those manufacturers that put the burden of demonstrating code compliance entirely on the builder, standard code provisions for a number of typical ICF usage conditions above grade could eliminate the need for a builder to pay an engineering consultant for code compliance calculations.

A wider market for ICF products in general should also result in lower prices to builders. As the demand increases, the ICF can benefit from inherent economies of scale. Many smaller ICF companies are selling to a limited geographical region, and there are many duplications of storage and distribution facilities across the ICF industry. Consolidation of the number of ICF products together with larger production runs of all available ICF products can mean a lower per unit cost to the manufacturer, and a consequent lower price to the builder-buyer.

Codes

- No major building code problems were identified by the builders at any of the four demonstration sites.
- Individual builder and ICF distributor efforts to educate local building officials were successful in avoiding code problems.

Equipment

- Mechanical contractors reported some difficulty in sizing equipment for ICF homes. This may be related to the approach of current design tools that do not easily accommodate the unusual weight of the exterior walls in ICF homes. This "mass effect" impacts peak-energy needs and the sizing requirement of the HVAC equipment.
- Many residential contractors tend to oversize air conditioning equipment to assure sufficient heating and cooling capacity. Any oversizing may lead to moisture control problems in a humid cooling climate, due to short equipment run-times which prevent the equipment from effectively removing moisture in the inside air. For ICF homes this becomes more of a problem since the thermal inertia (or thermal mass) of the exterior wall structure typically means less running time for typically sized HVAC equipment.

R-value

The foam product used in ICF systems has an easily measurable R-value, per inch of material. When an individual manufacturer of an ICF product molds or fabricates this foam, the resulting R-value of the ICF product, combined in the wall with concrete, steel, and framing around openings, is unique to the particular manufacturer's system. This R-value is both measurable and can be calculated, as discussed in the individual demonstration home sections.

Infiltration

Tested leakage rates and thermographic images reveal the importance of sealing air leakage paths in all components of the exterior envelope. Even the use of a leakage resistant wall system such as ICF does not automatically eliminate leakage from windows, doors, ceilings, floors, and architectural details. Infiltration reduction is most effective with a systematic treatment of the entire house.

Builders' Views

- By the third ICF house, an acceptable familiarity with the special differences related to ICF construction was reported.
- The use of ICF construction gave builders increased job control over both scheduling and production time.

- ICF construction allowed builders to eliminate contractors such as the masonry foundation contractor, the wall insulation contractor, and the infiltration membrane contractor.
- There were few problems with subcontractors. Attaching trim, siding or cabinets posed the most initial problems due to the need for unfamiliar attachment requirements. Framing connections between interior frame walls and ICF walls also required attention.

Homeowners ' Views

- Homeowners interviewed were very positive about their satisfaction with their new homes. Among the specific reasons for homeowner satisfaction were:
    - Reduced noise from the exterior
    - Wide attractive interior window sills
    - Reduced drafts and improved energy efficiency
    - The attractiveness of new technology

Needs for Additional Research

- A different system of installing and securing wiring for typical branch electrical circuits is needed to overcome builder concerns about keeping the wires from coming loose before drywall as well as to reduce any reluctance of the electrical subcontractor to adapt to the ICF system.
- Additional information about local code processes for reviewing and approving building plans, and inspecting houses during construction is needed.
- Better information for builders in practical ways to combine ICFs with other innovative products and optimize the advantages of alternatives to wood frame construction.
- Cost reduction research, as a priority of the ICF industry, would assist builders in overcoming this major home purchase issue.

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APPENDICIES

Appendix A

Sample Builder Cost Survey

1. Is this your first experience with ICFs?

2. If not, how many previous houses have you built?

3. What number of houses constitute "the learning curve" for ICFs? That is, how many houses before you have the system down. Is this the same for your subs?

4. Which sub has the most trouble with ICFs?
   Plumber -
   Electrician -
   Mechanical contractor -
   Framer -
   Drywall contractor -
   Siding contractor -

5. Which factor(s) influenced you to try/continue using ICF construction?
   cost issues -
   product differentiation -
   energy efficiency -
   product strength/durability -
   lumber quality -
   other incentives (elaborate) -

6. Give us some idea of the cost issues around the builder decision to use ICFs?

7. How much did the ICF construction cost?
   labor -
   ICF materials -
   concrete -
   misc. materials -
   total -
   extra time/construction delays -

8. Who installed your ICF system?
   factory authorized contractor/distributor -
   your regular concrete contract -
   some other concrete contractor -
   framing crew -
   other -
9. How many blocks did you buy?

Sample Builder Cost Survey
(con't)

10. How many blocks did you have left over?

14. What was your block waste? (volume estimate OK, manufacturers claim 10%)

15. Do any of the following trades charge you more when you use ICFs?
    Framer -
    Plumber -
    Mechanical -
    Electrical -
    Drywall -
    Exterior finish contractor -

13. What are typical lumber framing costs in your area?

14. Is there a shortage of framers in your area? Any other labor issues?

15. Any extra costs for:
    engineering of the house (who did it) -
    code acceptance -
    permit fees -
    builder warranty -
    customer service -

16. Would you use ICF construction again? Why or why not?

17. May we talk to your customer?

Appendix B

Sample Homeowner's Survey

1. What factors prompted you to purchase this home?
   builder -
   look of house -
   location of house -
   type of construction -
   energy efficiency -
   other -

2. Do you consider your home a good value? Why or why not?

3. Do you know how your home is framed?

4. Do you have a personal preference in the type of framing material used in a home you live in? Why?
   environmental or "green" perception -
   look of "solidness" or "feel" of house -
   new technology "innovative" -
   other -

5. Are there any features of insulated concrete form construction that you notice are different from conventionally framed homes?
   outside noise -
   environmental comfort -
   utility costs -
   depth of window sill -
   exterior finish -
   other -

6. How do you rate the impact of these features on the re-sale value of your home?
   outside noise -
   environmental comfort -
   utility costs -
   depth of window sill -
   exterior finish -
   other -

7. Do you like or appreciate your home more the longer you live in it?

8. Is there anything about your home you would like different?

9. Would you buy another home made with insulated concrete form construction?

10. Is this your first home? If not, how many others?

Appendix C

Sample Construction Practices and Code Approval Survey

CONSTRUCTION PRACTICES

1. Did you have problems squaring the forms for the pour? Did you develop short cuts for placing, leveling or bracing the forms?

2. Most ICF manufacturers recommend a small aggregate (3/8"), high flow concrete (6" slump), a standard compressive strength (3000 psi) and a 2" pump to control the pour. What was your?
   aggregate size ____ (in)slump _____ (in) concrete strength _____ (psi)

   Did you need the 2" pump?

3. How did you make the corners? How was the corner bracing done? Was this more difficult or less difficult than wood stud construction?

4. How did you tie in the floor joists to the walls? Did you have to do any "field engineering" to place the floor joists?

5. Did you have any trouble setting the windows or doors? Was the depth of the wall a problem?

6. Did you have any trouble with planning the utility chases/ductwork? What are the short cuts that you've learned?

7. Did you have any trouble hanging drywall, cabinets, or trim? What are the short cuts that you've learned?
8. What are the interior walls framed with?

9. Did you take the ICF walls all the way up to the roof-line? What was difficult with the roof details?

10. What have you learned to do differently from the first few ICF homes that you constructed? On what issues did you need to contact the ICF manufacturer?

11. Were they helpful? Did they provide engineering support? Did the ICF manufacturer provide detailed construction instructions?

12. Were the instructions clear? Did you have to make field modifications?

CODE APPROVAL SURVEY

1. Did you need engineering reports from the manufacturer?

2. What was your rebar placement (Horizontal and Vertical)? What was the rebar placement around windows and doors? How did you determine your rebar requirements (for example, hired a structural engineer, followed ACI Code, ICF Manufacturer's literature, ICF Manufacturer? s Engineer, local code official)?

3. Fire Code - What was your firestopping requirement? Did you have to firestop horizontally and vertically every 8 feet?

4. Fire Code - Did you need a one hour fire-rated wall assembly for a load bearing wall?

5. Fire Code - Did you have to cover all exposed foam with a 15minute thermal barrier? (add sheet rock to basement and attic walls)

6. What were the major concerns of the fire code officials?

7. What were the major concerns of the building code officials?

8. Any Notes, Thoughts, Sketches:

Appendix D

Building R-value Calculations

	Wall Component R-values
Virginia Beach	
Outside air film	0.17
Stucco, 3/8 inch	0.06
: inch expanded polystyrene	2.89
Polysteel block plus concrete[a]	17.48
Drywall	0.45
Inside air film	0.68
Total	21.73
Austin	
Outside air film	0.17
Stucco, 3/8 inch	0.06
2 inch expanded polystyrene	1.90
I.C.E. Block **J** plus concrete[a]	17.48
Drywall	0.45
Inside air film	0.68
Total	20.74
Sioux City	
Outside air film	0.17
Vinyl siding	0.0
Fold Form plus concrete[b]	15.2
Drywall	0.45
Inside air film	0.68
Total	16.50
Chestertown	
Outside air film	0.17
Vinyl siding	0.00
Reddi-Form plus concrete[c]	18.27
Drywall	0.45
Inside air film	0.68
Total	19.57

Note: [a] *Physical measurements taken and calculated with ASHRAE parallel path method; no reduction considered for metal wall tie*
[b] *Four inches of expanded polystyrene*
[c] *Tested under ASTM C-236; report*

Table D1: Calculated Wall R-values of Demonstration Houses

	R-value per Inch of Material	**R-value as Specified**
Expanded polystyrene foam, 4-inches	3.80	15.2
Fiberglass insulation, 3.5 inches	3.71	13.0
Plywood, **2**-inch	1.25	0.62
SPF studs, 3.5 inches	1.23	4.30
Double pane, vinyl window (2862)	**	2.17
Drywall, **2**-inch	0.90	0.45
Concrete, 8-inches	0.0625	0.50

Note: [a] Physical measurements taken and calculated with ASHRAE parallel path method; no reduction considered for metal wall tie
[b] Four inches of expanded polystyrene
[c] Tested under ASTM C-236; report available from manufacturer

Table D2: Material R-values

Appendix E

Cost Analysis Charts

	Site 1 Virginia Beach, VA	Site 2 Austin, TX	Site 3 Sioux City, IA	Site 4 Chestertown, MD
Labor Cost Multiplier	0.83	0.81	0.89	0.70
Framing Cost Factors				
Material	0.83	.83	0.94	.83
Installation	0.94	.94	0.85	.94
Cavity Insulation Cost Factors				
Material	0.4	0.4	0.564	0.4
Installation	0.1	0.1	0.096	0.1
House Wrap and Vapor Barrier Cost Factors				
Material	0.16	0.13	0.16	0.13
Installation	0.099	0.039	0.099	0.039
Rigid Insulation Cost Factors				
Material	0	0.20	0	0
Installation	0	0.22	0	0

Table E1 - Means Cost and Material Multipliers

	Site 1 Virginia Beach, VA	Site 2 Austin, TX	Site 3 Sioux City, IA	Site 4 Chestertown, MD
House Characteristics				
Gross wall area	2694	5105	2231	1191
Floor area	2775	3894	2505	1008
ICF Construction				
ICF material cost	$7,084	$12,496	$2,590	$2,091
Concrete cost	$3,766	$4,288	$2,403	$898
Misc. materials costt	$1,228	$1,638	$297	$142
Total material cost	$12,078	$18,422	$5,290	$3,130
Total Installation cost	$5,837	$11,900	$1,695	$983
Total cost	$17,916	$30,322	$6,985	$4,114
Cost per wall area	$6.65	$5.94	$3.13	$3.45
Cost per floor area	$6.46	$7.79	$2.79	$4.08
Comparable Wood-Framed Construction				
Framing				
Solid Wall	2x4 @ 16" oc	2x4 @ 16" oc	2x6 @ 24" oc	2x4 @ 16" oc
Material cost	$1,856	$3,432	$1,866	$692
Installation cost	$2,102	$3,887	$1,688	$783
Total cost	$3,958	$7,319	$3,554	$1,475
Window & door openings				
Material cost	$143	$256	$126	$31
Installation cost	$217	$407	$199	$59
Total cost	$360	$663	$325	$90
Total Exterior Wall framing				
Material cost	$1,999	$3,688	$1,992	$722
Installation cost	$2,319	$4,294	$1,887	$843
Total cost	$4,318	$7,982	$3,879	$1,565
Energy features				
Cavity Insulation	R-13	R-13	R-19	R-13
Material cost	$748	$1,276	$982	$298
Installation cost	$187	$319	$167	$75
Total cost	$935	$1,595	$1,149	$373
Rigid Insulation	none	**2** " XPS	none	none
Material cost		$649		
Installation cost		$712		
Total cost		$1,360		
House wrap				
Material cost	$301	$417	$280	$98
Installation cost	$185	$125	$173	$29
Total cost	$486	$542	$452	$127
Total Energy features				
Material cost	$1,048	$2,342	$1,261	$396
Installation cost	$372	$1,156	$340	$104
Total cost	$1,421	$3,497	$1,601	$500
Grand total wall				
Material cost	$3,048	$6,030	$3,254	$1,118
Installation cost	$2,691	$5,450	$2,227	$947
Total cost	$5,739	$11,479	$5,480	$2,065
Cost per wall area	$2.13	$2.25	$2.46	$1.73
Cost per floor area	$2.07	$2.95	$2.19	$2.05

Table E2 - Detailed Cost Analysis