PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

U.S. Department of Housing and Urban Development
Office of Policy Development and Research

COSTS AND BENEFITS OF INSULATING CONCRETE FORMS FOR RESIDENTIAL CONSTRUCTION

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EXECUTIVE SUMMARY

The concept of assessing the value of something is as much an art as it is a science. This observation is particularly true of decisions related to a new home purchase. One person may determine “best” value by lowest cost or highest quality while another makes a decision purely on intangibles (i.e., comfort, aesthetics, “peace of mind”). Regardless of the method to determine value, a homebuyer, builder, or designer should make informed decisions about house construction options. This guide provides for that need by evaluating the costs and benefits of using Insulating Concrete Forms (ICF) in the construction of a home or other similar buildings.

Through several studies of ICF construction costs, it has been determined that using ICF wall construction generally adds about 3 to 5 percent to the total purchase price of a typical wood-frame home and land (about 5 to 10 percent of the house construction cost). In other words, the added cost is about \$2 to \$4 per square foot of the floor area of a typical home. For a typical 2,500 square-foot, two-story home and lot (sale price of \$180,000), the additional cost amounts to about \$7,000. The additional first cost of ICF construction should be weighed against longer-term benefits.

Several benefits of ICFs are discussed in this guide and are quantified to the extent possible based on available technical data and analysis. The benefits of ICF house construction considered in this study are as follows:

> **Structural Safety**. This factor involves the ability of ICF construction to resist damage and protect occupants from fire, wind, earthquakes, and flooding. Of these, the inherent strength of ICF construction against severe wind loads, including hurricanes and tornadoes, are most notable.
>
> **Comfort**. Though somewhat intangible, comfort deals with important issues such as even distribution of air temperature in the home and the quietness or acoustical properties of the home. ICF construction provides improved reduction of "outdoor" noise relative to standard home construction practices.
>
> **Energy Efficiency**. Energy efficiency is the ability to maintain acceptable indoor living conditions (i.e., air conditioning or heating) at a low monthly energy cost. ICF construction, in general, provides improved energy efficiency relative to standard home construction practices.
>
> **Durability**. This factor deals with a building or material’s ability to resist rot, decay, corrosion, pest attack, and other forms of degradation that may occur over time. While concrete is known to be highly resistant to degradation, there is insufficient data to provide meaningful comparisons to standard home construction.

Some benefits of ICF construction help to minimize the monthly cost of home ownership by reducing insurance premiums and energy/utility bills. On the basis of monthly costs to own the typical home described above, ICF construction adds only about \$24 per month (accounting for a decrease in monthly energy cost and insurance premiums) in comparison to a standard wood-frame home. The cost difference can approach $35 per month in comparison to a wood-frame home upgraded to achieve similar energy performance.

The following conclusions address the major findings of this study:

1. ICF construction costs about three to five percent more than a typical new home and land in today's market (about five to ten percent of house-only construction cost).
2. Relative to standard housing construction practices, ICF construction offers several performance benefits.
3. Based on any single benefit of ICF construction, it is generally more economical to consider upgrading standard wood-frame construction to achieve "equivalent" performance.
4. It is generally more economical or practical to consider ICF construction based on the collective benefits.
5. The individual performance attribute which has greatest technical significance to ICF construction is structural safety.
6. Based on the above conclusions, the cost-benefits of ICF construction are most appealing when considered as a "package deal" with special emphasis on structural performance, particularly in extreme wind environments.

1. INTRODUCTION

The concept of assessing the value of something is as much an art as it is a science. This observation is particularly true of decisions related to a new home purchase. One person may determine "best" value by lowest cost or highest quality while another makes a decision purely on intangibles (i.e., comfort, aesthetics, "peace of mind"). Regardless of the method to determine value, a homebuyer, builder, or designer should make informed decisions about house construction options. This guide provides for that need by evaluating the costs and benefits of using Insulating Concrete Forms (ICF) in the construction of a home or other similar buildings.

Three objectives have shaped the content of this guide:

- provide objective information on the cost of typical ICF home construction relative to standard housing construction;

- compile credible information on the benefits of ICF construction relative to standard home construction; and

- evaluate and compare cost benefits of ICF and wood-frame house construction based on the above data.

Many sources of technical and anecdotal information have been considered in fulfilling the above objectives, including some of the latest test data on the strength of ICF wall construction and other benefits such as energy efficiency, wind-debris impact resistance, fire resistance, and noise control. Since ICFs offer many benefits relative to traditional home construction materials and methods, it is important to understand the entire "package" of benefits associated with ICF construction relative to other options, such as standard or up-graded wood-frame construction. Thus, an informed decision can be made regarding the value of ICF construction relative to other choices. Of course, the final assessment of value is for the reader to decide. The intent of this guide is to simply help make that decision an informed decision.

This report begins with a brief survey of housing market perspectives regarding the value of ICF construction (Section 2). In Section 3, data is presented to capture the range of construction costs that have been documented for actual ICF and wood-frame construction. Next, Section 4 presents comparative data on the performance benefits of ICF and standard wood-frame house construction, including structural safety, hazard mitigation, fire resistance, durability, energy efficiency, and noise control. Section 5 provides a cost-benefit evaluation making use of information provided in previous sections. Finally, conclusions are provided in Section 6.

2. HOUSING MARKET PERSPECTIVES

One important factor that is considered in making any purchase is the experience of other users of a product. In this section, the experience and opinions of various builders, designers, and homeowners are presented to assist in judging the costs and benefits of ICF construction. The following information has been gathered from various sources including news articles, reports, web pages, and personal communications. While this information is purely anecdotal, it does represent considerations important to understanding the value of ICF construction as perceived through the actual experience of homebuyers, builders, engineers, and others who have used the product. Negative experiences were not usually found in the available sources, nor were they specifically sought in this study.

- Cost vs. Benefits Testimonials

"*Our highest [utility] bill in a month was $110 in summer. Our neighbors hit $200-$300 in August and September*." (Source: Survey of ICF homeowners conducted by Dr. Pieter VanderWerf at Boston University as reported in Concrete Homes Newsletter, Skokie, IL.) This sentiment is shared by many ICF homeowners who are willing to pay a little extra on the front end for downstream energy cost savings, not to mention the benefits of added safety and comfort.

"*There's a certain degree of protection that you can build into every house*," says Robert Hannon, a plans examiner for the City of Coral Springs in Florida. "*The question is how much the homeowner wants to pay for when they're building the house*." (Source: PBF Magazine, November 15, 1999.)

Recent market data shows evidence of increased use of ICF construction in the housing market and even production builders have made attempts to incorporate ICF construction on the scale of entire developments. One such builder/developer reports that "while ICF construction is viable, the market interest in the benefits of ICF construction [at additional cost] does not appear to generate the volume of sales necessary to support a production building operation".

- Tornado Survival

The house shown in Figure 1 survived a tornado strike and resisted a blow from a snapped tree. Adjacent homes were completely destroyed. This ICF house belongs to a family in Washington, Iowa. The family's two children were in the home when the tornado hit. The owner's response to this experience may be summed up by the statement "*The kids didn't even hear the tree hit the house*." (Source: Reward Wall Systems, www.rwsinc.com/news_tornado.htm.)

Figure 1

Tree impact to an ICF house with no damage to the ICF wall caused by the tornado.

(Photo courtesy of Reward Wall Systems, Omaha, Nebraska, www.rwsinc.com)

The Urbana, Illinois, house shown in Figure 2 survived a direct hit from an F2-F3 tornado which tore a substantial part of the roof apart, but the ICF wall construction remained intact. The ICF walls protected the owners and their pets from the fierce wind and debris even when the roof was gone. Adjacent homes suffered 100 percent damage. "*When the city engineer came out to look, he was absolutely amazed*," stated the owner. (Source: Reward Wall Systems.)

Figure 2
An ICF home survives a direct tornado strike with windows, siding, and roof destroyed.
(Photo of Polysteel ICF home courtesy of Reward Wall Systems, Omaha, Nebraska, www.rwsinc.com)

- Hurricanes

"*I figured it couldn't hurt to learn about a building system that's both strong and energy efficient. On the barrier islands where I build, we feel the effects of almost every hurricane and nor'easter that hits the East Coast…Insulating walls rated to withstand 200-mph winds and promising to cut electric bills in half might sell themselves*," says Ralph Woodard, a builder on North Carolina's Outer Banks. (Source: Journal of Light Construction, June 1998.)

On Long Beach Island, New Jersey, homeowner Stuart Stainecker explains, "*The most prominent reason I chose to build my Barnegat Light home with Blue Maxx™ insulated concrete wall system is because of the product's resistance against tropical storms, hurricanes, and flooding*." (Source: Concretenetwork.com)

"*We have a responsibility to build safe homes for consumers, and this is the safest product to do that with*," says Guy Collins, a developer in Myrtle Beach, SC. (Source: www.pca.org, September 24, 1999, press release, Skokie, IL).

- Floods

In a flood that exceeded the 100-year level for the Gadalupe River in Texas, an ICF home (see Figure 3) withstood rushing flood waters and debris while other homes were torn from their foundations and heavily damaged. "*If this had been a conventional home [the debris] would* *have gone straight through*," said the owner, Earl Roberts, who goes on to say, "*It truly held up well*." (Source: PBF Magazine, April 1, 1999.)

Figure 3
An ICF home withstands flood waters of Guadalupe River, Texas.

- Earthquakes

According to Gene St. Onge, the structural engineer of an ICF home in earthquake-prone California, "*With a little more concrete reinforcement and strengthening of the roof and floor, incurring not that much more expense, a structure can be designed to withstand major quake damage using an ICF system*." (Source: PBF Magazine, August 15, 1999.)

3. COST

3.1 GENERAL

There are essentially two aspects to considering cost or "affordability" in purchasing a house. First cost, including all costs that affect the purchase price of the home, is important to consider because it directly influences the buyer's qualification for mortgage, down payment amount, and monthly mortgage payments. Ownership, or long-term costs, is also important to consider (given that the buyer is able to afford the first cost). Some features that increase first cost may bring future benefits in terms of reduced monthly costs for certain items such as energy consumption, maintenance, and insurance premiums. This section provides information to help assess first (construction) costs of ICF construction and standard wood-frame construction. Monthly or long-term costs are evaluated in Section 5, Cost-Benefit Evaluation.

3.2 CONSTRUCTION COST

First, and foremost, the cost of ICF construction (like any other type of building construction) is very dependent on the familiarity of the contractor and trades people with the product. In most cases, there is a "learning curve" in any new construction process that requires building several houses to eventually economize the overall approach to construction. Therefore, the experience of the contractor is an important factor that will have an impact on cost and quality. Fortunately, ICF construction is a fairly simple method of construction using a system of conventional materials (i.e., concrete, reinforcement, and insulation) and it is easily learned and understood by contractors, trades people, and "do-it-yourselfers".

There are several methods to obtain information on construction cost. One of the most reliable methods is to conduct detailed time-and-motion studies of actual construction. Fortunately, such a study has been done on a number of ICF homes and, in some cases, identical wood-frame homes to give side-by-side comparisons. The findings from this type of study are summarized in Table 1 below. While the costs are specific to the sites studied, some general observations can be made from the data as a whole:

1. ICF Construction does cost more than typical wood-frame home construction;

2. On average, the additional cost of ICF construction (per square foot of floor area) is about \$4 when compared to typical wood-frame house construction; and

3. Actual cost differences vary depending on the size and complexity of the home, the type of ICF used, and other site-specific factors; thus, the additional cost of ICF construction relative to wood-frame construction may typically range from \$3 to \$5 per square foot.

TABLE 1
COST PER SQUARE FOOT
FROM TIME-AND-MOTION AND FIELD COST STUDIES

HOUSE TYPE, SIZE, AND ESTIMATED SALES PRICE	COST OF WALL CONSTRUCTION (per square foot of wall area) [floor area]		
	ICF	Wood	Difference
Economy One-story/1,008 sq ft $90,000 to $100,000	$4.56 [$6.19]	$2.37 [$3.42]	$2.19 [$2.77]
Custom One-story/two-story mix/3,894 sq ft	$5.95 [$7.79]	$2.25 [$2.95]	$3.70 [$4.84]
Custom One-story/2,775 sq ft	$6.65 [$6.46]	$2.14 [$2.08]	$4.51 [$4.38]
AVERAGE	$5.72 [$6.81]	$2.25 [$2.82]	$3.47 [$3.99]

Sources:
1. Insulating Concrete Forms for Residential Construction – Demonstration Homes, HUD, July 1997
2. Insulating Concrete Forms: Installed Cost and Acoustic Performance, HUD, March 1999.

A second and common method to estimate construction cost is through the use of estimating guide books such as RSMeans Residential Cost Data, 19th Annual Edition. This source of construction cost data allows for a detailed assessment of the cost of house construction. However, it does not necessarily account for the nuances of non-traditional construction methods. Thus, such an approach may often over- or under-estimate actual costs depending on a number of job-specific variables, namely the experience of the contractor with the product, local availability, and cyclic market trends (i.e., demand and supply). For example, RSMeans cost data for a traditional 2x4 wood-frame wall and a traditional concrete wall with furring and insulation are shown in the Table 2. Unlike the data for the test site above, indirect cost impacts to the electric, HVAC, or plumbing installations are not considered. In addition, other design changes such as wall thickness may add cost to windows and doors (i.e., need extension jambs). Therefore, these numbers should not be blindly used for estimating the actual cost of ICF construction for specific cases. The cost estimates are, however, not very different from the cost figures reported in actual field studies. Again, the purpose here is to give a general level of expectation for cost differences between typical wood-frame construction and ICF construction.

TABLE 2
ESTIMATES USING RESIDENTIAL COST DATA[1]

WALL CONSTRUCTION	COST PER SQUARE FOOT OF GROSS WALL AREA
4" thick concrete wall[2]	$5.63
2x4 wood-frame wall[3]	$2.60
Cost Difference	$3.03

Notes:
[1] Table values are based on application of RSMeans, Residential Cost Data, 19th Annual Edition.
[2] Estimate based on lightly reinforced basement wall with thickness adjusted to 4" from 8"wall thickness, 1x2 furring both sides added, form rental/cost not included, two layers of 2" polystyrene insulation added.
[3] Typical wood-frame wall includes 2x4 studs at 16"oc, 7/16" OSB sheathing, and R13 fiberglass batt insulation.

The reader is again reminded that the actual cost for any specific house will depend on a variety of factors which may not be represented by the "ballpark" data outlined above. Therefore, actual costs are ultimately defined by actual bids from real contractors and real homes. However, pricing that varies substantially from the figures shown above should be carefully scrutinized. The above cost data is relevant to the value of money in the 1997-99 time frame and may need adjustment; the proportionate differences should, however, remain relatively constant with time. Other factors that can easily alter the above cost data include significant changes in construction practice, in material attributes, and cost of raw materials (i.e., lumber vs. concrete).

4. BENEFITS

4.1 STRUCTURAL SAFETY AND HAZARD MITIGATION

Understanding Risk

Individuals are subject to a variety of risks or hazards that can result in health problems, injury, or even death. The magnitude of common risks in terms of the chance of any one of them happening over the lifetime of an individual is shown Figure 4. It can be seen that certain risks are much more likely to happen than others. These higher risks are often what drive "calculated" risk-management decisions of the public or individuals. However, for some, risks at the lower end of the scale (often referred to as "Acts of God") are perceived as being important based on unique personal experience or perception. It should be noted that the values in Figure 4 represent a national average, whereas certain individuals, depending on life-style and where they live, may be subject to significantly higher or lower risks in some categories. For example, people living in the mid-western U.S. will not experience a hurricane, but severe thunderstorms and tornadoes are common threats (regional reasons).

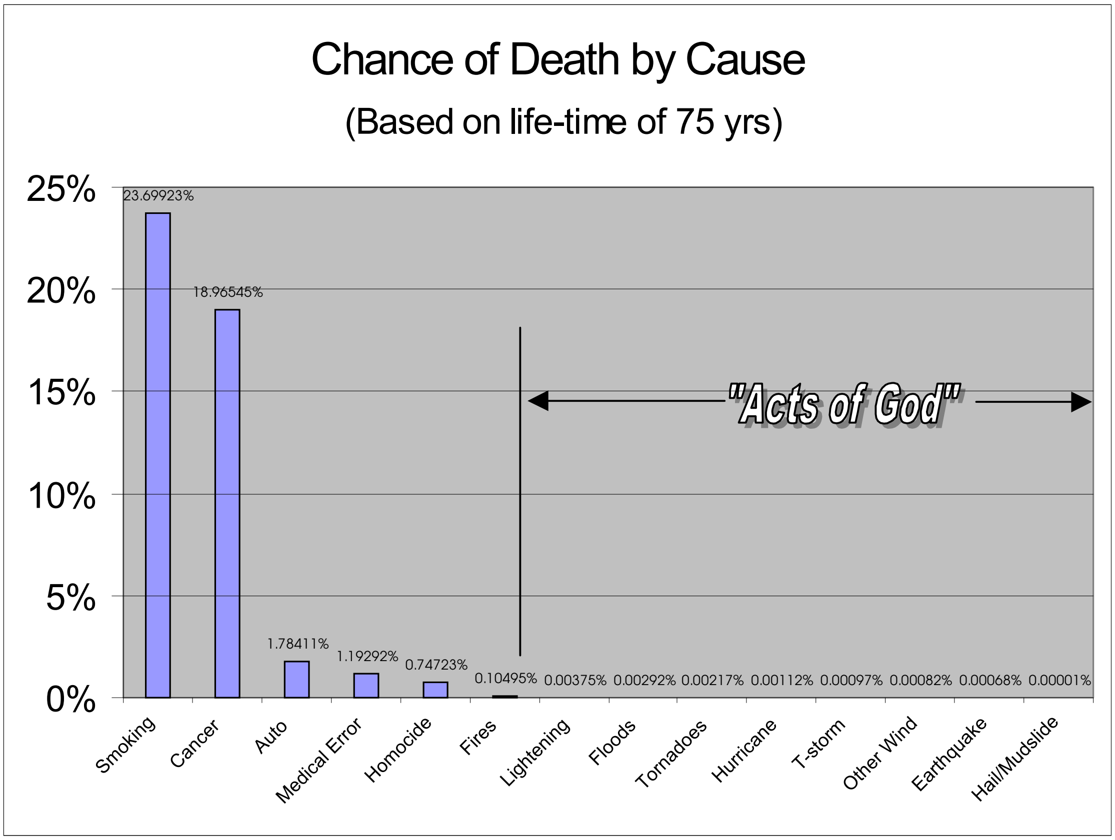
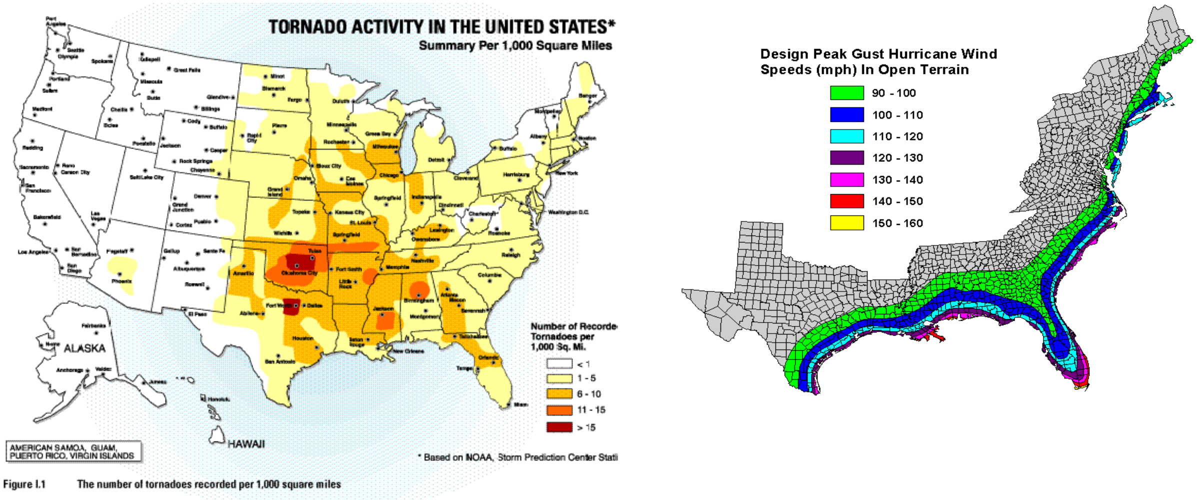


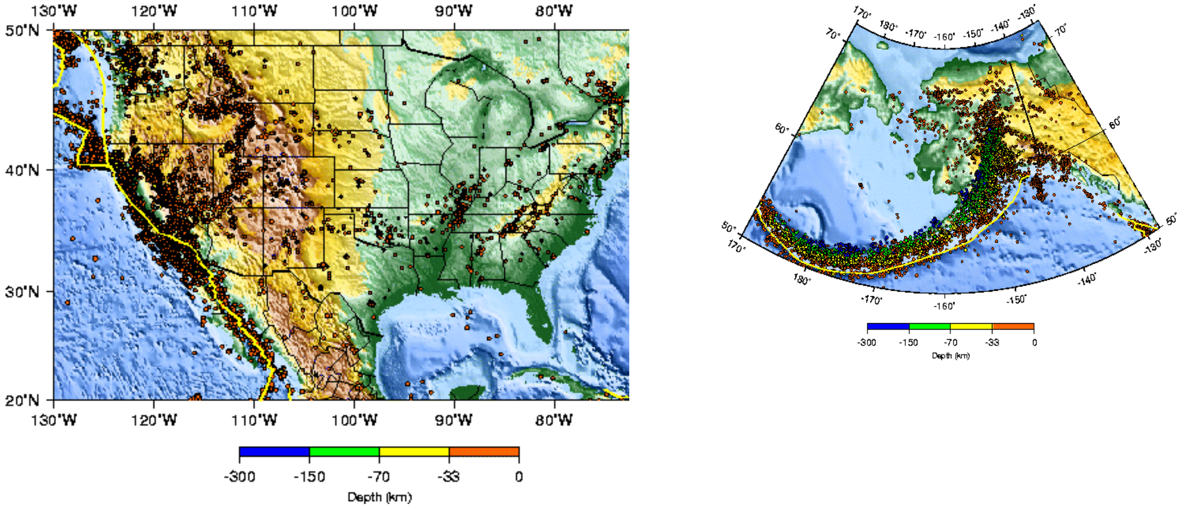
Figure 4
Chart of Various Consumer Risks*
(*Chance of happening per individual life-time based on national averages and a life-expectancy of 75 years; includes deaths unrelated to housing)
Reference: Residential Structural Design Guide (HUD, 2000)

Of similar interest is the chance of injury by cause. While the availability of data is limited, one useful example involves risk of injury due to a tornado. As shown in Figure 4, the estimated chance of death by tornado is about 0.002 percent (i.e., two thousandths of a percent chance in a lifetime of 75 years). However, the chance of experiencing an injury from a tornado incident (over a lifetime of 75 years) is about 0.04 percent (i.e., four hundredths of a percent). Thus, it can be seen that the risk of injury by certain causes may be several times greater than the risk of death by the same cause.

While emotional decisions definitely transfer into the home purchasing process, they cannot be predicted from one individual to the next and the "market" is often fickle in this respect. Conversely, regional differences in certain risks are much more predictable and can be based on historic climatic and geologic data. Regional differences in risk, as related to natural hazards, are shown in Figure 5.



(a) Tornado Activity Map of the United States **(b) Hurricane Design Wind Speed Map (U.S. Atlantic Coast)**



(c) Earthquake Occurrence (Seismicity) Map of the United States and Alaska

Figure 5
Regional Variation of Natural Hazard Risk in the United States

The geographic distribution of risk in Figure 5 illustrates why, as a national average, some risks are of little concern to the overall population but have significant local or regional impact. For example, people in the mid-western region known as “tornado alley” may be more inclined to consider a strong house construction method, such as provided by Insulating Concrete Forms. Similar trends in public or individual risk management decisions can be expected for other regional risks, such as hurricanes and earthquakes.

ROLE OF BUILDING CODES:
Building codes are comprised of minimum requirements that represent a balance of many competing interests, not the least of which are affordability and safety. The building code merely establishes a minimum level of risk that is considered to be socially acceptable on national and local or regional scales. It is always possible to build a home that exceeds the minimum building code requirements and, therefore, further reduce certain risks below the accepted norms. However, it must be understood that any and all risks cannot be "zeroed" or eliminated.

Managing Risk

Risk management is really a money management decision regarding the design and purchase of a home. It is perfectly normal to purchase a home that meets the minimum requirements (and implied acceptable risk level) of the local building code. However, additional investment can be made to enhance a building's "survivability" in extreme hazards. This enhancement can be achieved by designing a more resistant structure of a certain construction type or by electing to use a type of construction that is inherently more resistant to certain hazards of interest. In some cases, it may be most practical or economical to use a stronger material or construction technique in only part of the structure (i.e., use of a "hardened room" for an in-home tornado shelter).

IN-HOME TORNADO SHELTERS
For information on the use of ICF construction and other materials for in-home tornado shelters, refer to "Taking Shelter from the Storm: Building a Safe Room Inside Your House" (Publication 320) by the Federal Emergency Management Agency, Washington, DC (www.fema.gov). The document includes construction plans and cost estimates.

Safety and Hazard Mitigation Benefits

There is substantial "real world" evidence that an ICF home has a greater chance of surviving certain natural hazards with less damage (refer to 'Testimonials' section) than a typical wood home. This experience is also confirmed in laboratory structural tests and design theory. This section explores the structural safety benefits of ICF construction.

- Racking Strength

Certain walls in a building experience in-plane shear or "racking" from lateral (i.e., sideways) loads created by wind and earthquakes. The racking strength of these walls prevent the building from collapsing or being pushed over by wind or earthquake forces. Data comparing racking strength of ICF walls and wood-frame walls are shown in Table 3.

TABLE 3
RACKING STRENGTH DATA
(Based on 4-foot long by 8-foot tall wall segments)

WALL CONSTRUCTION	PEAK UNIT SHEAR (pounds per foot of wall length)
Wood-Frame	300 to 2,000
ICF	2,500 to 8,500

Sources:

1. In-Plane Lateral Load Resistance of Wall Panels in Residential Buildings, Portland Cement Association, PCA R&D Serial No. 2403, Skokie, IL, 2000.
2. In-Plane Shear Resistance of Insulating Concrete Form Walls, U.S. Department of Housing and Urban Development, Washington, DC, April 2001.
3. International Building Code, International Code Council, Falls Church, VA, 2000.
4. Residential Structural Design Guide, U.S. Department of Housing and Urban Development, Washington, DC, 2000.

Notes:

1. Comparisons are based on a 4-foot wall segment or "panel" length and an 8-foot wall height.
2. Longer wall segments can result in higher values for both ICF and wood-frame wall constructions. Conversely, shorter (more narrow) wall segments without compensating structural enhancements can result in significantly lower values for both construction types.
3. Values can vary significantly depending on actual wall configuration, amount of supported dead load, amount of openings, and special detailing such as connections in wood framing and reinforcement in ICF walls.

In general, ICF wall construction provides 5 to 10 times the racking resistance of conventional wood-frame walls. To provide resistance comparable to the lowest strength ICF wall construction, a wood-frame wall construction using 3x4 studs, 1/2-inch-thick structural sheathing, 10d common nails at 2 inches on center, and special connection hardware to restrain the walls from overturning is necessary. The construction of such a wall adds about $2.00 per square foot of gross wall area which reduces the average cost difference in comparison to ICF wall construction by more than 50 percent (refer to Table 1). It is not practical or feasible to achieve the higher racking strength capability of ICF walls by further enhancement to light-frame wood construction.

While it is not necessary to have the racking strength potential of ICF walls to meet minimum building code requirements, the added strength does have benefit in terms of safety and protection of building occupants in extreme events. For example, conventional wood-frame buildings often begin to suffer damage at wind speeds typical of severe hurricanes (i.e., 130 mph gust or higher). At wind speeds of 160 mph gust or higher (a "Category 5" or catastrophic hurricane event), conventional and even moderately reinforced wood-frame homes can begin to suffer major structural damage, including collapse.[1] In excessive wind speeds that could be expected in moderate to severe tornadoes, wood-frame homes are frequently totally destroyed.[2] In contrast, with 5 or more times the in-plane shear resistance, a typical home with ICF walls could be expected to withstand "Category 5" hurricane winds (not considering storm surge effects seen by coastal homes) and even a moderate to severe tornado with minimal damage due to wind pressure on the building and the associated racking loads on walls. While the risk-benefit is small because the risk of a direct tornado strike or catastrophic hurricane is relatively low (see Figure 4), the added strength of ICF construction provides exceptional protection against

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[1] "Assessment of Damage to Single-Family Homes Caused by Hurricanes Andrew and Iniki," U.S. Department of Housing and Urban Development, Washington, DC, September 1993.

[2] "Midwest Tornadoes of May 3, 1999," Federal Emergency Management Agency, Washington, DC, October 1999.

extreme wind hazards. Similar benefits are found in the resistance of ICFs to forces that may be experienced by buildings located in velocity flow zones of coastal or riverine flood plains. It should be noted, however, that flood areas constitute very unique and localized hazards that can often best be avoided by site selection and appropriate land management practices.

It is also important to note that ICF walls are stiffer than wood-frame walls. Thus, greater racking force is required to deform the wall which helps to protect non-structural components, such as wall finishes, windows, and doors from damage. However, in seismic conditions, heavy and stiff ICF walls generate greater racking loads than wood-frame walls. This effect offsets some of the racking strength benefit of ICF construction relative to light-frame wood construction in regions prone to earthquakes.

- Bending Strength

Building walls experience out-of-plane bending loads from wind, seismic, flood water, and earth pressure (i.e., basement foundation wall). Data on bending strength of ICF walls and wood-frame walls are shown in Table 4.

TABLE 4
COMPARISON OF BENDING STRENGTH
(8-foot wall height)

WALL TYPE	ULTIMATE BENDING LOAD (pounds per square foot)
ICF Construction (various types/thicknesses)	200 to 400
2x4 Wood Construction (various species, facings, and stud spacings)	50 to 100

Sources:

1. Polensek, A. and Atherton, G. H., Compression Bending Strength and Stiffness of Walls with Utility Grade Studs, Forest Products Journal, Vol 26, No 11, November 1976.
2. Design Criteria for Insulating Concrete Form Wall Systems, Portland Cement Association, Skokie, IL, 1996.
3. Stress and Deflection Reduction in 2x4 Studs Spaced 24 inches on Center Due to the Addition of Interior and Exterior Surfacings, NAHB Research Center, Inc., Upper Marlboro, MD, July 1974.

A 200 to 400 psf ultimate bending load can be associated with a 280 to 395 mph (gust) wind event which implies an ability to withstand a severe tornado (i.e., F3 or higher by Fujita tornado scale). A wood-frame wall provides bending resistance comparable to a 140 to 200 mph (gust) wind speed which implies an ability to withstand a moderate tornado (i.e., F2 or less by Fujita tornado scale). While this level of protection is clearly sufficient relative to typical building code requirements, the added strength of ICF walls in bending does provide enhanced protection in extremely rare (i.e., low risk) events such as a direct strike by a severe tornado. While the possibility of a near or direct strike of a tornado exists in many parts of the United States (see Figure 5), the risk of such an incident to any one home is only about once in a hundred thousand years or more on average. The fact that several hundred homes and buildings are affected by tornadoes in any given year is then the result of the millions of existing buildings that each have exposure to this slight risk (see Figure 4).

NOTE ON IMPORTANCE OF CONNECTIONS:
In most buildings, damages associated with wind events are often caused by connections that form a "weak link" in transmitting the loads between structural components that are otherwise capable of resisting the load. The potential impact of connections on house performance is not reflected in the above discussion on bending strength of ICF and wood walls. Given that ICF homes are of monolithic concrete construction (i.e., no joints within walls), connections can be expected to have a minimal effect on a typical ICF home compared to a typical wood home. However, ICF homes are frequently built with wood-frame roofs. Since wood-frame roofs are often the location where wind damage begins in a home, the full benefit of ICF wall construction may not be realized when used with wood-frame roofs that are not additionally reinforced. This reinforcement can be achieved by the use of additional fasteners in roof sheathing and enhanced connections between an ICF wall and a roof system by use of metal tie straps or other similar devices.

- Compressive strength

Building walls experience compressive loads from the weight of the building itself as well as the weight of contents, including people and furnishings. Therefore, the compressive strength of a wall prevents the collapse of a building when heavily loaded with people or contents. Data comparing the compressive strength of ICF walls and wood-frame walls are shown in Table 5. For homes, the compressive strength of ICF walls generally exceeds plausible extreme gravity (compressive) loads that could be experienced in typical homes or similar structures.

TABLE 5
COMPRESSIVE STRENGTH DATA
(based on 8-foot wall height)

WALL CONSTRUCTION	MAXIMUM COMPRESSIVE LOAD (pounds per foot of wall length)
Wood Frame (various 2x4 configurations)	4,500 to 10,000
ICF (4- to 6-inch wall thickness)	60,000 to 100,000

Note:
Values are based on unpublished test data and analysis by NAHB Research Center, Inc.

- Wind-borne Debris Impact Resistance

ICF wall systems have been tested for wind-borne debris resistance by subjecting them to the impact of a 2x4 wood stud traveling at speeds of up to 100 mph. This level of impact is considered to be representative of the nature of impacts that could be expected in a severe tornado (i.e., 250 mph wind speed). Data on the wind-borne debris impact resistance of ICF walls and wood-frame walls is shown in Table 6. While it is possible to upgrade the impact resistance of standard wood-frame wall construction to levels suitable for protection against potential debris in moderate hurricanes and less severe tornadoes, it is impractical to upgrade standard wood-frame wall construction to give comparable performance to ICF walls. It should be noted that the ICF wall data in Table 6 applies to ICF types that result in a "solid" concrete wall.

TABLE 6
WIND-BORNE DEBRIS IMPACT DATA

WALL CONSTRUCTION	IMPACT RESISTANCE
Wood Frame (various typical constructions)	8 to 26 mph (9 lb 2x4)[1]
ICF (4" and 6" flat and waffle-grid)	100+ mph (15 lb 2x4)[2]

Notes:
[1] Based on testing performed by Clemson University for the Region IV Mitigation Division of the Federal Emergency Management Agency, Atlanta, GA.
[2] Based on Investigation of Wind Projectile Resistance of Insulating Concrete Form Homes, Portland Cement Association, Skokie, IL.

4.2 FIRE RESISTANCE

Fire resistance is important to the protection of occupants from fire and to allow sufficient time for warning and evacuation. Concrete walls have superior fire resistance in comparison to most other building materials. Solid concrete ICF walls can generally sustain as much as four hours of extreme fire exposure (as reported at www.rwsinc.com), whereas typical wood-frame walls in houses generally do not exceed a one-hour fire rating. For housing, building codes typically require a minimum 15-minute rating with the exception of special fire separation requirements for multifamily construction, apartments, and townhouse units, where a minimum one- to two-hour fire rating is required between dwelling units.

While building contents are often the initiating source of fuel for fire-related incidents in homes, concrete is not a fuel source that can contribute to fire growth and spread in a building. It is also important to realize that doors, windows, and other penetrations can create a "short-circuit" for fire spread, if not similarly fire-rated in comparison to the walls. Regardless, fire resistance is a recognized benefit of ICF construction and can result in reduced fire insurance premiums.

4.3 DURABILITY

Little data is available to exactly quantify durability benefits in the varying use-conditions of building materials. Therefore, experience is often the most reliable guide. Concrete construction is well-known for its durability in building construction. In particular, concrete used in ICF walls is further protected from moisture and other environmental factors. While wood is similarly protected within the walls of a home, it is susceptible to rot in areas where water often penetrates the exterior weather-resistant barrier of a home, particularly in hot/humid climates. Wood materials are also subject to termite attack which can result in significant structural damage and necessitate structural repairs.

To obtain a higher level of durability in wood-frame construction would require additional costs in protecting the wood, either by design and detailing of the building, or by use of preservative-treated wood or naturally decay-resistant wood species. For example, treated lumber is often used for house construction in Hawaii because of severe termite problems. The cost increase relative to typical house construction with untreated lumber is about $0.50 per square foot of wall or approximately 15 percent of the cost difference between ICF and standard wood construction (see Tables 1 and 2).

In summary, concrete is able to maintain it's structural capabilities over a long period of time and extend the life-expectancy of buildings. Life-expectancy and maintenance of a home is a concern of homebuyers and designers with a long-term perspective.

4.4 ENERGY EFFICIENCY

ICF construction, as a result of the use of insulating form materials (i.e., polystyrene foam), provides an inherently high level of thermal resistance. In field comparisons of similar ICF and wood-frame house constructions, it has been found that ICF wall construction can provide a 20 to 25 percent savings in annual heating and cooling costs[3]. To achieve a similar level of energy performance, a typical wood-frame home would require an "energy upgrade" that adds about $2,640 to an average home cost of $200,000 (or about $1.32 per square foot of living area). This amount is equivalent to about one-third of the cost difference between ICF and typical wood-frame house construction reported in Tables 1 and 2.

4.5 NOISE CONTROL

The ability of a wall to decrease the amount of sound (or noise) passing through is measured by testing the wall to give it a rating. This rating is known as the Sound Transmission Class (STC) and can be used to compare the noise control or privacy afforded by various wall constructions. For ICF wall construction, the primary noise control benefit is in the reduction of noise from outside-the-home sources. Control of inside-the-home noise sources may require special detailing of partition walls and floor systems inside the home and is beyond the scope of this document.

First, it is important to understand the difference between various STC ratings as described in Table 7. Since a tolerable level of noise is dependent on the nature of the noise source (e.g., frequency), the individual perception, and other factors, the descriptions of "privacy afforded" given in Table 7 do not indicate an acceptable level of noise suppression. Such determinations are left up to the reader. As a point of reference, for party walls separating attached dwelling units, U.S. building codes usually require a minimum STC rating of 45.

TABLE 7
SOUND TRANSMISSION CLASS DESCRIPTION

STC RATING	PRIVACY AFFORDED
25	Normal speech easily understood
30	Normal speech heard but not understood
35	Loud speech heard and somewhat understood
40	Loud speech heard but not understood
45	Loud speech barely heard
50	Shouting barely heard
55	Shouting not heard

Source:
Quieting: A Practical Guide to Noise Control, NBS Handbook 119, National Bureau of Standards, U.S. Department of Commerce, Washington, DC, 1976.

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[3] *Insulating Concrete Forms: Comparative Thermal Performance*, U.S. Department of Housing and Urban Development, Washington, DC, December 1999.

Data on the STC ratings of ICF and wood walls are summarized in Table 8. ICF construction provides a clear benefit relative to typical wood-frame wall construction. To obtain similar performance from a wood-frame wall, certain enhancements are required (i.e., thicker gypsum board layers, resilient channels, acoustic insulation, etc.). These enhancements can add about $0.70 per gross square foot of wall area, which accounts for about one-fifth of the cost difference between ICF and standard wood-frame construction (refer to Tables 1 and 2).

TABLE 8
SOUND TRANSMISSION CLASS RATINGS

WALL CONSTRUCTION	STC RATINGS	FSTC RATING[1]
Typical Wood Wall	35 to 49	35
Enhanced Wood Wall[2]	50 to 54	--
ICF	48 to 58	40

Sources:

1. Fire Resistance Design Manual, Sound Control, Gypsum Systems (GA–600–94), Gypsum Association, Washington, DC, 1994.
2. Insulating Concrete Forms: Installed Cost and Acoustic Performance, U.S. Department of Housing and Urban Development, Washington, DC, March 1999.
3. Manufacturer data.

Notes:

1. FSTC is tested in actual field conditions and may be 1 to 5 points lower than STC rating. The FSTC rating also includes the effect of windows and other sources that can "short-circuit" noise control provided by a wall. Therefore, to maximize the sound deadening benefits of ICF construction, enhanced window and door construction should be considered.
2. Enhanced wood wall includes 2x4 @ 16"oc, resilient channels 24"oc, 5/8" gyp board both sides, and 3-1/2 inch batt insulation.

5. COST-BENEFIT EVALUATION

5.1 GENERAL

ICF construction, while generally more expensive than standard wood-frame construction, has several performance benefits that require consideration relative to first cost, monthly (operating) costs, and comparative performance of standard wood-frame construction. Comparative cost-benefits with respect to energy efficiency is addressed in the next section, Monthly Costs. The assignment of a dollar value was found to be difficult for other performance attributes such as structural safety, durability, fire resistance, and noise control for a variety of reasons, including lack of reliable data or the inherent subjective or non-economic "value" associated with a particular performance attribute (i.e., noise control). Recognizing that there are important differences in performance and value, however, a comparison of relative performance and cost to achieve "equivalent" performance is presented in Section 5.3 based on the data presented in Sections 3 and 4.

5.2 MONTHLY COSTS

Since most homes are purchased using mortgages, the monthly cost of home ownership is primarily related to financing. Thus, interest rate and the term of the loan (usually 15 or 30 years) are key factors that govern monthly and overall cost. Any increase in the first cost of a home will directly effect the monthly mortgage payment and the amount paid in principal and interest over the term of the loan. However, certain benefits that come at additional first cost may convey a net cost savings over the term of a mortgage or period of ownership.

Key monthly or periodic costs include:

- mortgage (principal and interest);
- utilities (electric, gas, etc.);
- home owner's insurance (required by mortgager, optional otherwise);
- maintenance (painting, repairs, etc.); and
- taxes.

Maintenance and long-term replacement costs are not factored in to the monthly cost comparison of Table 9 because of the lack of reliable data on this issue, particularly for ICF homes. Table 9 compares a standard wood-frame home to a typical ICF home in terms of monthly housing cost. Also included is a wood-frame home with an upgraded energy package that compares more closely with the energy efficiency of typical ICF construction. Long-term maintenance and repair costs are not included. Monthly maintenance and repair costs for a typical home is about $25 to $50.

TABLE 9
COMPARISON OF TYPICAL MONTHLY COSTS OF HOME OWNERSHIP

	STANDARD WOOD HOME	UP-GRADED WOOD HOME	TYPICAL ICF HOME	COMMENTS
Purchase Price	200,000	202,640	208,000	ICF 4% more
Principal and Interest	1,119	1,133	1,163	7.5% interest/20% down
Taxes	300	304	312	.15% tax rate
Insurance	25	25.33	22.50	10% savings
Energy	145	116	116	20% savings
TOTAL MONTHLY COST	1,589	1,578.33	1,613	ICF is $24 to $35 more per month

Notes:
1. Values for standard wood home and typical ICF home are based on similar data found at www.pca.org.
2. Upgraded wood home includes a typical energy efficiency option of 2x6 studs, R13 fiberglass batt insulation, and 1-inch exterior foam insulation.

5.3 COMPARATIVE PERFORMANCE

A comparison of the relative performance of ICF construction and wood-frame construction is shown in Table 10. While subjective in nature, the comparison is based on quantitative data presented in Section 4.

TABLE 10
COMPARISON OF RELATIVE PERFORMANCE

PERFORMANCE CHARACTERISTIC	ABOVE-GRADE WALL CONSTRUCTION TYPE	
	Concrete (ICF)	Wood-Frame
Safety and Damage Prevention	Excellent	Adequate to Good
Energy Efficiency	Excellent	Adequate to Excellent
Fire Resistance	Excellent	Adequate
Durability	Excellent	Adequate
Sound Control	Excellent	Adequate to Good

5.4 COST COMPARISON BASED ON EQUIVALENT PERFORMANCE

A summary of cost increases to standard wood-frame construction to achieve (or nearly achieve) a level of performance comparable to ICF construction for various performance attributes is shown in Table 11. It can be seen that if comparable performance is desired on all counts, the cost of an upgraded wood-frame home can exceed that of ICF house construction. However, if only one performance attribute is of concern, such as energy efficiency, the option to upgrade wood-frame construction is more economical. Conversely, ICF construction compares most favorably in the area of structural safety where the cost to upgrade wood framing to similar performance is greatest, particularly in areas with high wind hazard.

TABLE 11
COST TO UPGRADE WOOD-FRAME WALL PERFORMANCE[1]

PERFORMANCE CHARACTERISTIC	PERCENTAGE OF COST DIFFERENCE BETWEEN ICF AND STANDARD WOOD CONSTRUCTION
Safety & Hazard Mitigation	50% or more
Fire Resistance	Not considered practical to upgrade
Energy Efficiency	33%
Durability	15%
Sound Control	20%
TOTAL	118%

Notes:
1. Table values are based on data presented within the report.
2. Cost difference between ICF and standard wood construction is found in Tables 1 and 2. This difference is about \$3.99 per square foot of floor area, \$3.47 per square foot of gross wall area, or about \$7,000 for a typical 1,800 sq ft house plan costing an average \$208,000.

6. CONCLUSIONS

The following conclusions are based on the findings of this study:

1. ICF construction costs about three to five percent more than a typical new home and land in today's market (about five to ten percent of house-only construction cost).

2. Relative to standard housing construction practices, ICF construction offers several performance benefits.

3. Based on any single benefit of ICF construction, it is generally more economical to consider upgrading standard wood-frame construction to achieve "equivalent" performance.

4. It is generally more economical or practical to consider ICF construction based on the collective benefits.

5. The individual performance attribute which has greatest technical significance to ICF construction is structural safety.

6. Based on the above conclusions, the cost-benefits of ICF construction are most appealing when considered as a "package deal" with special emphasis on structural performance, particularly in extreme wind environments.