A FAST, SOLID, HIGH-EFFICIENCY WALL

Insulating Concrete Forms Offer an Affordable Wall System With High Performance

By Gary Brown and
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The concept of insulating concrete form (ICF) construction is simple and elegant: Configure a high-performance insulating material to act as stay-in-place formwork for casting a concrete wall. The concrete is cast in place in a continuous channel at the perimeter of the building; it becomes a solid, structurally robust, airtight wall. The formwork becomes high-efficiency continuous insulation, both interior and exterior to the concrete.

The result is a building that has very energy-efficient properties, is extremely durable, and is fast and affordable to construct. Concrete walls can be engineered to meet even the most stringent seismic and wind codes. The system derives its energy efficiency from the airtightness of the walls, the thermal insulating properties of the expanded polystyrene (EPS), and the thermal mass of the concrete. With new energy code requirements for continuous insulation, ICF is a construction method whose time has clearly arrived.

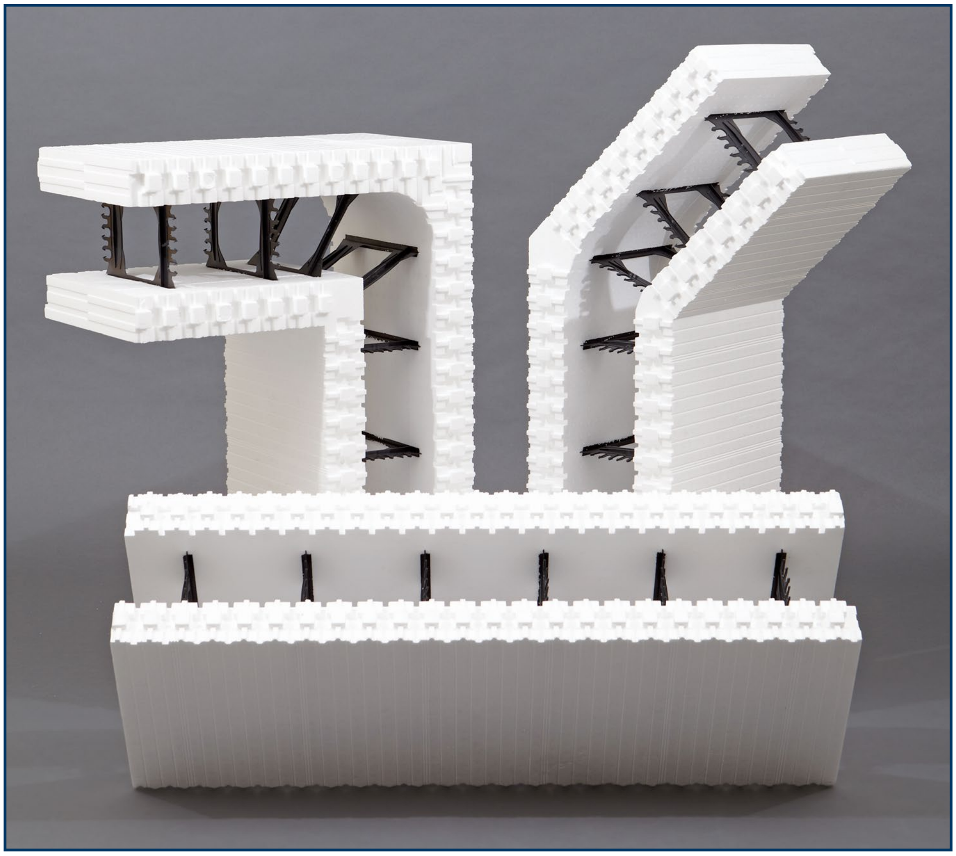

Figure 1 – The basic units of ICF construction: straight, 90°, and 45° blocks. (Image courtesy of Amvic Building System.)

DESIGN OF THE SYSTEM

The implementation of the ICF concept is a series of blocks that look like giant versions of children's Lego® bricks (*Figure 1*). They are made of EPS, a rigid foam material with high air content and concomitantly high insulating properties.[1] Like a Lego®, the block's top features large square tenons (or ridges, domes, or cylinders, depending on the ICF manufacturer) that mate into matching indentations in the bottom of a block. The EPS is usually bright white but may be green or silver-gray, depending on the brand and the composition of the EPS.

Unlike Legos®, however, ICF blocks are open through the middle. They are actually two panels of EPS, connected by an array of thin composition ties that hold the panels in parallel alignment. The foam used in ICF block, Type 2 EPS, has a density of 1.5 lbs./cubic ft., making the block very lightweight and contributing to its high thermal and acoustic insulating value.

Since the original introduction of EPS ICFs, most available systems have featured pairs of 2.5-in.- (65-mm-) thick panels, for a total insulation thickness of 5 in. (130 mm). Recently, systems with thicker blocks (hence more insulating ability) have become available. (See *Enhanced Performance ICF*, Page 12.)

In addition to basic straight-wall blocks (two flat panels), most systems include corner blocks, 45° blocks, and brick-ledge blocks—blocks with built-in shelves that form a cast concrete support for exterior brick or stone veneer.

Figure 2 – Concrete is pumped into the ICFs, filling in around the reinforcement and webs, creating a solid concrete wall. (Image courtesy of Royalton Construction.)

The ties in the blocks, referred to as webs, are an important aspect of the engineering of ICF units. In addition to holding the EPS in place, they provide supports for horizontal steel reinforcement and tie points to align the vertical steel. The ends of the webs act as connection points (screw anchors) for both interior finishes and exterior cladding. ICFs are available with webs made from 100% recycled plastic. This makes the entire ICF block 60% recycled material by weight, a possible contribution to a LEED® credit for recycled materials.

ICF walls are poured in 4-ft. lifts, so both the EPS and the webs have to be strong enough to bear the load of a 4-ft. column of fluid concrete (weighing approximately 140 lbs./cubic ft.). Embedment in the EPS must be designed so the webs will hold the EPS in place and not pull through it under pressure (*Figure 2*).

ICF can be used both above and below grade. When it was originally introduced in North America nearly a half-century ago, ICF was a stay-in-place concrete forming system for residential foundations. The system has evolved to include complete home construction and a wide range of commercial applications—even 22-story condominiums.

ICF foundations below grade are required to be protected from moisture similar to poured concrete foundation walls. Moisture protection products include peel-and-stick membranes and spray- or trowel-applied coatings. Coatings must be approved for EPS foam (water-based, not petroleum-based) products. Plastic dimple board products are also recommended to be used either with the membrane products or alone as a moisture-protected system.

PERFORMANCE

An ICF wall is a solid, cast-in-place concrete wall. Its load-bearing capacity and resistance to wind or seismic movement depend on the engineering of the wall. ICF blocks are available in a range of concrete thicknesses, typically from 4 to 10 inches, covering most construction situations. Custom thicknesses are possible.

Energy performance is where ICF really shines. The wall assembly achieves a high degree of thermal control through several means.

First, the EPS drastically reduces heat transfer through all three means of heat movement: conduction, convection, and radiation. (See sidebar "How Heat Travels.") The foam structure is virtually impenetrable to air movement, thus stopping convection. The foam has high air content, and air is a poor conductor. Moreover, the cell walls of the foam provide minimal solid bridges for conduction. The light color of EPS is caused by the material's high reflectance of electromagnetic radiation, both in the visible spectrum (light) and in the invisible range, where heat energy is radiated.

White EPS is generally given an R-value of about 4.1 per inch of thickness. R-value testing primarily measures resistance to conduction, so two materials with similar R-values may have different performance due to radiant energy absorption or reflection. Dark-colored EPS would absorb more heat and, therefore, have more heat available to transfer than white EPS.

Adding in the (low) insulating value of the concrete wall, plus additional value from the interior and exterior finishes, a total system resistance of about R-22 has been common for ICF walls. The thermal mass effect increases temperature control performance further (see Concrete's Contribution, page 14) such that, in Canada, ICF walls of nominal R-22 are approved in applications where other building products (e.g., wood and light-steel framing) would require R-27.

ENHANCED PERFORMANCE ICF

Recently, ICF blocks with high R-value have become available, made possible by increasing the thickness of the EPS. For years, the cost of reengineering the blocks and investing in new molds has deterred manufacturers from offering thicker EPS panels, but as sustainability has moved from a novelty to the norm, demand for higher-performing ICFs was evident.

The earliest approach to making enhanced performance ICF (EPICF) was to make EPS insert panels that would slip inside standard ICF blocks. This avoided having to invest in new tooling. For a 6-in.-thick wall with an R-value of 30, 8-in. ICFs have two 1-in. panels added along the inside of the blocks. This system is functional for the purpose of increasing R-value, but there is some risk of insert panels' getting displaced and essentially becoming voids in the concrete instead of insulating its surfaces.

The second approach was to add EPS thickness to an existing design. That concept kept the panel's top and bottom male/female mating configuration unchanged, 2.5 in. across, and minimally altered the mold to add a "slab" of unmated EPS thickness to the outside of the block. These blocks can be very thick, upping R-values higher than most construction demands. The drawback to this approach has proved to be in attaching finishes to the ICF webs. The embedment of the webs from the inside surface is

HOW HEAT TRAVELS

Heat transfer occurs through three mechanisms: thermal convection, thermal conduction, and thermal radiation.

Thermal convection is the bulk movement of excited (i.e., hot) molecules within a fluid such as air or water. Heat is transferred because hot molecules move from one location to another. The tendency of hot air to rise is an engine of natural thermal convection.

Thermal conduction is the transfer of heat energy from one molecule to the next. Heat is the excitation of molecules, which then vibrate with greater force and bump into adjacent molecules. So, at the molecular level, heat is pressure—excited molecules pushing against their neighbors. If a neighbor is equally excited, it pushes back equally hard, and heat is not transferred. However, when an adjacent molecule is less excited, some energy transfers from the more-excited to the less-excited molecule, attempting to equalize its energy. This gets repeated with other adjacent, less-excited molecules. Heat energy is thus conducted from one molecule to the next, even though no molecule ever changes its location in space. A thermometer under the tongue acquires body heat by conduction from the mouth surfaces in contact with the glass of the thermometer.

Thermal radiation is, in a sense, a side effect of the movement inside excited molecules. Charged particles moving within the molecule produce electromagnetic radiation: radiant energy. At temperatures greater than absolute zero (-273˚C [-460˚F]), all matter emits some radiant energy. Highly excited levels emit in the visible spectrum (i.e., light); lower excitation emits infrared. The sun heats the earth entirely by radiant energy; no molecules move from sun to earth, and there is 150 million km (93 million miles) of vacuum preventing conduction.

The three mechanisms often work together. For example, air is heated in a furnace by conduction and radiation, is carried throughout the house by convection, and then heats cooler objects (e.g., occupants) by conduction and radiation.

Effective insulation must control all three modes of heat transfer:

- Radiant heat can be reflected away, typically by white or light-colored materials.
- Conduction can be reduced by providing little or no physical path for energy. Air is a conduction barrier, because molecules are spaced far apart, making energy transfers few and far between.
- Convection can be prevented by sealing the space against interior/exterior air movement.

the same as on a 2.5-in. block, so the end of the web is buried deep in the extra foam. Special long screws must be used to apply finishes, and the potential for installation error rises.

Recently, one manufacturer fully redesigned its blocks with 3.25-in.-thick panels made from new molds. Web size and placement have been reengineered appropriately. R-value is increased to R-30 (*Figure 3*). Additional benefits have resulted from the redesign. The webs now have deeper embedment from the inside, making them more resistant to pullout, while keeping the attachment ends accessible. The thicker EPS is more resistant to blow-outs during concrete placement and vibration. The increase in horizontal interlocking surface results in easier and more secure assembly of the blocks. Field reports indicate that it's easier to keep the unfilled wall straight and true, as well, before concrete casting.

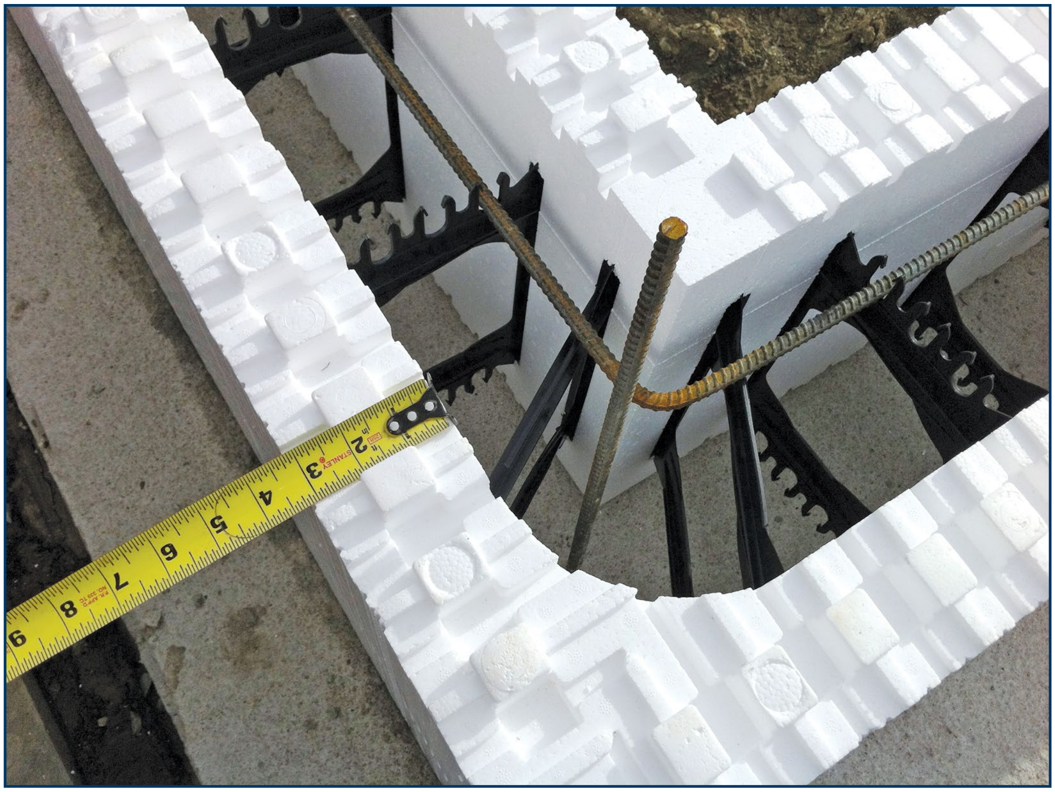

Figure 3 – The new 3-inch, R-30 ICFs offer enhanced insulating performance over standard ICF designs, are easier to build with, and are more secure against blow-outs during construction. (Image courtesy of Amvic Building System.)

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Figure 4 – The foundation of this project was formed with 2.5-in. ICF, and the above-grade walls with 3.25-EPICF blocks. The foundation is seen here partially exposed. It was later backfilled up to the brick ledge.

Figure 5 – Temporary braces are placed around the interior of the walls before pouring, in order to keep the walls plumb during concrete pouring.

CONCRETE'S CONTRIBUTION

In terms of energy efficiency, concrete is often dismissed because of its low insulating properties. However, in addition to its legendary structural robustness, concrete in ICF construction contributes two forms of thermal control.

First, it stops heat leaks through convection, because it is airtight. The entire perimeter wall is essentially a single piece of artificial stone. If the doors and windows are installed properly and don't leak, and the roof system does not leak and then heated or cooled interior air is going to stay in the interior, controlled by the HVAC system. (For a sustainable means of refreshing interior air, see sidebar "Sustainable Ventilation for an Airtight Structure" on page 15.)

Second, concrete has high thermal mass, giving it the ability to absorb and hold heat. In locations where there is a significant differential between daytime and nighttime temperatures, the thermal mass effect can increase the effective performance of the wall assembly. During summer, as the rising sun heats the wall, whatever heat gets through the outer layer of EPS begins to collect in the wall; but it can take hours before the concrete's heat capacity "fills up" and conducts heat freely toward the interior. At night, the concrete will give up heat, helping reduce the need for nighttime heating and preparing the concrete to "load up" the next day. In winter, the thermal mass effect is less pronounced, but the concrete will store some heat during the day that will slow interior heat loss at night.

USING ICFS

The basic procedure of ICF construction could be summarized as:

- Build the blocks.
- Place the concrete.
- Add finishes.

Most ICFs come fully assembled from the factory, ready to use for construction. Certain types are available as "knock-down panels"—that is, panels that have not been assembled with their webs to form blocks. This type of product saves shipping and storage space, but it adds time and labor at the jobsite to assemble the blocks. It may also lead to improperly assembled blocks.

The EPS block wall is built from the foundation up. This can include below-grade applications. In fact, ICF's earliest acceptance in the construction industry was for basement walls. Recently, as sustainability has become a more significant driver in design and construction, the energy efficiency of ICF has raised its status beyond the basement, into walls for multistory structures.

As the blocks are assembled, steel reinforcement is placed within the blocks and tied to the reinforcement bars embedded in the foundation (*Figure 3*). Horizontal reinforcement can be laid across the webs, which are cast with notches to hold the steel in the optimum position within the wall thickness.

Blocks are stacked in offset layers, like brick masonry. The interlocking of alternating layers forms a strong in-plane assembly that can withstand the pressure of fluid concrete. It is desirable to avoid a straight joint that runs the height of the wall, because the pressure could push it apart. The best way is to design the dimensions of the wall for whole ICF blocks. Alternatively, if blocks have to be cut to accommodate design, and a straight joint occurs, the contractor must apply temporary bracing on the outside of the block assembly—usually plywood or light lumber—that spans the joint and braces it to properly interlocked layers. Once the concrete hardens, pressure is off the blocks, so this bracing becomes redundant and is removed.

Figure 6 – After the concrete wall is complete, stone and stucco finishes are applied; and the ground around the wall is backfilled up to grade level. (Image courtesy of Royalton Construction.)

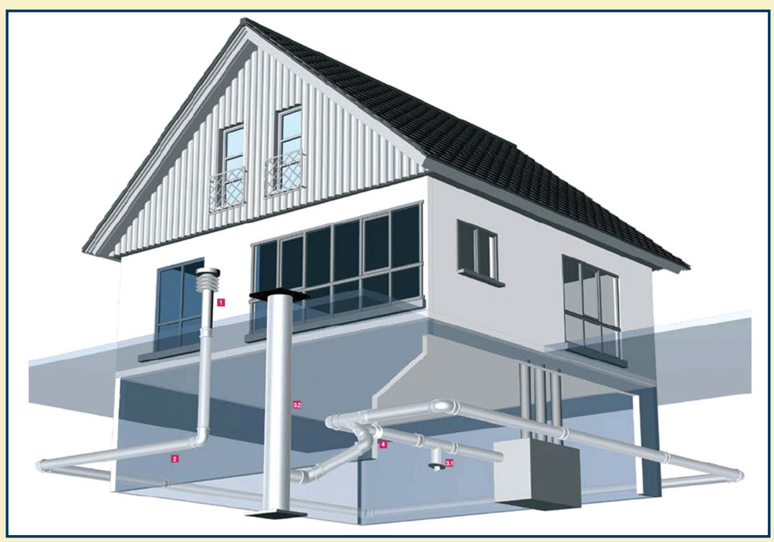
The load-resisting interaction between webs and panels is engineered to work when the blocks are complete and unaltered. Sometimes during construction, it becomes necessary to cut panels shorter in order to form certain architectural features. This can eliminate some webs from a block, putting more load on the remaining webs. In such situations, the altered blocks should be temporarily braced to adjacent, uncompromised blocks to prevent blowouts during the concrete pour.

Temporary vertical braces are customar-

SUSTAINABLE VENTILATION FOR AN AIRTIGHT STRUCTURE

An airtight structure such as an ICF building can be highly efficient in its use of heating and cooling energy, because little of the energy consumed for thermal control is lost through air leakage. However, if humans or animals are to occupy the building, used air must be exchanged for fresh air from outside the building. The loss of conditioned air and its embodied energy is unavoidable. However, the fresh air can be passively preconditioned to minimize the energy spent to bring it to the desired interior temperature.

Using the thermal mass of the earth, fresh air can be preconditioned by piping it in through an underground tube system. The tubes are typically buried around the foundation perimeter. An above-ground intake filter is designed to minimize debris and moisture intrusion into the system. Fans draw fresh air into the system, where its temperature equalizes to that of the earth around it, which usually is more stable and far less extreme than ambient conditions. This minimizes the amount of energy that must be spent bringing it to the desired temperature.



This fresh air intake system uses the thermal mass of the earth to precondition an area before introducing it into the HVAC system, increasing energy efficiency of the building. (Image courtesy of Amvic Building System.)

ily erected along the entire interior (*Figure 5*) to control the tilt of the block wall. The dry, unfilled assembly of blocks has enough flexibility that the wall can lean out of plumb.

If wet concrete is introduced while the wall is leaning, the added weight could increase the inclination, and the wall may "get away" from the installers and break the ICFs. To prevent this, the wall is intentionally leaned very slightly inwards against the vertical braces. This aligns the blocks evenly, too. Once the concrete is placed, while it is still fluid, jack screws on the vertical braces are adjusted to bring the wall into plumb.

Once the concrete hardens, braces are removed and finishes are applied using the ends of the ICF webs as fastener anchor points (*Figure 6*).

CONCLUSION

ICF construction offers an affordable, energy-efficient wall system. In addition, it has the strength and durability of a solid concrete wall. Speed of construction is excellent: Forms build quickly and do not need to be stripped after concrete placement. The blocks provide a ready-to-finish wall, often without additional furring.

Since ICF has long been associated with below-grade construction, it is not yet a top-of-mind alternative for the walls of low-rise buildings. As architects become more aware of ICFs, expect to see the range of ICF structures broaden and become more architecturally interesting and imaginative.

FOOTNOTE

1. EPS is often inaccurately, referred to as "styrofoam." Styrofoam™ is actually a trade name of the Dow Chemical company, and refers to a different material, an extruded polystyrene (XPS).

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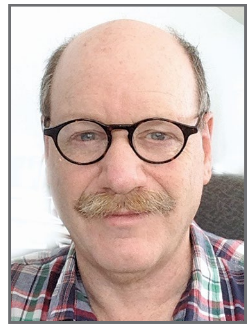

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