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A Comparative Study between Wall Bearing Steel Reinforced Expanded Polystyrene Composite Wall System and Insulated Concrete Forms

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Abstract: Wall bearing system was the main structure system for buildings long decades before the innovation of the reinforced concrete. Despite of its limitation of having wide span openings it is considered to be the easiest way to construct economic house units. Green building, Energy saving, construction speed, and economy were the major factors that influenced the creation of new wall bearing systems. This paper compares between two foam composite wall bearing systems showing their fulfillment to the green building requirements, their application capabilities in the Egyptian low income housing projects.

Key words: Wall bearing, Composite wall, Green building, Low income housing

INTRODUCTION

Panelized construction is a method of structured construction in which the building is subdivided into basic planar elements that are typically constructed under some form of mass production and then shipped directly to the construction site and assembled to form the finish structure.

Structural Insulating Panels, (SIPs), are a composite building material. They consist of a sandwich of two layers of structural skin with an insulating material in between. Concrete, plywood sheathing and oriented strand board are used for the structural skin. Expanded polystyrene foam (EPS), extruded polystyrene foam (XPS) and polyurethane foam are used as the insulating material.

The concept of SIP dated back to the 1930s. Research and testing of the technology was done primarily by Forest Products Laboratory (FPL) in Madison, Wisconsin as part of U.S. Forest Service's attempts to conserve forest resources[1]. In 1947, structural insulated panel development began with corrugated paperboard cores were tested with various skin materials of plywood, tempered hardboard and treated paperboard. By the 1960s rigid foam insulating products became readily available resulting in the production of the structural insulating panels[2].

Concrete sandwich panels, one of the SIP types, have been produced in North America for more than 40 years[3]. They are composed of two concrete wythes separated by a layer of insulation. The two concrete wythes are connected through the insulation layer by concrete webs, metal connectors, plastic connectors, or a combination of these elements[4].

Another type of construction system is the Insulating Concrete Forms (ICF). These types of construction are forms used to hold fresh concrete that remain in place permanently to provide insulation for the structure they enclose.

Their history dates back to the period after World War II, when blocks of treated wood fibers held together by cement were used in Switzerland. In the 1940s and 1950s, chemical companies developed plastic foams, which by the 1960s allowed a Canadian inventor to develop a foam block that resembles today's typical ICFs[5].

The above two systems, SIPs and ICFs, are favored over other wall systems because of their superior thermal, structural efficiency, energy efficiency and resultant cost savings.

This paper compares between the above two systems, showing their fulfillment to the green building requirements, their application capabilities in the Egyptian low income housing projects.

Methodology:

The paper begins by describing the construction steps for both systems, followed by a technical comparison for the minimum wall thickness in both systems.

For the reason that the ICF construction system is not yet available in the Egyptian market, an applied construction systems user evaluation is done through gathering and analyzing global users comments for both systems through the internet, and indicate which system is more applicable in the Egyptian low income housing projects from the user point of view. Structural and architectural comparative study is made showing both systems' ability to fulfill the needs of the majority of Egyptian users. That needs are mainly concentrated in changing the interior residential unit spaces through house lifetime by removing or adding internal walls, electrical and plumbing alterations.

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Systems Description:

Two wall bearing construction systems will be used for the sake of comparison. The first system represent the SIPs and commercially known as Emmedure M2 Building System, whereas the second system represents the ICFs and is commercially known as AMVIC Building System.

Emmedure M2 Building System:

This system is composed of polystyrene board imbedded in concrete composite wall section. The system consists of two types:

The first type is a single panel wall section that consists of 100 Cm polystyrene core with prefabricated zinc coated steel wire mesh reinforcement, which is encased later by sprayed concrete after its site erection. The second type is the double panel which consists of a polystyrene permanent shutter for an insitu poured structural concrete core. Sprayed concrete encases the polystyrene also in the double panel type. Both wall panel types have 2.5 mm diameter zinc coated steel wire mesh reinforcement at 65mm centers on each face.

Front and the back meshes are connected by zinc coated 3mm steel ties (82 per square meter) passing through the polystyrene. Polystyrene surface has corrugations of depth 10mm and length 70mm. Sprayed fiber reinforced concrete has a minimum thickness of 35mm and a characteristic 28 days cubic strength of 25 MPa.

Insulated Concrete Foam:

This concrete bearing wall system consists of two flame-resistant EPS (Expanded polystyrene) boards separated by polypropylene webs. The EPS foam boards are a minimum 70 mm thick, and can range in thickness up to 178 mm. The webs separate the EPS boards to form wall cavity range from 102 mm up to 305 mm which creates the concrete wall thicknesses. Using that system the concrete wall thickness can be increased to virtually any thickness. The webs are spaced every 203 mm on center horizontally and 406 mm on center vertically, and contain a 32 mm wide furring strip that extends the height of each ICF block. The furring strips shall facilitate fasteners for attachment of both exterior and interior finishes.

A furring strip is located in the corners of corner forms. The furring strip consists of both a vertical and horizontal component. The vertical component extends nearly the full height of the form, extends a minimum of 64 mm from both sides of the corner, and a minimum of 5 mm thick. The horizontal component is a minimum 51 mm in height, extend a minimum of 152 mm from both sides of the corner, and a minimum of 5 mm thick.

Construction Method:

Both of the SIPs and ICFs are characterized by the ease of construction and construction time saving , a comparison between system methods of construction follows:

Foundations:

Both systems use either ordinary concrete ground floor slab or ordinary concrete strip footings according to the desired number of floors and type of soil. Emmedue M2 system uses starter steel dowel bars of diameter 10 mm and length 350 mm stagger assembled at wall locations at the ground floor slab level[6] Figure (1) , while the ICF system uses steel bars of diameter 10 mm imbedded in the ordinary concrete footings at a depth of minimum 230 mm and projecting above the slab for a minimum of 230mm aligned at intervals of 1200 mm. Figure (2).

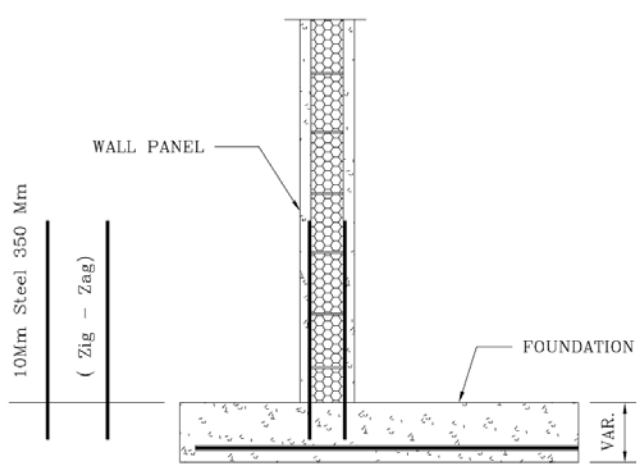

Fig. 1: Emmedue M2 system foundation.

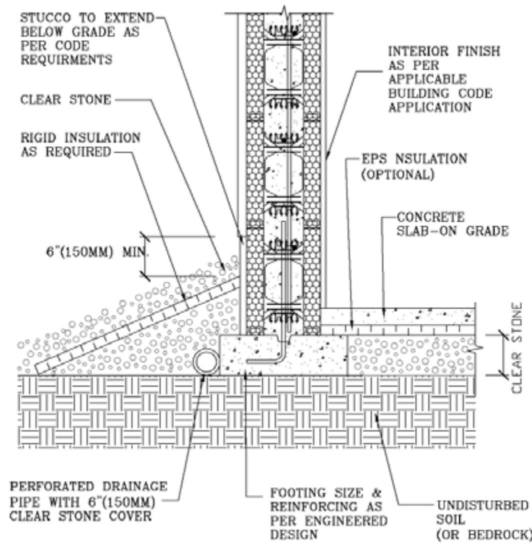

Fig. 2: AMVIC (ICF) SHALLOW FOUNDATION WALL.
Source: www.amvicsystem http://www.amvicsystem.com/icf/cad

Walls Assembly:

Emmedue M2 system, wall panels are anchored to foundation at ground level with dowel bars. The panels are equipped on both sides with mesh overlap from panel to panel to provide continuity of elements and to prevent the formation of gaps between adjacent panels. Figure (3). All internal and external walls are reinforced with angular galvanized steel mesh to provide greater structural mesh continuity Figure (4).

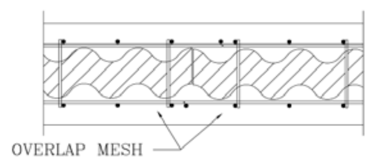

Fig. 3: Emmedue M2 panel to panel connection joint.
Source: www.Emmedue.com -10 Step Guide English.pdf.

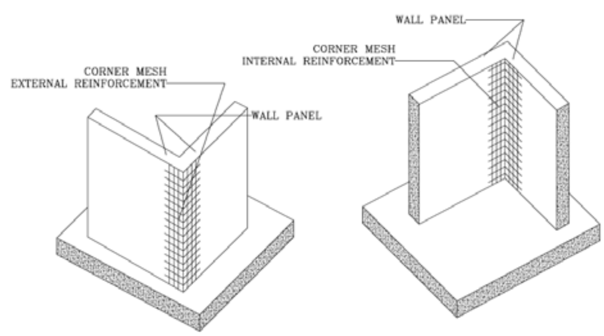

Fig. 4: Wall panel to wall panel corner connections.

AMVIC (ICF) system walls assembly beings after concrete floor slab or strip footing is poured and the outline of the foam blocks is located. First corner blocks are placed on each corner then straight blocks are laid toward the center of each wall segment. On the first course zip-ties are used to connect the blocks, following horizontal rebar is placed in the clips at the top of the internal webs within the block cavity. Figure (5).

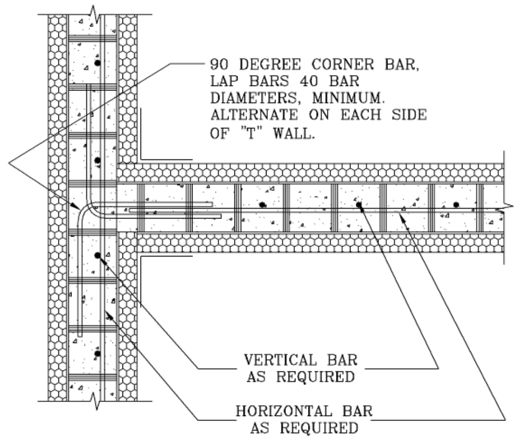

Fig. 5: AMVIC (ICF) HORIZONTAL AND VERTICAL REBAR FOR T WALL CONNECTION.
Source: www.amvicsystem.com http://www.amvicsystem.com/icf/cad

Second course of block is then installed by reversing the corner blocks so that the second course of block is offset from the first in a running bond pattern, at this point blocks leveling is checked.

After installing Window & door frames at their locations foam blocks are cut to fit around, the following courses of block are installed by continuing to overlap the courses so that all joints are locked both above and below by overlapping blocks. Blocks are to be stacked to the full wall height for a single story construction, or to just above floor height for multi-story construction. Vertical rebar is cut to length and installed from the opening at the top of the wall through spaces between the horizontal rebar.

Doors & Windows Assembly:

Emmedue M2 system, main openings for doors and windows are considered as foreseen in design during walls assembly. Minor openings can be made after walls panels’ assembly stage is finished by using cutting instruments such as circular saws, knives and pliers, Figure (6).

Openings are braced with flat mesh at 45° above and below its corners. Window sills whose span is longer than 1.2 m can be integrated with additional reinforcement on both sides. To avoid cold bridging at door and window openings a thermal break is provided between internal and external concrete, Figure (7).

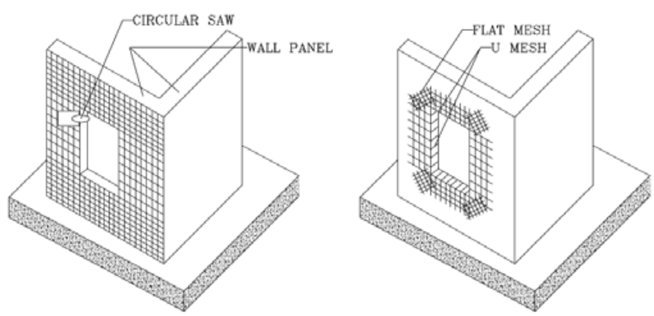

Fig. 6 and 7: Emmedue M2 adding window opening.

AMVIC (ICF) system, Window & door frames are installed during walls block installation stage. These frames are used to hold back the concrete and stay in place permanently to provide a nailing surface for the installation of windows and doors.

Concrete Stage:

Emmedue M2 system, single wall panel system is either Sprayed by Concrete mix or concrete plastered on subsequent layers. Minimum cover to reinforcement is 30mm starting at the bottom and working up. Guide rails are used to ensure require thickness.

For the double wall system concrete is poured in the inside wall core then sprayed or plastered concrete is applied for both internal and external surfaces.

AMVIC (ICF) system Concrete is poured into stacked walls using a boom pump. This process is done in layers approximately 1 meter height at a time, circling the structure until the top of the wall is reached. Mechanical pencil vibrator is used to vibrate the concrete and remove all air pockets within the wall.

Concrete is screed off until it is even with the block top and then wet set anchor bolts into the concrete top. These bolts are used later to install the top plate for installation of rafters or trusses for single story buildings.

Electrical & Plumbing Services:

Emmedue M2 system laying of pipes for plumbing, electrical installation, heating services takes place after the polystyrene panels have been erected and before the spraying of concrete takes place.

The polystyrene is melted using a hot air gun or similar tool. The electrical flexible pipes are placed under the meshwork, Figure (8).

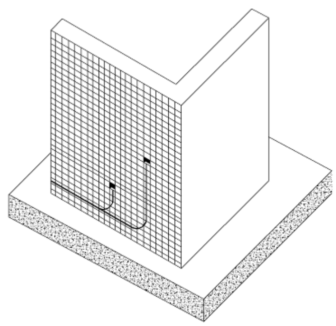

Fig. 8: Emmedue M2 adding electrical work.

For the ICF system, the plumbing main conduits are located before pouring concrete, wood sleeves are assembled to form the plumbing main cavities; 2" water pipes and electrical conduits are installed in the outer 5 cm thick block foam surface, Figure (9).

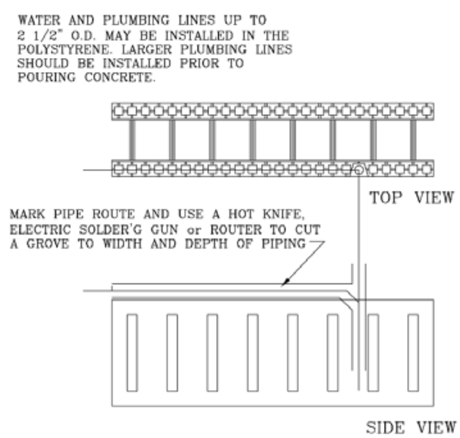

Fig. 9: AMVIC (ICF) PLUMBING INSTALLATION.
Source: www.amvicsystem.com http://www.amvicsystem.com/icf/cad

Structural Behavior:

Concrete SIPs have a different structural behavior than conventional solid reinforced concrete panels. The behavior can be broadly classified into three possible types: fully composite, non-composite and partially composite panel behavior. A fully composite behavior is one in which the two concrete wythes act integrally to resist bending. A non-composite behavior is one in which each concrete wythe acts independently to resist bending. A partially composite behavior is a one in which the shear connectors can transfer between zero and 100% of the longitudinal shear required for a fully composite panel[4]. On the other side, ICFs is a typical bearing wall system, except that they have non removable forms which provide non-structural characteristics to the wall, such as insulation and sound proofing.

Table 1 compares the minimum thickness used for each system. The minimum thickness available in the SIP system is 150 mm, composed of 100 mm foam panel covered by 25 mm concrete layer on each side of the foam. However, for the ICF system, the available minimum thickness is 225 mm. This thickness is composed of two layers of foam, 62.5 mm thick each, encompassing a 100 mm layer of concrete. From the above comparison it could be seen that the SIP system provide a 33% reduction in the panel thickness than the ICF system, 50% reduction in the concrete thickness, and 20% reduction in the foam thickness. From the structural point of view, if the two panels bear the same ultimate capacities, then the SIP system will be a preferable choice than the ICF system.

Table 1: Minimum Panel Thickness Used for Both Systems.

Minimum Thickness (mm)	SIP System	ICF System
Total panel thickness (Concrete + Foam)	150	225
Concrete thickness	25x2 = 50	100
Foam thickness	100	62.5x2 = 125

Figure 10 compares the axial compressive load of the two systems. The SIP axial load shown in the figure, represent the lowest ultimate value of three samples tested in the laboratory as per the guidelines of AC 15[5], section 4.3, Paragraph 2, which states that "The average maximum strength from each set of tests may be the average ultimate value, provided the ultimate value for each test is within 15 percent of the average. Otherwise, the lowest ultimate value shall be used."

However, the axial compressive strength of the ICF system shown in Figure 10 is calculated theoretically using the equation 6.48 of the ECP 203-2007[8], section 6.5.2.1.2 as follows:

$$P_u = 0.8\left[0.35 f_{cu} A_c \left(1 - \frac{kH}{32t}\right)^2\right]$$

Where,

Pu = Ultimate load of the wall

f_{cu} = Compressive strength of concrete at 28 days taken equal to 17.5 MPa, the same value used for the SIP system

A_c = Gross area of the wall; 1200 x 100

k = Factor equal to 0.8 assuming the wall is fixed at one or both of its ends

H = Wall height; 2400 mm

t = Wall thickness; 100 mm

The panel dimension used for the SIP system was 1200 x 2400 x 150 mm, while for the ICF system the panel dimension was 1200 x 2400 x 225 mm. However, in the above equation the wall thickness was taken equal to the concrete part of the wall, neglecting the foam on both sides of the wall.

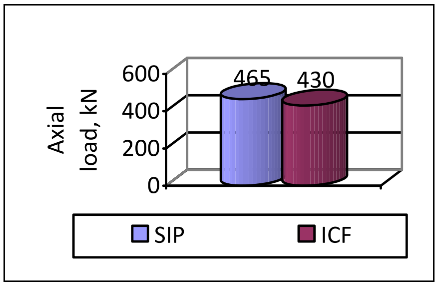

Fig. 10: Axial Load for the two systems.

Figure 10 shows that there was no significant difference in the ultimate axial load for the two systems. SIP system provides 8% more in the ultimate axial load than the ICF system. This slight increase in the ultimate loads makes, once more, SIP a preferable choice than the ICF system.

Although, SIP system can be used as floor slabs up to a specific span, based on the loading condition, it can be modified by replacing part of the foam by concrete ribs to increase the span limitations and the load carrying capacity, as shown in Figure (11).

On the other hand, ICF floor and roof system depends mainly on installing steel joists every 400 mm, these joists carry the foam blocks and form concrete ribs that carry the load to the bearing walls. Using steel joists and specific foam blocks in the ICF system limits its use to determined spans, besides the use of steel joists in Egypt is not economically a good choice, specially, if compared with the traditional hollow block system.

From the above discussion it could be concluded that SIP system is more preferable choice than ICF system because it provides less panel thickness with higher ultimate load. Moreover, it provides more alternatives in choosing the slab system.

Architectural Comparison:

1- No. of Floors

Emmedue M2 system, Single wall panel system gives the possibility of building up to six floors, while by using the double wall panel system it is possible to build up to 20 floors[9]. The ICF system it is possible to build up to twenty floors.

Fig. 11: Modified SIP system slab system Source: Global Example EMIC Company digital catalog.

2- Construction Equipment:

M2 system - single panel uses either shoot Crete machine or manual plastering simple tools to apply two structural concrete layers for both sides of wall panel, while ICF system uses ready mixed concrete and requires concrete pump if it is going to be applied in upper floors, also concrete vibrator is required for compacting the concrete wall core layer.

3- The Ability to Integrate with Different Construction Systems:

M2 system is considered to be a versatile construction system, it is completely compatible to use with other construction systems. In fact the M2 system elements are suitable for completing reinforced concrete skeleton system traditionally used in the Egyptian local market, also M2 single wall panels can be used as a light weight isolated external wall combined with the reinforced concrete skeleton system.

ICF system is a structural concrete wall bearing system that can not integrate or act as external isolated wall with reinforced concrete skeleton system.

4- Capability for Indoors Design Alterations:

4.1. Indoor Wall Demolishing:

M2 system, depending on the structural system is designed to use the internal walls as bearing wall that does not give flexibility of removing any of them, while In case that the M2 interior wall panels are designed to act as non bearing space dividers they can be demolished.

AMVIC (ICF) system is a structural wall bearing system that neither any of its structural walls can be demolished.

4.2. Electrical Work Modifications:

M2 system, electrical plugs and switches wall locations can be changed after construction stage through vertical shipping of the internal concrete layer, making all horizontal line changes under finish floor material is a preferable, also cutting galvanized wire mesh is needed for electrical wire pipes lines.

AMVIC (ICF) system electrical plugs and switches wall locations can be changed after construction stage by shipping the indoor finishing material, then by using a heated metal blade the expanded polystyrene layer can be easily grooved in either horizontal or vertical direction to fit electrical wire pipes, polystyrene layer thickness is enough to hold standard electrical boxes[10].

4.3. Plumbing Work Modifications:

M2 system wall imbedded plumbing pipe locations can be changed in vertical direction by shipping the internal concrete layer - making all horizontal pipe location changes under the floor finish material is preferable, while cutting galvanized wire mesh is needed for 1/2" water pipes lines.

AMVIC (ICF) system, wall imbedded water pipes locations can be changed in both vertical and horizontal directions easier than the M2 system, that is by shipping the internal finish material and grooving the internal expanded polystyrene layer using pre heated metal blade.

4.4. Doors & Windows:

M2 system can be adapted to fit all types of doors and windows. After construction door openings locations changes can be done by chipping the finishing material and concrete layer then cutting the door size through both the metal wire mesh and the polystyrene layer, reinforcing metal mesh is installed to the new door frame surrounds and new concrete plaster layer is applied for both wall sides. While for IFC system, doors and window locations are more difficult to change after construction, to do that finishing material layer for the new door – window location is to be chipped followed by the full thickness of the middle concrete layer then the horizontal rebar is to be cut off to fit the new door - window frame size and location.

1- Finishing Materials

M2 wall panels can be finished with the application of a thickness covering material directly on the raw plaster as an alternative or by applying a traditional paint on the smoothened plaster. Finishing application of any type is possible without any limitation. Structural concrete layers act as a plaster surface that accepts applying of any finishing material such as stucco – wood cladding, ceramic tiles. AMVIC (ICF) system accepts application of any finishing material.

2- Façade Shaping Possibilities and System's Ability to form Cantilevers:

Emmedue M2 system has the ability to form building elevation massing using cantilevers, while ICF system does not give that ability.

3- Wall Thermal Performance:

The Emmedue M2 system R Value rating for the single panel is R-37, while the ICF wall system R value has a rating of up to R-50 which saves up to 50% heating and cooling costs.

4- Sound Insulation:

Emmedue M2 System for panel PSM80 of thickness finish thickness 60 mm shows sound proofing index of 41 dBvv, whereas the ICF System STC has a rating of 50.

5- Fire resistance:

For Emmedue M2 system the quality of the foam polystyrene used for these panels is of the self-extinguishing type; moreover, the two concrete layers which coat the panel sides prevent its combustion.

The fire resistance has been also verified in tests carried out at different laboratories, complying in full with the minimum requirements of the most demanding regulations. For example, a wall realized using the PSM80 panel has shown a fire resistance greater than REI120[11].

6- Shell Shape Roofing:

Emmedue M2 system single panels can be used to form structural insulated domes and vaults curved roofing forms , while ICF system is limited for structural concrete bearing walls, shell shaped roofing if need to be used will be of brick or integrated reinforced concrete shell shape roofing.

7- Green Building Approach:

Expanded polystyrene is a leader as regards respect for the environment:

- It is SAFE: It does not release toxic or harmful substances and it is totally inert. It does not contain chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs). Furthermore, as it contains no organic material, it inhibits the growth of microorganisms and mould. The mechanical and thermal characteristics are supplied for the whole life of the building in which it is installed. It does not suffer permanent damage if exposed to vapor or humidity.
- It is RECYCLABLE: No waste materials are produced during production and the production process for the EMMEDUE® panel aims to optimize its cut, reducing waste to a minimum. Any leftover EPS is recycled directly in the production plant itself.
- It is NON-TOXIC: It does not create allergies and it does not damage the health of those producing or installing it.
- It is SELF-EXTINGUISHING: The EPS used for the EMMEDUE® panels is self-extinguishing so, once the striking cause has been eliminated, the material does not produce flames, nor does it continue to burn.

The environmental cost of producing expanded polystyrene is minimal if compared to how much energy is saved during the entire life of a building which has been correctly insulated with EMMEDUE® panels[12].

EMMEDUE® Panels Provide:

- Structures which are thermally insulated from the foundations

- continuous walls without discontinuities in construction
- Total elimination of thermal bridges
- Floors and roofs with continuous insulation on the intrados
- Load-bearing walls, also with a double layer of insulation
- Insulated ducts inside the panels

Amvic ICF structures combine expanded polystyrene (EPS) insulation and concrete thermal mass. This highly effective combination of materials minimizes temperature fluctuations by absorbing and storing heat to make superb wall forms. This equates to an average of approximately 30-50% reduction in energy consumption for heating and cooling, which results in an equivalent reduction in harmful emissions[13].

Amvic manufacturing centers use steam and cold water to produce ICFs. No CFC's, HCFC's, formaldehyde or any chemicals are used in Amvic's manufacturing process and no off-gassing is present.

Amvic ICF webs are manufactured using 100% post-industrial recycled polypropylene. This means that over 60% of the weight of an Amvic ICF block is comprised of recycled materials.

User Comments for Both Systems:

Emmedue M2 System:

On August 8, 2009 at 11:45 am, Bernardo Sánchez M mail BERN456@YAHOO.ES commented as follows:

The Emmdue M2 system is long applied in panama The problem with the panamanian construction worker is that if they born and raise with the old system, the going to shock with the saving aspects of the new, in the block system, two workers put 6 or 7 square meters (71 Sqf) in 8 hours without plaster; with M2 the same two workers put 20 or 25 square meters in the same time and need only 15 minutes for the first layer of cement plaster. The problems come depending the contractual terms, The contractors do make more profit using the block wall system so there is no financial benefit from applying M2 system unless the contractors charges the house owner the same amount of profit that he was going to gain using the traditional reinforced concrete skeleton and brick block system.

On January 15, 2010 at 12:52 pm John commented as follows:

Friends tell me to follow the traditional way of constructing buildings (at least in my country) and make my home by concrete and double red bricks for walls (with the blue insulator material intermediate). They tell me that M2 is very good in cold countries but in hot areas it is getting warm quickly and keep the heat inside for many hours after the sunset. This seems that in summer months I will have my A/C to work intensively. keeping in mind that in my country we have almost 9 months hot weather with the maximum temperature to reach 45-50oC.

Results and conclusion:

- Emmedue M2 minimum single panel 150mm thick wall uses half the concrete thickness that is used in the minimum AMVIC (ICF) wall type of thickness 250 mm thick.
- Emmedue M2 minimum single panel 150mm thick wall uses less steel weight than the horizontal and vertical rebar in the AMVIC (ICF) wall type of thickness 250 mm thick.
- AMVIC (ICF) wall type of thickness 250 mm thick ICF walls have a higher R-value, lower noise infiltration than Emmedue M2 single panel 150mm thick wall.
- AMVIC (ICF) system can be used to construct basement floor while Emmedue M2 can only be used above grade.
- Both construction systems shared the green-building approach of energy saving by reducing the amount energy used for heating and cooling residential units.
- M2 system applied in the Egyptian market showed flexibility to be used as independent construction system or to combine with reinforced concrete skeleton systems and act as isolated wall element. In some cases the M2 system is applied for raising extra floors in exiting buildings for its lightness in weight and wall thickness. Also it had showed acceptance for the benefit that external and internal wall surface has a cement plaster look that most of the Egyptian building user is accustomed to have.

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