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Moisture in ICF Walls

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KEYWORDS

Concrete, details, distress, drying, foundations, insulating concrete form, ICF, moisture, relative humidity, water vapor retarder, windows.

ABSTRACT

The use of insulating concrete form (ICF) wall systems is growing at an exponential rate throughout North America. ICF wall systems are being used for a variety of housing types ranging from custom to production, expensive to affordable, and single- to multi-family. The scale on which ICF wall systems are being used has grown from scattered individual buildings to entire subdivisions.

The potential for moisture problems in ICF walls was investigated to determine if the walls have any inherent properties that make them susceptible to moisture problems. The investigation was conducted in several phases. In the first phase, wall sections were constructed and instrumented to determine rates of drying as affected by various combinations of exterior and interior finishes and vapor retarders. After one year of monitoring in a controlled atmosphere, the walls were carefully disassembled and examined for signs of moisture-related distress. No signs of moisture damage or distress were noted.

The second phase involved analyses of the condensation potential of wall sections utilizing various interior finishes, vapor retarders, and exterior finishes. Analyses were performed for winter and summer seasons for locations throughout North America. Results of the analyses led to recommendations on vapor retarders.

The final phase involved recommending standard window details to mitigate water entry at joints. Additional details were developed to address proper practices for exterior walls, from the foundation to the eave, for a variety of exterior finishes and construction types. Details were developed with the assistance of construction tradespeople to facilitate effective, yet practical, means of ICF construction.

REFERENCE

Gajda, John, and VanGeem, Martha G., *Moisture in ICF Walls*, R&D Serial No. 2190a, Portland Cement Association, Skokie, Illinois, 2001, 65 pages.

Moisture in ICF Walls

by John Gajda and Martha VanGeem*

INTRODUCTION

The use of insulating concrete form (ICF) walls has increased significantly in the residential housing market. Initially, ICFs were utilized primarily in custom homes, but these systems are being used more often to construct homes in a variety of sizes, and price ranges, and in developments of various sizes.

ICF wall systems are promoted as superior to conventional wood-frame construction because of their energy efficiency and ease of construction. However, like their wood-frame counterparts, ICF walls also require attention to detail so that moisture problems can be avoided.

Moisture problems encountered using wood frame include condensation, peeling paint, mold, and mildew. These conditions often occur simultaneously with high indoor relative humidity. The cause of moisture-related problems can be high levels of moisture within the conditioned living space, improperly designed HVAC equipment, or an improperly designed building envelope. Undetected moisture ingress at window joints can cause rotting of wood-frame construction.

An investigation was performed to determine the potential for moisture problems in ICF walls due to moisture from construction, water vapor transmission, improper placement of a vapor retarder, and window framing and flashing details.

This report summarizes the complete report that thoroughly details all aspects of the investigation. The complete report(1), entitled "Investigation of Moisture in Insulating Concrete Form Walls," is available through the Portland Cement Association. The reader is strongly encouraged to read and understand the information provided in the compete report.

DRYING OF ICF WALLS

ICF walls contain large quantities of moisture immediately after placement of the concrete. Normally this moisture escapes after construction as the concrete dries; however, questions have arisen as to whether the concrete contributes to moisture problems common in some climates.

Building materials such as polystyrene insulation, vapor retarders, and EIFS are relatively impermeable to water vapor transmission. These materials may trap water vapor within the wall, or may slow the water vapor transmission so that moisture-sensitive materials such as wood and drywall may become wet for long periods of time. Although concrete is not damaged by moisture, wood and drywall are easily damaged by moisture.

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Six typical ICF walls were constructed and monitored for one year to determine their drying rates. These walls each had different insulation, exterior finishes, and interior finishes. The internal relative humidity of the walls was measured for steady-state (constant) drying conditions to investigate the effect of different construction materials on the rate of drying of ICF walls.

Walls

ICF wall sections were constructed utilizing a variety of commercially available ICFs, interior finishes, and exterior finishes, as indicated in Table 1.

Table 1. ICF Wall Construction Matrix

<table>
<tr><th>Wall No.</th><th>Interior Finish</th><th>Vapor Retarder</th><th>Insulation Type*</th><th>Exterior Finish</th></tr>
<tr><td>1</td><td rowspan="6">Painted Drywall</td><td rowspan="2">None</td><td>XPS</td><td rowspan="3">EIFS</td></tr>
<tr><td>2</td><td rowspan="5">EPS</td></tr>
<tr><td>3</td><td rowspan="2">Interior</td></tr>
<tr><td>4</td><td rowspan="2">Hardboard Lap Siding</td></tr>
<tr><td>5</td><td>None</td></tr>
<tr><td>6</td><td>Interior</td><td>Portland Cement Stucco</td></tr>
</table>

* EPS is expanded polystyrene (bead) board insulation and XPS is extruded polystyrene board insulation.

Wall sections were approximately 4-ft (1220-mm) wide by 4-ft (1220-mm) high and ranged from 10¾-in. (273-mm) to 11 -in. (295-mm) in total thickness, depending on the exterior finish materials.

Materials. For all walls constructed, the ICF wall system consisted of a typical flat panel system with plastic ties that penetrated the exterior of the insulation. Insulation was approximately 2-in. (50-mm) thick, and the concrete core was approximately 6-in. (150-mm) thick.

A commercially available pumpable 3,000 psi (21 MPa) concrete was used in the wall sections. The concrete had a slump of 6½ in. (165 mm), an air content of 7%, and a measured 28-day compressive strength of 3,600 psi (24.8 MPa). Reinforcing steel was included as described in the complete report(1).

Interior finishes for all walls consisted of nominal ½-in. (13-mm) drywall. The drywall was painted with one coat of a latex-based primer-sealer and one coat of latex flat wall paint. The interior vapor retarder consisted of clear 6-mil (0.15-mm) polyethylene plastic. Drywall was fastened directly to the plastic ties on the surface of the ICF units.

Exterior finishes consisted of portland cement stucco, EIFS, or hardboard lap siding. The portland cement stucco consisted of a standard three-coat system. The total thickness of the stucco was approximately ¾-in. (19-mm). The EIFS consisted of a commercially available three-coat system. The total thickness of the EIFS coating was approximately ¼ in. (6 mm). The portland cement stucco and EIFS finishes were supplied and applied by a reputable plastering contractor, and were applied in direct contact with the polystyrene insulation. Hardboard lap siding with a nominal thickness of in. (10 mm) was furred with x 1½-in. (10 x 38-mm) wood furring strips because the spacing of the integral ICF plastic fastening tabs did not correspond with fastener spacing requirements of the hardboard lap siding. The exterior face of the hardboard siding was factory painted. Barrier materials such as asphalt saturated felt or house wrap were not used.

All finishes were attached to the ICF walls three to seven days after placement of the concrete. Although this timeframe was shorter than actual practice, finishes were attached at this time to simulate the “worst-case” situation with a high initial quantity of trapped moisture.

Measurement Ports. Relative humidity and temperature measurement ports were installed in the center of the concrete, at the concrete-polystyrene interfaces, and at interfaces between the polystyrene and interior/exterior finishes. Measurement ports were installed prior to or during wall assembly.

Measurement ports consisted of ½-in. (13-mm) inner-diameter PVC pipes that extended from outside the wall section to the desired interface. Ports were installed in such a manner to ensure that no moisture escaped by migrating along the inside or outside of the measurement port.

Measurement ports were located near the center of each wall section to guard against edge effects and were adequately spaced to minimize the potential for one port to affect the measurements at adjacent ports.

Commercially available high-accuracy (±3%) relative humidity probes and thermocouples were installed in the measurement ports. Type T thermocouples with special limits of error (±0.4%) were used to measure the temperature of the walls and the storage environment. Temperature and humidity data were logged by a multichannel data logger at 4 to 8 hour intervals.

Edge Sealing. The sides of the wall sections were sealed to prevent moisture from escaping and to force all moisture migration through the interior and exterior finishes of the walls. The sealing material consisted of a composite material of Mylar and aluminum foil. The manufacturer indicated that the material was impermeable to moisture with a permeability of 0 perms (0 ng/Pa s m^2). Figure 1 shows the application of the sealing material to the sides of the walls. Note the three measurement ports denoted by the arrows.

Figure 1. Photograph showing edge sealing being applied to a wall section with three measurement ports.

Storage Environment. Walls were stored and continuously monitored in a temperature and humidity controlled room for a period of one year. The nominal ambient conditions in the room were 73ºF (23ºC) and 50 percent relative humidity (RH).

Drying Results

In general, all wall sections dried adequately. The rate of drying is dependent on the materials used for construction of the walls. Over the one-year period, the wall sections lost 0.5 to 1.5% of their total initial weight. This weight loss is attributable to drying of the concrete and other materials.

Relative humidity measurements within the wall sections also indicated that the walls dried. Figure 2 presents the typical change in relative humidity in a wall section over the one-year period.

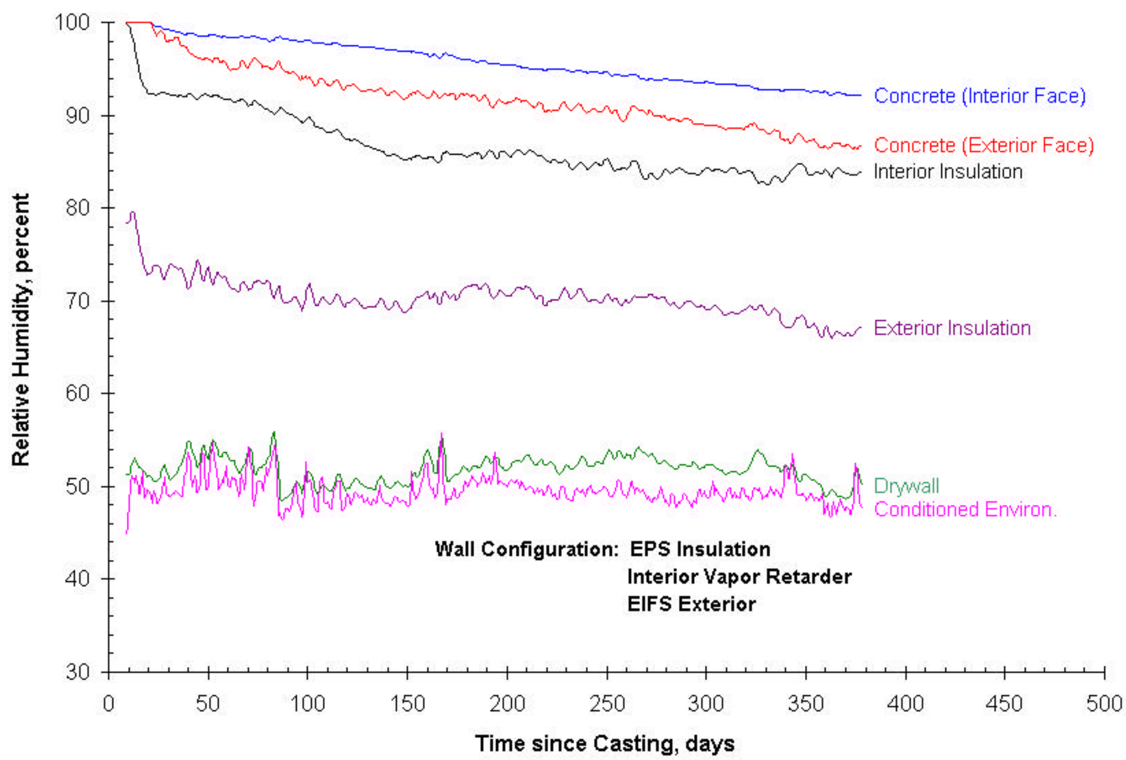

Figure 2. Relative humidity data showing the drying of a wall section.

Summary results of initial and final measured relative humidity data are presented in Table 2. Detailed results are presented in the complete report[1].

Walls were disassembled and materials from the walls were visually examined for moisture-related damage such as mold, mildew, corrosion, rot, and fungi attack. Visual inspection revealed that none of the building materials from any of the walls suffered from moisture damage. The only exception was that minor surface corrosion (rust) was observed on portions of drywall screws removed from the walls. The corrosion was limited to the portion of the screw that penetrated the polystyrene insulation, as shown in Fig. 3. It was not possible to determine when the corrosion started, or if it may be a long-term concern. It is important to note that the interior finishes were installed within three to seven days after the concrete was placed in the ICF. This was done with the intent of trapping moisture in the wall and is not typical of actual construction practices.

Table 2. Summary of Measured Relative Humidity from Walls.

Wall No.**	Measured Relative Humidity*, %						
		Drywall	Interior Insulation	Concrete			Exterior Insulation
				At Interior	Center	At Exterior	
1	Initial	50	66	100	–	100	70
	Final†	52	59	86	–	89	64
2	Initial	56	77	100	100	100	67
	Final†	52	57	82	87	82	61
3	Initial	51	100	100	–	100	79
	Final†	50	84	92	–	87	67
4	Initial	53	92	100	–	100	75
	Final†	51	76	89	–	82	68
5	Initial	60	98	100	–	100	60
	Final†	54	65	77	–	77	58
6	Initial	51	94	100	–	100	98
	Final†	51	82	91	–	89	71

* The average relative humidity of the storage environment was 50%.
** For a description of the each wall, please refer to Table 1.
† After one year.

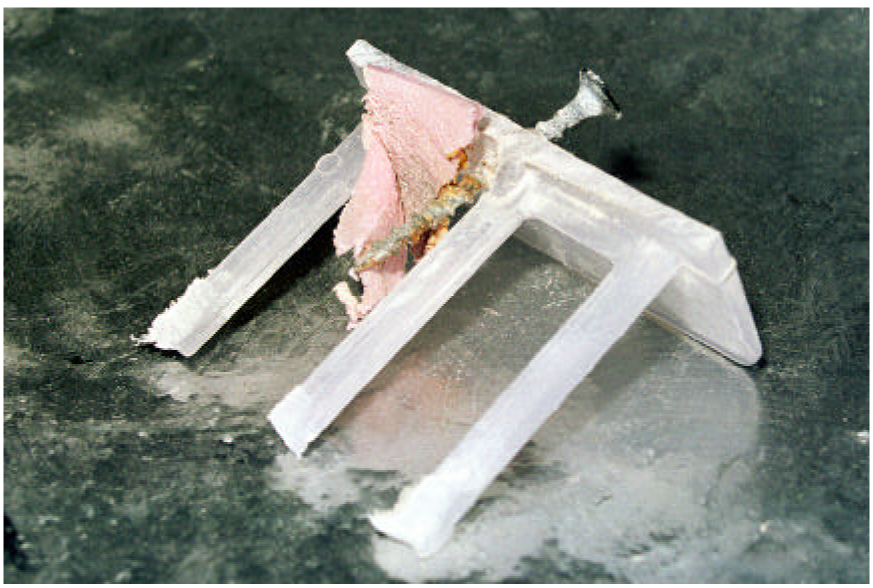

Figure 3. Drywall screw with minor surface corrosion (see details in the text).

The moisture content of samples removed from the wall sections was determined on the oven-dry mass basis. All materials had typical moisture contents that fell in typical equilibrium ranges as reported by others[(2,3)]. The average moisture content of the concrete, drywall, insulation, wood siding, stucco, and EIFS was 4.8%, 0.6%, 0%, 6.2%, 2.9%, and 2.4%, respectively.

Based on the rate of drying measurements, no changes to current practice are recommended regarding the use of concrete, polystyrene insulation, exterior finishes, or interior finishes. These materials all performed adequately and did not show signs of moisture-related distress after the one-year period.

CONDENSATION ANALYSES

The potential for condensation within ICF walls was modeled for a variety of climates throughout North America. Condensation problems can potentially lead to degradation of the effective insulation R-value(4), deterioration of drywall or finishes, and mold or mildew.

The ultimate goal of the analyses was to determine if a vapor retarder is required and, if so, to develop a standard guideline for the use of vapor retarders in ICF construction applicable to North America.

Locations and Climate

Twelve climates throughout North America were selected for the condensation analyses. These locations were selected to represent a wide range of climates, with a bias towards those with known moisture problems. Selected climates include 11 locations in the U.S. and one location in Canada. Locations included:

- Charlotte, North Carolina
- Cincinnati, Ohio
- Edmonton, Alberta
- Fairbanks, Alaska
- Lake Charles, Louisiana
- Los Angeles, California
- Madison, Wisconsin
- Miami, Florida
- Minneapolis, Minnesota
- Phoenix, Arizona
- Seattle, Washington
- Washington, D.C.

Analyses required the use of constant indoor and outdoor temperatures and relative humidity conditions. Outdoor temperature conditions consisted of the ASHRAE winter and summer design conditions(2), and historical average January and July conditions(5, 6). Design temperatures are more extreme than average temperatures. Outdoor climatic data utilized in the analyses are presented in Table 3.

Indoor conditions were assumed to vary by season. The winter indoor condition was assumed to be 72°F (22°C) and 50% RH. Two summer indoor conditions were assumed. The summer indoor condition without air conditioning was assumed to be 75°F (24°F) and 80% RH. The air-conditioned indoor summer condition was assumed to be 73.5°F (23.1°C) and 65% RH.

Table 3. Outdoor Conditions for the Condensation Analyses

Location	Winter Design		Avg. January		Summer Design		Average July	
	°F	% RH	°F	% RH	°F	% RH	°F	% RH
Fairbanks, AL	-47	67	-12.8	67	78	60.5	61.5	60.5
Edmonton, AB	-25	73	9.5	73	82	66	60.1	66
Minneapolis, MN	-12	69	11.2	69	89	67	73.1	67
Madison, WI	-7	73.5	15.6	73.5	88	71	70.6	71
Cincinnati, OH	6	73	28.9	73	90	71	75.4	71
Seattle, WA	26	77	39.1	77	80	65	64.8	65
Washington, D.C.	17	61	35.2	61	91	64.5	78.9	64.5
Charlotte, NC	22	67	40.5	67	93	73	78.5	73
Lake Charles, LA	31	78	51.5	78	93	78.5	82.3	78.5
Los Angeles, CA	43	64.5	56	64.5	80	76.5	69	76.5
Phoenix, AZ	34	50	52.3	50	107	32.5	92.3	32.5
Miami, FL	47	71.5	67.1	71.5	90	74	82.4	74

Note: °C = (°F - 32) ÷1.8

Wall Materials

All exterior and interior finishes described in the *Drying of ICF Walls* section of this report were analyzed for condensation potential. Additional wall sections and materials were also analyzed.

Interior finishes included latex paint and vapor retarding paint. Vapor retarders consisted of 4-mil (0.1 mm) polyethylene sheeting on interior (those between the insulation and the drywall), exterior (those between the insulation and the exterior finish), or no vapor retarder. Exterior finishes included hardboard lap siding, EIFS, and portland cement stucco. Insulation included XPS, EPS, and no insulation. Cases with no insulation were analyzed to consider the effect of embedded electric conduits, plumbing, gaps in the insulation, and other reasons for reduced or missing insulation.

The reader is referred to the compete report[1] for additional details regarding the analyses and the moisture transmission properties of the materials.

Analysis Method

Steady-state water vapor diffusion analyses were performed to evaluate the potential for condensation in typical ICF wall sections. Analyses were performed in accordance with Annex A1 of ASTM C 755-97, “Standard Practice for Selection of Vapor Retarders for Thermal Insulation.” The analyses provided the location of the surfaces on which condensation potentially occurs.

Condensation Philosophy

Designing wall sections to prevent condensation during winter design conditions is good practice, but may result in over-design of the wall.

The ASHRAE winter design conditions used in the analyses are predicted to occur 54 hours per year, but occasionally occur for continuous periods of three to five days. Typically, condensation that occurs in the winter design condition, but not in the average January condition, is frequently able to evaporate during other periods and not cause damage. However, continuous condensation without drying periods will result in accumulation of moisture in or on the walls.

Recommendations in this report utilize the winter design criteria, but also accept walls that exhibit potential condensation in the winter design condition but not during the average January condition.

Although some industry experts argue that ICF walls have the capability of storing a large amount of condensation and other moisture without adverse effects, this capability was considered to be an additional factor of safety against moisture problems, and was not considered in these analyses. Therefore, recommendations regarding the use of vapor retarders in this report are conservative. The utilization of less stringent criteria may result in condensation problems and potential long-term moisture damage to walls.

Results of Condensation Analyses

Analyses indicate that to prevent condensation, a vapor retarder* with maximum permeance of 0.1 perm (6 ng/Pa · s · m^2) is recommended between the insulation and interior finish (drywall) for Madison, WI, and colder climates. Therefore, interior vapor retarders are recommended for climates with 7000+ heating degree-days, base 65°F (HDD65). Figure 4 provides general guidance as to the locations where an interior vapor retarder is recommended. Table A1 in Appendix A provides this information by state and major city. The National Climatic Data Center (www.ncdc.noaa.gov) has additional heating degree data for thousands of additional locations across the U.S. and Canada.

Warmer climates do not require the use of an interior vapor retarder. An exterior vapor retarder is <u>not</u> recommended in hot and humid climates.

Gaps or holes in insulation can cause condensation on walls in most locations. To prevent condensation due to gaps between insulation boards or holes in insulation, it is advisable to fill or seal all holes and gaps using a material with a low water vapor permeability. Such materials include may include expanding foam and silicone sealants.

* Polyethylene sheeting with a thickness of at least 4 mil (0.1 mm) meets this requirement.

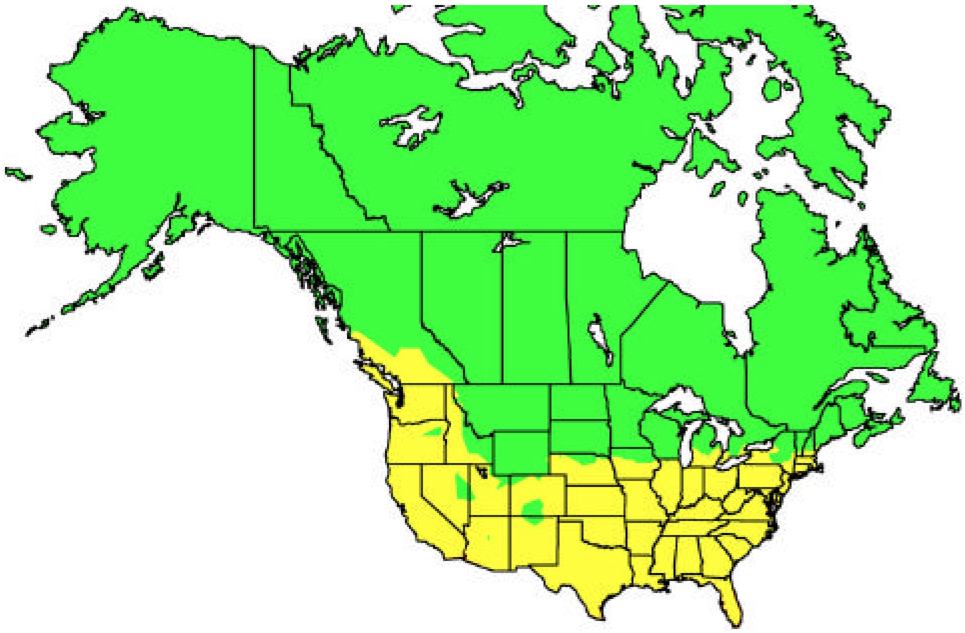

Figure 4. General guide showing locations (shown in green) where an interior vapor retarder is recommended.

Damage can occur to unprotected hardened concrete subjected to cycles of freezing and thawing. Insulation in the analyzed flat-panel ICF systems protects concrete from freezing when the outdoor temperatures are in the range of 32 to -15°F (0 to -26°C); however, use of adequately air-entrained concrete in ICF walls is recommended for locations where the outdoor temperature regularly falls below -15°F (-26°C). Table A1 indicates locations where air-entrained concrete is recommended.

DEVELOPMENT OF ICF WINDOW AND WALL DETAILS

Generalized standard details for whole-wall sections and windows were developed for ICF wall systems. These details consider a variety of exterior finish materials, window types, and building types.

Details were designed to be robust yet practical, with multiple layers of protection against infiltration of water. Details were developed using good building science principles and were designed to last for the life of the structure.

These details represent the best available practices, which were generalized to be applicable to most ICF wall systems. Manufacturer-supplied details for a specific ICF system should be used if available.

Building Science Principles

An understanding of good building practices is essential for developing and constructing walls that shed water and do not leak. Understanding the design philosophy is the first step in constructing high quality ICF walls that do not leak.

The details utilize the exterior finish as the first defense against water intrusion. This barrier stops a majority of the water. The polystyrene of the ICF is utilized as a secondary rain-screen barrier to protect the interior of the house from water that passes through the exterior finish. The practice of utilizing a secondary rain-screen barrier is common in wood-frame construction.

Use of the outside surface of the polystyrene as a secondary rain-screen barrier assumes that the ICFs are free of gaps (at joints), holes, and other defects. Holes or other defects in the ICF must be sealed with water-resistant materials that are compatible with the ICFs. Materials may include expanding foam or silicone sealant. Sealant materials should be of the highest quality with an expected life similar to that of the ICF walls. Vertical and horizontal gaps between non-interlocking ICFs, greater than -in. (3-mm) should be sealed. Gaps in interlocking ICF systems where the concrete can be seen should also be sealed. Alternatively, if sealing a large number of gaps is impractical, a water-resistant building paper should be utilized. The details presented in this report do not utilize building paper; therefore if building paper is utilized, proper design and construction practices should followed so the building paper functions properly as a secondary rain-screen barrier.

Caulking (sealant) is not utilized as the only means of defense against water intrusion. Caulk is fragile, with a limited life estimated at 5 to 10 years. Homeowners normally neglect maintenance of caulking and are often unaware of its importance.

EIFS, by design, requires the use of sealant at joints as the primary defense against water intrusion. For this reason, EIFS manufacturers have recently redesigned their systems to include a drainage plane. The incorporation of a drainage plane between the EIFS and the polystyrene of the ICF wall is recommended for ICF construction. In litigations, it is common for the EIFS manufacturers to deny any responsibility for damage if the installation deviated in any way from their specific installation instructions. Use of the complete EIFS system minimizes potential liability concerns for ICF manufacturers, in the event that moisture penetrates the EIFS surface.

Window Detail Philosophy. Recessed windows typically utilize a recessed wood buck, placed within the polystyrene panels. This type of buck is difficult to form during construction because it requires precision cutting and fitting, and it does not work with all types of ICF systems. For these reasons, the window details developed utilize a treated wood buck that spans the full thickness of the ICF walls.

All bucks are positively anchored into the concrete by galvanized screws. Anchors are fastened to the rough buck before the buck is placed in the ICFs. Galvanized anchors are required because moisture from the concrete will corrode non-galvanized anchors in a short period of time. Rough bucks should be constructed using high quality pressure-treated lumber. Untreated wood, in direct contact with concrete, will rot and decay.

It is assumed that seals within windows will eventually fail and cause leaks. The details include a means for water to be diverted out of the wall with flashing below the windows.

Recessed windows are preferred over flush-mount windows because many moisture-related problems are attributed to the use of flush-mount windows. This is due to flush-mount windows having a majority of the joints between dissimilar materials present at the exterior surface of buildings. Flush-mount windows are subject to as much precipitation as the exterior finish, while recessed windows are somewhat more protected. Protection of these joints from precipitation results in decreased rates of degradation of sealant and moisture-susceptible materials.

Whole Wall Detail Philosophy. Proper drainage away from the building is essential for long-term successful performance of any type of wall. In all of these details, foundation drainage systems have not been shown. Considerable debate exists as to the ideal placement of the drainage system. In addition, these systems are not required in many locations throughout North America. The reader is left to consult local building codes for the proper type and placement of the system.

For control of moisture, the soil should be a minimum of 6-in. (150-mm) below the top of the foundation. This is commonly required in residential building codes. Soil is shown to slope away from the foundation at a 5% grade for approximately 10-ft (3-m). Additional moisture control considerations for areas with a high water table include installation of a capillary break between the footing and foundation wall. This will prevent moisture from wicking into the concrete of the foundation wall.

Dampproofing and waterproofing are called out in the details. It is important to note the differences between the two, since dampproofing is not intended to resist the flow of water. Dampproofing is typically used on cast-in-place concrete in locations with porous soils with no water head. Waterproofing may be used under all conditions. The physical differences between dampproofing and waterproofing are also significant. Dampproofing is typically a fluid applied bituminous film that is applied to the outside surface of a cast-in place concrete wall. Waterproofing, at a minimum, typically consists of two plies of 6-mil (0.15-mm) polyvinyl chloride, or two plies of 55-lb (25-kg) asphalt saturated felt paper hot mopped into place. These materials may not be compatible with ICFs; however some ICF manufacturers have or recommend ICF-compatible waterproofing systems.

Wall reinforcement, floor anchoring, foundation size, and minimum foundation depth are not included or implied. Additionally, while spread footings are shown in most details, this type of footing should not be assumed to be appropriate. Foundation details must be engineered to address local codes. Design of the structure must provide the basis for these details. The details provided in this report address only the management of water and moisture.

Window Details

Window details were developed and designed to be applicable to all types of ICF systems, including flat panel, waffle-grid, and screen-grid systems. More information on various types of ICF systems is presented in Reference 7. Consideration was given to developing cost effective designs that are easily constructible.

In an effort to make this report more readable, window details are presented in Appendix B. Additional information, including step-by-step directions and three-dimensional sequenced renderings for installing windows in ICF wall systems are provided in the complete report[1].

General notes regarding all of the window and wall details are provided in Fig. B1. Figure B2 shows typical head flashing end dam, flashing, and sealant details common to all of the details. End dams on window head flashing are common to the flush-mounted windows presented. The head flashing with end dams is utilized to channel any water that penetrates the exterior finish out of the wall. The sealant detail illustrates the proper method of applying sealant to joints. This detail is provided because proper installation of sealant is important, and it is often not properly installed.

Figure B3 presents an ICF wall with a flush-mount (surface mount) vinyl window and lap siding. The detail shows a flanged window. Because wood and cement board lap siding can hold significant amounts of moisture, the lap siding is separated from the polystyrene by an air space. The air space is formed by using 1x furring.

Figure B4 presents an ICF wall with a flush-mount wood window and EIFS. Almost any window with or without a flange can be used. The EIFS is not bonded directly to the polystyrene of the ICFs. The EIFS industry recommends the use of an exterior drainage plane. This is accomplished by using an additional layer of fluted polystyrene board, as required by the EIFS industry. Use of the complete EIFS system minimizes potential liability concerns for ICF manufacturers, in the event that moisture penetrates the EIFS surface.

Figure B5 presents an ICF wall with a flush-mount wood window and a portland cement stucco exterior finish. Almost any window with or without a flange can be used. Portland cement stucco is placed over a paper backed metal lathe. The paper backing is used as a bond breaker and also creates a drainage plane.

Figure B6 presents a recessed vinyl clad window with a nailing flange and a portland cement stucco exterior finish. This detail includes a pre-cast concrete sill. The detail utilizes a buck with special framing and partial removal of insulation to provide support for the concrete sill. Building codes require that masonry sills be supported by concrete.

Figure B7 presents an ICF wall with a flush-mount vinyl window and vinyl siding. Figure B8 presents a recessed vinyl-clad window and vinyl siding. Details presented in Figures B7 and B8 are anticipated to be the most common details for use in production housing.

Whole Wall Details

Standard details for exterior ICF walls are presented that consider the entire wall, from the roof to the footing. The details consider a variety of exterior finishes including vinyl siding, lap siding, portland cement stucco, and EIFS. Details also consider a variety of foundation types including slab-on-grade, exterior insulated concrete basement / crawlspace walls, and ICF basement / crawlspace walls.

Sixteen details were developed and are presented in Appendix C. The details are divided into four groups. The first group considers above-grade ICF walls constructed on below-grade ICF walls. The second group considers above-grade ICF walls constructed on a concrete slab-on-grade with an integral perimeter beam. The third group considers above-grade ICF walls constructed on below-grade insulated concrete walls. The final group considers the termination of the ICF wall at the roofline. Within each group, four exterior finishes are considered. The exterior finishes include vinyl siding, lap siding, portland cement stucco, and EIFS. The details are provided to complement the window details presented in Figs. B3 though B8.

Control measures for insect infestation have not been included in the details; however, consideration of their potential for damage is very important.

General notes regarding the wall details are provided in Fig. C1.

ICF Walls on Below-Grade ICF Walls. Figures C2 through C5 show construction of below-grade ICF wall systems. The below-grade ICF walls are provided to form a basement or crawlspace.

The basement or crawlspace floor sits on polyethylene and a compacted coarse aggregate sub-base. The role of the polyethylene is two-fold. First, it acts as a vapor retarder. Second, it provides a capillary break so that water that may exist in the base is not drawn through the concrete into the house. Welded wire mesh is shown in the concrete floor to control potential cracking. Interior finishes are shown in the basement or crawlspace area. The interior finishes are required for ICF walls by most building codes.

The wood floor framing is hung from a pressure-treated ledger at the perimeter of the building. The pressure-treated lumber is attached to the concrete of the ICF wall with anchor bolts. The concrete boss (projection) is not continuous. Edges of the boss should be cut at 45° angles to minimize potential cracking of the hardened concrete. A polyethylene sheet is used to provide a capillary break between the lumber and the concrete.

An elastomeric waterproofing is recommended on the below-grade exterior face of the ICF wall. The waterproofing should be compatible with the ICF materials and should have the ability to bridge any gaps due to future settlement. An additional below-grade foam material is recommended for protection of the waterproofing material from soil. Because the insulation of the ICF is relatively soft, waterproofing materials are easily punctured by debris in the soil as well as movement of the soil during freezing conditions.

Polystyrene on the exterior face of the wall requires protection from the environment. Portland cement stucco or UV-resistant membrane is required. In areas with a high water table or moist soil, a capillary break should be placed between the footing and ICF foundation wall to prevent capillary rise of water into the wall. The capillary break may consist of polyethylene sheeting or any other ICF compatible membrane-forming material.

Figures C2, C3, C4, and C5, respectively, show the vinyl siding, lap siding, portland cement stucco, and the EIFS variations.

ICF Walls on a Concrete Slab-on-Grade. Figures C6 through C9 present above-grade ICF walls constructed on a concrete slab-on-grade with a perimeter grade beam.

The concrete slab-on-grade is placed on polyethylene plastic and on a compacted coarse aggregate sub-base. The role of the polyethylene is two-fold. First, it acts as a vapor retarder. Second, it provides a capillary break so that water that may exist in the base is not drawn through the concrete into the house. The polyethylene should continue under the below-grade insulation board. The role of the welded wire mesh is to control cracking of the concrete.

It is assumed that the below-grade insulation board is used as formwork in casting the foundation. Therefore, waterproofing is not shown. In locations with a high water table, it is advisable to apply waterproofing to the insulation board. Waterproofing, if applied, should be compatible with the insulation. An additional below-grade foam material is recommend for protection of the waterproofing material from soil. Because the insulation is relatively soft, waterproofing materials are easily punctured by debris in the soil as well as movement of the soil during freezing conditions.

Above-grade insulation board requires protection from the environment. Portland cement stucco or a UV-resistant membrane is required.

Figures C6, C7, C8, and C9, respectively, show the vinyl siding, lap siding, portland cement stucco, and the EIFS variations.

ICF Walls on Below-Grade Insulated Concrete Walls. Figures C10 through C13 present above-grade ICF walls constructed on below-grade insulated cast-in-place concrete walls. The below-grade walls are provided to form a basement or crawlspace. The below-grade insulation board is assumed to be polystyrene. Interior finishes are not shown.

The basement or crawlspace floor sits on polyethylene plastic and on a compacted coarse aggregate sub-base. The role of the polyethylene is two-fold. First, it acts as a vapor retarder. Second, it provides a capillary break so that water that may exist in the base is not drawn through the concrete into the house. Welded wire mesh is shown in the concrete floor to control shrinkage cracking. Expansive joint filler is shown at the perimeter because a compressible material is required at the interface of the wall and floor.

The wood floor decking is hung from a pressure-treated ledger at the perimeter of the building. The pressure-treated lumber is attached to the concrete of the ICF wall with anchor bolts. The concrete projection (boss) is not continuous. Edges of the boss should be cut at 45° angles (not shown) to minimize potential cracking of the hardened concrete. A polyethylene sheet is used to provide a capillary break between the lumber and the concrete.

Polystyrene on the exterior face of the wall requires protection from the environment. Portland cement stucco or a UV-resistant membrane is required. In areas with a high water table or moist soil, a capillary break should be placed between the footing and foundation wall to prevent capillary rise of water into the wall. The capillary break may consist of polyethylene sheeting or any other compatible membrane-forming material.

Dampproofing or waterproofing is required on the below-grade exterior face of the concrete wall. The details do not use the polystyrene as a free-draining membrane or board. Although water may get behind or into the insulation board, it is utilized only as insulation.

Figures C10, C11, C12, and C13, respectively, show the vinyl siding, lap siding, portland cement stucco, and the EIFS variations.

ICF Walls at the Roofline. Figures C14 through C17 present the termination of the ICF walls at the roofline. For these details it is assumed that the attic space is not utilized as a living area.

Overhangs (eaves) of 18 to 24-in. (450 to 600-mm) provide additional protection to walls, windows, and joints. Structures with overhangs have less moisture-related problems than those without overhangs.

To provide a means for ventilation, full depth blocking with a "V" notch is used. Although not widely enforced, most building codes require full depth blocking between trusses. A vapor retarder is shown above the drywall in the ceiling. Considerations should be made for the placement or need of this vapor retarder based on local codes and climate conditions.

Figures C14, C15, C16, and C17, respectively, show the vinyl siding, lap siding, portland cement stucco, and the EIFS variations.

SUMMARY AND CONCLUSIONS

An investigation was performed to explore the potential for moisture problems associated with ICFs and to develop standard recommendations and guidelines to avoid problems.

During the investigation, wall sections were constructed and instrumented with temperature and relative humidity sensors to determine rates of drying as affected by various combinations of exterior and interior finishes and vapor retarders. As a worst-case, interior and exterior finishes were applied to the ICF within 3 to 7 days after the concrete was placed, and wall sections were stored in a 50% RH environment. In actuality, interior finishes are applied several weeks or more after concrete is placed into the ICFs.

Analyses were performed to evaluate the condensation potential of wall sections utilizing various interior finishes, vapor retarders, and exterior finishes. Steady-state condensation analyses were performed for winter and summer design conditions and average January and July conditions for 12 locations throughout North America.

Standard window details were developed to mitigate water entry at joints. Six standard window details were developed to work with the majority of ICF systems. The details were designed to be robust but practical, with multiple barriers against water intrusion. The details considered both recessed and flush-mount wood and vinyl windows.

Additional details were developed to address proper practices for exterior walls, from the foundation to the eave, for a variety of exterior finishes and construction types. Foundations consisted of an ICF basement or crawlspace wall, a conventional exterior insulated concrete basement or crawlspace wall, and a concrete slab-on-grade with a perimeter beam.

The following conclusions are based on the drying of walls in the laboratory and the condensation analyses.

1. ICF walls and materials dried during the one year of monitoring in the 50% RH environment.
2. At the end the one-year period, the concrete, polystyrene, drywall, and exterior finishes performed adequately and did not show any signs of moisture-related distress. Additionally, the moisture content of the various materials in the ICF walls at the end of the one-year period was found to be similar to equilibrium moisture contents reported by others.
3. Upon removal from the wall sections, minor surface corrosion was noted on the portion of drywall screws embedded in the polystyrene. It was not possible to determine the onset of corrosion, or if it would be a long-term problem. It should be noted that moisture was purposely trapped in the wall sections by installing finishes much sooner than normal.
4. Results of the condensation analyses indicate that a vapor retarder is recommended between the drywall (interior finish) and insulation in cold weather climates (Madison, WI and colder). Cold weather climates, in this case, consist of locations with average annual heating degree-days base 65 (HDD65) of 7000 or greater.
5. Analyses indicated that an exterior vapor retarder is <u>not</u> recommended in hot and humid climates because it can potentially cause condensation within ICF walls.
6. Analyses indicate the potential for freeze-thaw damage to hardened concrete in ICF walls at outdoor temperatures below -15°F (-26°C). As a result, adequately air entrained concrete is recommended for ICF walls in locations with winter design temperatures below -15°F (-26°C). Locations where this may be a potential problem are presented in Appendix A.

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DISCLAIMER

The recommendations and ideas presented in this report are based on a specific laboratory program and analyses, engineering judgment, and best available practices at the time of publication. Performance testing of the details was not performed. The authors and sponsors of this report make no warranties, either written or implied, of details provided within this report.

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APPENDIX A

CLIMATE DATA

This appendix contains climate data regarding the heating degree-days (base 65°F) for a large number of locations throughout the U.S. and Canada. Figure 4 in the body of the report was generated using this data.

It is recommended that Fig. 4 be used as a quick reference as to whether a vapor retarder is recommended in the reader's area. Table A1 in this appendix should be used as a confirmation.

Alternately, the National Climatic Data Center (www.ncdc.noaa.gov) has historical heating degree data for thousands of additional locations across the U.S. and Canada. In the event of a conflict between the heating-degree data presented in this report and the historical heating-degree data obtained though the National Climatic Data Center, the NCDC data should be used.

Table A1 also indicates locations where ICF walls may be subject to freeze-thaw damage if air entrained concrete is not utilized.

Table A1. Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete**
Alabama	Alexander City	2,910		
	Anniston	2,854		
	Birmingham	2,918		
	Dothan	1,703		
	Gadsden	3,317		
	Huntsville	3,323		
	Mobile	1,702		
	Montgomery	2,224		
	Selma	2,249		
	Talladega	2,790		
	Tuscaloosa	2,661		
Alaska	Anchorage	10,570	Recommended	Air Entrained
	Barrow	20,226	Recommended	Air Entrained
	Fairbanks	13,940	Recommended	Air Entrained
	Juneau	8,897	Recommended	
	Kodiak	8,817	Recommended	
	Nome	14,129	Recommended	Air Entrained
Arizona	Douglas	2,767		
	Flagstaff	7,131	Recommended	
	Kingman	3,212		
	Nogales	2,928		
	Phoenix	1,350		
	Prescott	4,995		
	Tucson	1,678		
	Winslow	4,776		
	Yuma	927		
Arkansas	Blytheville	3,656		
	Camden	2,953		
	Fayetteville	4,040		
	Ft Smith	3,478		
	Hot Springs	3,181		
	Jonesboro	3,504		
	Little Rock	3,155		
	Pine Bluff	3,016		
	Texarkana	2,295		
California	Bakersfield	2,182		
	Blythe	1,144		
	Burbank	1,204		
	Crescent City	4,397		
	El Centro	1,156		

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
California (cont.)	Eureka	4,496		
	Fresno	2,556		
	Laguna Beach	2,157		
	Livermore	2,909		
	Lompoc	2,651		
	Long Beach	1,430		
	Los Angeles	1,458		
	Merced	2,687		
	Monterey	3,125		
	Needles	1,309		
	Oakland	2,644		
	Oceanside Marina	2,010		
	Ontario	1,488		
	Oxnard	1,992		
	Palm Springs	985		
	Palmdale	2,948		
	Pasadena	1,453		
	Petaluma	3,050		
	Pomona	1,713		
	Redding	2,855		
	Redlands	1,875		
	Richmond	2,574		
	Riverside	1,861		
	Sacramento	2,749		
	Salinas	2,964		
	San Bernardino	1,821		
	San Diego	1,256		
	San Francisco	3,016		
	San Jose	2,387		
	San Luis Obispo	2,498		
	Santa Ana	1,238		
	Santa Barbara	2,438		
	Santa Cruz	2,969		
	Santa Maria	2,984		
	Santa Monica	1,819		
	Santa Paula	2,039		
	Santa Rosa	2,883		
	Stockton	2,707		
	Ukiah	2,954		
	Visalia	2,511		
	Yreka	5,386		
Colorado	Alamosa	8,749	Recommended	Air Entrained
	Boulder	5,554		

* “Recommended” indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** “Air Entrained” indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Colorado (cont.)	Colorado Springs	6,415		
	Denver	6,020		
	Durango	6,911		
	Ft Collins	6,368		
	Grand Junction	5,548		
	Greeley	6,306		
	La Junta	5,265		
	Pueblo	5,413		
	Sterling	6,541		
	Trinidad	5,483		
Connecticut	Bridgeport	5,537		
	Hartford	6,155		
	Norwalk	5,865		
	Norwich	5,869		
Delaware	Dover	4,337		
	Wilmington	4,937		
Florida	Belle Glade	451		
	Daytona Beach	909		
	Ft Lauderdale	171		
	Ft Myers	418		
	Ft Pierce	490		
	Gainesville	1,267		
	Jacksonville	1,434		
	Key West	100		
	Lakeland	588		
	Miami	200		
	Ocala	930		
	Orlando	686		
	Panama City	1,216		
	Pensacola	1,617		
	St Augustine	1,040		
	St Petersburg	603		
	Tallahassee	1,705		
	Tampa	725		
	West Palm Beach	323		
Georgia	Albany	2,205		
	Americus	2,430		
	Athens	2,893		
	Atlanta	2,991		

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Georgia (cont.)	Augusta	2,565		
	Brunswick	1,578		
	Columbus	2,261		
	Dalton	3,552		
	Dublin	2,476		
	Gainesville	3,500		
	La Grange	2,667		
	Macon	2,334		
	Savannah	1,847		
	Valdosta	1,552		
	Waycross	2,025		
Hawaii	Hilo	0		
	Honolulu	0		
	Kaneohe Mauka	0		
Idaho	Boise	5,861		
	Burley	6,745		
	Idaho Falls	8,063	Recommended	
	Lewiston	5,270		
	Moscow	6,782		
	Mountain Home	6,176		
	Pocatello	7,180	Recommended	
	Twin Falls	6,769		
Illinois	Aurora	6,699		
	Belleville	4,878		
	Carbondale	4,865		
	Champaign	5,689		
	Chicago	6,536		
	Danville	5,610		
	Decatur	5,522		
	Dixon	6,873		
	Freeport	7,169	Recommended	
	Galesburg	6,314		
	Joliet	6,463		
	Moline	6,474		
	Mt Vernon	5,189		
	Peoria	6,148		
	Quincy	5,763		
	Rantoul	6,183		
	Rockford	6,969		
	Springfield	5,688		
	Waukegan	7,136	Required	

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Indiana	Anderson	5,916		
	Bloomington	5,309		
	Columbus	5,536		
	Evansville	4,708		
	Ft Wayne	6,273		
	Goshen College	6,282		
	Hobart	6,043		
	Indianapolis	5,615		
	Kokomo	6,429		
	Lafayette	6,228		
	Marion	6,260		
	Muncie	6,027		
	Peru	5,908		
	Richmond	5,963		
	Shelbyville	5,784		
	South Bend	6,331		
	Terre Haute	5,581		
	Valparaiso	6,267		
Iowa	Ames	6,776		
	Burlington	5,943		
	Cedar Rapids	6,924		
	Clinton	6,324		
	Des Moines	6,497		
	Dubuque	7,327	Recommended	
	Ft Dodge	7,261	Recommended	
	Iowa City	6,227		
	Keokuk	5,969		
	Marshalltown	7,170	Recommended	
	Mason City	7,837	Recommended	
	Newton	6,783		
	Ottumwa	6,269		
	Sioux City	6,893		
	Waterloo	7,406	Recommended	
Kansas	Atchison	5,184		
	Chanute	4,650		
	Dodge City	5,001		
	El Dorado	4,587		
	Garden City	5,216		
	Goodland	5,974		
	Great Bend	4,679		
	Hutchinson	5,103		
	Liberal	4,706		

* “Recommended” indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** “Air Entrained” indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada(8)

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Kansas (cont.)	Manhattan	5,043		
	Parsons	4,606		
	Russell	5,338		
	Salina	5,101		
	Topeka	5,265		
	Wichita	4,791		
Kentucky	Ashland	5,225		
	Bowling Green	4,328		
	Covington	5,248		
	Hopkinsville	3,928		
	Lexington	4,783		
	Louisville	4,514		
	Madisonville	4,167		
	Owensboro	4,334		
	Paducah	4,279		
Louisiana	Alexandria	2,003		
	Baton Rouge	1,669		
	Bogalusa	1,911		
	Houma	1,429		
	Lafayette	1,587		
	Lake Charles	1,616		
	Minden	2,533		
	Monroe	2,407		
	Natchitoches	2,152		
	New Orleans	1,513		
	Shreveport	2,264		
Maine	Augusta	7,550	Recommended	
	Bangor	7,930	Recommended	
	Caribou	9,651	Recommended	
	Lewiston	7,244	Recommended	
	Millinocket	8,902	Recommended	
	Portland	7,378	Recommended	
	Waterville	7,382	Recommended	
Maryland	Baltimore	4,707		
	Cumberland	5,036		
	Hagerstown	5,293		
	Salisbury	4,027		
Massachusetts	Boston	5,641		
	Clinton	6,698		

* “Recommended” indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** “Air Entrained” indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Mass. (cont.)	Framingham	6,262		
	Lawrence	6,322		
	Lowell	6,339		
	New Bedford	5,426		
	Springfield	5,754		
	Taunton	6,346		
	Worcester	6,979		
Michigan	Adrian	6,737		
	Alpena	8,284	Recommended	
	Battle Creek	6,416		
	Benton Harbor	6,303		
	Detroit	6,167		
	Escanaba	8,593	Recommended	
	Flint	6,979		
	Grand Rapids	6,973		
	Holland	6,747		
	Jackson	6,791		
	Kalamazoo	6,230		
	Lansing	7,101	Recommended	
	Marquette	8,356	Recommended	
	Muskegon	6,924		
	Pontiac	6,653		
	Port Huron	6,898		
	Saginaw	7,139	Recommended	
	Sault Saint Marie	9,316	Recommended	
	Traverse City	7,749	Recommended	
	Ypsilanti	6,466		
Minnesota	Albert Lea	8,146	Recommended	Air Entrained
	Alexandria	8,999	Recommended	Air Entrained
	Bemidji	10,200	Recommended	Air Entrained
	Brainerd	9,437	Recommended	Air Entrained
	Duluth	9,818	Recommended	Air Entrained
	Faribault	8,279	Recommended	
	International Falls	10,487	Recommended	Air Entrained
	Mankato	8,005	Recommended	Air Entrained
	Minneapolis-St	7,981	Recommended	Air Entrained
	Rochester	8,250	Recommended	Air Entrained
	St Cloud	8,928	Recommended	
	Virginia	10,024	Recommended	Air Entrained
	Willmar	8,637	Recommended	
	Winona	7,694	Recommended	

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Mississippi	Biloxi	1,486		
	Clarksdale	3,188		
	Columbus	2,769		
	Greenville	2,778		
	Greenwood	2,698		
	Hattiesburg	2,180		
	Jackson	2,467		
	Laurel	2,327		
	McComb	2,115		
	Meridian	2,444		
	Natchez	1,903		
	Tupelo	3,079		
	Vicksburg	2,196		
Missouri	Cape Girardeau	4,386		
	Columbia	5,212		
	Farmington	5,041		
	Hannibal	5,628		
	Jefferson City	5,302		
	Joplin	4,303		
	Kansas City	5,393		
	Kirksville	5,867		
	Mexico	5,590		
	Moberly	5,204		
	Poplar Bluff	4,328		
	Rolla	4,748		
	St Joseph	5,590		
	St Louis	4,758		
Montana	Billings	7,164	Recommended	
	Bozeman	9,908	Recommended	Air Entrained
	Butte	9,517	Recommended	Air Entrained
	Cut Bank	8,904	Recommended	Air Entrained
	Glasgow	8,745	Recommended	Air Entrained
	Glendive	8,178	Recommended	Air Entrained
	Great Falls	7,741	Recommended	Air Entrained
	Havre	8,447	Recommended	Air Entrained
	Helena	8,031	Recommended	Air Entrained
	Kalispell	8,378	Recommended	
	Lewistown	8,479	Recommended	Air Entrained
	Livingston	7,220	Recommended	Air Entrained
	Miles City	7,796	Recommended	Air Entrained
	Missoula	7,792	Recommended	

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Nebraska	Chadron	7,020	Recommended	
	Columbus	6,543		
	Fremont	6,140		
	Grand Island	6,421		
	Hastings	6,506		
	Kearney	6,548		
	Lincoln	6,278		
	Mc Cook	6,115		
	Norfolk	6,873		
	North Platte	6,859		
	Omaha	6,300		
	Scottsbluff	6,729		
	Sidney	6,966		
Nevada	Carson City	5,691		
	Elko	7,077	Recommended	
	Ely	7,621	Recommended	
	Las Vegas	2,407		
	Lovelock	5,869		
	Reno	5,674		
	Tonopah	5,733		
	Winnemucca	6,315		
New Hampshire	Berlin	8,645	Recommended	
	Concord	7,554	Recommended	
	Keene	6,948		
	Portsmouth	6,572		
New Jersey	Atlantic City	5,169		
	Long Branch	5,253		
	Newark	4,888		
New Mexico	Alamogordo	3,232		
	Albuquerque	4,425		
	Artesia	3,527		
	Carlsbad	2,812		
	Clovis	3,983		
	Farmington	5,464		
	Gallup	6,244		
	Grants	5,907		
	Hobbs	2,851		
	Raton	6,103		
	Roswell	3,267		
	Socorro	4,074		

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
New York	Albany	6,894		
	Auburn	6,782		
	Batavia	6,657		
	Binghamton	7,273	Recommended	
	Buffalo	6,747		
	Cortland	7,168	Recommended	
	Elmira	6,845		
	Geneva	6,939		
	Glens Falls	7,635	Recommended	
	Gloversville	7,664	Recommended	
	Ithaca	7,207	Recommended	
	Lockport	6,703		
	Massena	8,255	Recommended	
	New York City	4,805		
	Oswego	6,733		
	Plattsburgh	7,837	Recommended	
	Poughkeepsie	6,391		
	Rochester	6,734		
	Rome	7,244	Recommended	
	Schenectady	6,881		
	Syracuse	6,834		
	Utica	7,066	Recommended	
	Watertown	7,540	Recommended	
North Carolina	Asheville	4,308		
	Charlotte	3,341		
	Durham	3,867		
	Elizabeth City	3,139		
	Fayetteville	2,917		
	Goldsboro	3,040		
	Greensboro	3,865		
	Greenville	3,129		
	Henderson	4,038		
	Hickory	3,728		
	Jacksonville	2,456		
	Lumberton	3,212		
	New Bern	2,742		
	Raleigh-Durham	3,457		
	Rocky Mount	3,321		
	Wilmington	2,470		
North Dakota	Bismarck	8,968	Recommended	Air Entrained
	Devils Lake	9,950	Recommended	Air Entrained
	Dickinson	8,657	Recommended	Air Entrained

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
N. Dakota (cont.)	Fargo	9,254	Recommended	Air Entrained
	Grand Forks	9,733	Recommended	Air Entrained
	Jamestown	9,168	Recommended	Air Entrained
	Minot	9,193	Recommended	Air Entrained
Ohio	Akron-Canton	6,160		
	Ashtabula	6,429		
	Bowling Green	6,482		
	Cambridge	5,488		
	Cincinnati	4,988		
	Cleveland	6,201		
	Columbus	5,708		
	Defiance	6,628		
	Findlay	6,302		
	Fremont	6,439		
	Lancaster	5,988		
	Lima	6,253		
	Mansfield	6,258		
	Marion	6,407		
	Newark	5,657		
	Norwalk	6,434		
	Portsmouth	4,913		
	Sandusky	6,131		
	Springfield	6,254		
	Steubenville	5,700		
	Toledo	6,579		
	Warren	6,402		
	Wooster	6,379		
	Youngstown	6,544		
	Zanesville	5,714		
Oklahoma	Ada	3,182		
	Ardmore	2,702		
	Bartlesville	3,777		
	Chickasha	3,366		
	Enid	3,788		
	Lawton	3,457		
	McAlester	3,354		
	Muskogee	3,413		
	Norman	3,295		
	Oklahoma City	3,659		
	Ponca City	4,226		
	Seminole	3,097		
	Stillwater	4,028		

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Oklahoma (cont.)	Tulsa	3,691		
	Woodward	3,900		
Oregon	Astoria	5,158		
	Baker	7,155	Recommended	
	Bend	6,926		
	Corvallis	4,923		
	Eugene	4,546		
	Grants Pass	4,219		
	Klamath Falls	6,634		
	Medford	4,611		
	Pendleton	5,294		
	Portland	4,522		
	Roseburg	4,312		
	Salem	4,927		
Pennsylvania	Allentown	5,785		
	Altoona	6,140		
	Chambersburg	5,574		
	Erie	6,279		
	Harrisburg	5,347		
	Johnstown	5,649		
	Lancaster	5,584		
	Meadville	6,934		
	New Castle	6,542		
	Philadelphia	4,954		
	Pittsburgh	5,968		
	Reading	5,796		
	State College	6,364		
	Uniontown	5,684		
	Warren	6,890		
	West Chester	5,283		
	Williamsport	6,087		
	York	5,256		
Rhode Island	Newport	5,659		
	Providence	5,884		
South Carolina	Anderson	2,965		
	Charleston	2,013		
	Charleston	1,866		
	Columbia	2,649		
	Florence	2,585		
	Georgetown	2,081		

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
S. Carolina (cont.)	Greenville	3,272		
	Greenwood	3,288		
	Orangeburg	2,534		
	Spartanburg	2,887		
	Sumter	2,506		
South Dakota	Aberdeen	8,446	Recommended	Air Entrained
	Brookings	8,653	Recommended	Air Entrained
	Huron	7,923	Recommended	Air Entrained
	Mitchell	7,558	Recommended	
	Pierre	7,411	Recommended	
	Rapid City	7,301	Recommended	
	Sioux Falls	7,809	Recommended	
	Watertown	8,375	Recommended	Air Entrained
	Yankton	7,304	Recommended	
Tennessee	Athens	4,054		
	Bristol	4,406		
	Chattanooga	3,587		
	Clarksville	4,159		
	Columbia	4,206		
	Dyersburg	3,536		
	Greeneville	4,392		
	Jackson	3,540		
	Knoxville	3,937		
	Memphis	3,082		
	Murfreesboro	3,992		
	Nashville	3,729		
	Tullahoma	3,630		
Texas	Abilene	2,584		
	Alice	1,062		
	Amarillo	4,258		
	Austin	1,688		
	Bay City	1,370		
	Beaumont	1,677		
	Beeville	1,372		
	Big Spring	2,772		
	Brownsville	635		
	Brownwood	2,199		
	Corpus Christi	1,016		
	Corsicana	2,396		
	Dallas	2,259		
	Del Rio	1,565		

* “Recommended” indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** “Air Entrained” indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Texas (cont.)	Denton	2,665		
	Eagle Pass	1,441		
	El Paso	2,708		
	Ft Worth	2,304		
	Galveston	1,263		
	Greenville	2,953		
	Harlingen	813		
	Houston	1,371		
	Huntsville	1,862		
	Killeen	2,127		
	Lamesa	3,159		
	Laredo	1,025		
	Longview	2,433		
	Lubbock	3,431		
	Lufkin	1,951		
	McAllen	778		
	Midland	2,751		
	Mineral Wells	2,625		
	Palestine	2,005		
	Pecos	2,505		
	Plainview	3,717		
	Port Arthur	1,499		
	San Angelo	2,414		
	San Antonio	1,644		
	Sherman	2,890		
	Snyder	3,185		
	Temple	2,153		
	Tyler	2,194		
	Vernon	3,186		
	Victoria	1,296		
	Waco	2,179		
	Wichita Falls	3,042		
Utah	Cedar City	5,962		
	Logan	6,854		
	Moab	4,494		
	Ogden	5,950		
	Richfield	6,367		
	Saint George	3,215		
	Salt Lake City	5,765		
	Vernal	7,562	Recommended	
Vermont	Burlington	7,771	Recommended	
	Rutland	7,066	Recommended	

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Virginia	Charlottesville	4,224		
	Danville	3,944		
	Fredericksburg	4,554		
	Lynchburg	4,340		
	Norfolk	3,495		
	Richmond	3,963		
	Roanoke	4,360		
	Staunton	5,273		
	Winchester	5,269		
Washington	Aberdeen	5,285		
	Bellingham	5,609		
	Bremerton	5,119		
	Ellensburg	6,770		
	Everett	5,311		
	Kennewick	4,895		
	Longview	5,094		
	Olympia	5,655		
	Port Angeles	5,695		
	Seattle	4,611		
	Seattle	4,908		
	Spokane	6,842		
	Tacoma	5,155		
	Walla Walla	4,958		
	Wenatchee	5,579		
	Yakima	5,967		
West Virginia	Beckley	5,558		
	Bluefield	5,230		
	Charleston	4,646		
	Clarksburg	5,512		
	Elkins	6,120		
	Huntington	4,665		
	Martinsburg	5,192		
	Morgantown	5,363		
	Parkersburg	5,094		
Wisconsin	Appleton	7,693	Recommended	
	Ashland	8,960	Recommended	Air Entrained
	Beloit	7,161	Recommended	
	Eau Claire	8,330	Recommended	
	Fond du Lac	7,541	Recommended	
	Green Bay	8,089	Recommended	
	La Crosse	7,491	Recommended	

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Wisconsin (cont.)	Madison	7,673	Recommended	
	Manitowoc	7,597	Recommended	
	Marinette	8,059	Recommended	
	Milwaukee	7,324	Recommended	
	Racine	7,167	Recommended	
	Sheboygan	7,087	Recommended	
	Stevens Point	8,009	Recommended	
	Waukesha	7,117	Recommended	
	Wausau	8,427	Recommended	Air Entrained
Wyoming	Casper	7,682	Recommended	
	Cheyenne	7,326	Recommended	
	Cody	7,431	Recommended	Air Entrained
	Evanston	8,846	Recommended	
	Lander	7,889	Recommended	Air Entrained
	Laramie	9,008	Recommended	
	Newcastle	7,267	Recommended	Air Entrained
	Rawlins	8,475	Recommended	
	Rock Springs	8,365	Recommended	
	Sheridan	7,804	Recommended	
	Torrington	6,879		
Alberta	Calgary	9,885	Recommended	Air Entrained
	Edmonton	11,023	Recommended	Air Entrained
	Grande Prairie	11,240	Recommended	Air Entrained
	Jasper	10,244	Recommended	Air Entrained
	Lethbridge	8,783	Recommended	Air Entrained
	Medicine Hat	8,988	Recommended	Air Entrained
	Red Deer	10,765	Recommended	Air Entrained
British Columbia	Dawson Creek	11,435	Recommended	Air Entrained
	Ft Nelson	12,941	Recommended	Air Entrained
	Kamloops	6,779		Air Entrained
	Nanaimo	6,054		
	New Westminster	5,520		
	Penticton	6,500		
	Prince George	9,495	Recommended	Air Entrained
	Prince Rupert	7,650	Recommended	
	Vancouver	5,682		
	Victoria	5,494		
Manitoba	Brandon	10,969	Recommended	Air Entrained
	Churchill	16,719	Recommended	Air Entrained
	Dauphin	11,242	Recommended	Air Entrained

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Manitoba (cont.)	Flin Flon	12,307	Recommended	Air Entrained
	Portage La Prairie	10,594	Recommended	Air Entrained
	The Pas	12,490	Recommended	Air Entrained
	Winnipeg	10,858	Recommended	Air Entrained
New Brunswick	Chatham	9,028	Recommended	
	Fredericton	8,666	Recommended	Air Entrained
	Moncton	8,731	Recommended	
	Saint John	8,776	Recommended	
Newfoundland	Corner Brook	8,756	Recommended	
	Gander	9,354	Recommended	
	Goose	12,017	Recommended	Air Entrained
	St John's	8,888	Recommended	
	Stephenville	8,869	Recommended	
Northwest	Ft Smith	14,192	Recommended	Air Entrained
	Inuvik	18,409	Recommended	Air Entrained
	Resolute	22,864	Recommended	Air Entrained
	Yellowknife	15,555	Recommended	Air Entrained
Nova Scotia	Halifax	8,133	Recommended	
	Kentville	7,683	Recommended	
	Sydney	8,364	Recommended	
	Truro	8,596	Recommended	
	Yarmouth	7,515	Recommended	
Ontario	Belleville	7,556	Recommended	
	Cornwall	8,062	Recommended	
	Hamilton	6,872		
	Kapuskasing	11,742	Recommended	Air Entrained
	Kenora	10,884	Recommended	Air Entrained
	Kingston	7,826	Recommended	
	London	7,565	Recommended	
	North Bay	9,794	Recommended	Air Entrained
	Ottawa	8,571	Recommended	Air Entrained
	Owen Sound	7,730	Recommended	
	Peterborough	8,037	Recommended	
	St Catharines	6,700		
	Sudbury	9,990	Recommended	Air Entrained
	Thunder Bay	10,562	Recommended	Air Entrained
	Timmins	11,374	Recommended	Air Entrained
	Toronto	7,306	Recommended	
	Windsor	6,619		

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table A1 (cont.). Climate Data for the United States and Canada[8]

State/Province	City	HDD65	Vapor Retarder Status	Concrete Type
Prince Edward	Charlottetown	8,598	Recommended	
	Summerside	8,411	Recommended	
Quebec	Bagotville	10,603	Recommended	Air Entrained
	Drummondville	8,601	Recommended	Air Entrained
	Granby	8,367	Recommended	Air Entrained
	Montreal	8,285	Recommended	Air Entrained
	Quebec	9,449	Recommended	Air Entrained
	Rimouski	9,665	Recommended	Air Entrained
	Sept-Iles	11,287	Recommended	Air Entrained
	Shawinigan	9,246	Recommended	Air Entrained
	Sherbrooke	9,464	Recommended	Air Entrained
	St Jean	11,277	Recommended	
	St Jerome	9,171	Recommended	Air Entrained
	Thetford	9,687	Recommended	Air Entrained
	Trois Rivieres	9,124	Recommended	Air Entrained
	Val d'Or	11,256	Recommended	Air Entrained
	Valleyfield	8,083	Recommended	
Saskatchewan	Estevan	10,092	Recommended	Air Entrained
	Moose Jaw	9,989	Recommended	Air Entrained
	North Battleford	11,127	Recommended	Air Entrained
	Princelbert	12,009	Recommended	Air Entrained
	Regina	10,773	Recommended	Air Entrained
	Saskatoon	11,118	Recommended	Air Entrained
	Swift Current	10,128	Recommended	Air Entrained
	Yorkton	11,431	Recommended	Air Entrained
Yukon Territory	Whitehorse	12,797	Recommended	Air Entrained

* "Recommended" indicates that a polyethylene vapor retarder is recommended between the drywall and the ICF.
** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

APPENDIX B

ICF WINDOW DETAILS

This appendix contains six window details developed based on best available construction industry practices. The details were designed to be applicable to all types of ICF systems, including flat panel, waffle-grid, and screen-grid systems. Details were designed to be robust, with multiple layers of protection against infiltration of water. Consideration was given to developing cost effective designs that are practical and easy to construct.

Please refer to the body of the report for important information related to the details.

GENERAL NOTES

Windows
- Mastic, sealant, and expanding foam should be compatible with ICF materials.
- All joints greater than -in. (3-mm) must be sealed.

Foundations and Below-Grade Walls
- Materials for subterranean insect control not shown.
- Some local building codes may not permit use of rigid foam insulation below grade or may require a combination of termiticide soil treatments and/or termite barrier methods to prevent undetected infestation. Consult with local code authorities and pest control operators for information on local requirements.
- Waterproofing materials must be compatible with ICF materials.
- Foundation detail to be engineered by others.
- Reinforcing steel to be engineered by others.
- Foundation drainage system not shown.
- Anchor bolt size, spacing, and concrete projection to be engineered by others.

Above-Grade Walls
- Reinforcing steel in walls to be engineered by others.
- Anchor bolt size and spacing to be engineered by others.
- Roof truss to be engineered by others.
- Full depth blocking (with ventilation notch) required by most building codes.

Other
- All materials including sealants, foams, self-adhering flashing, waterproofing, and dampproofing must be compatible with ICFs.

Figure B1. General notes for ICF window and wall details.

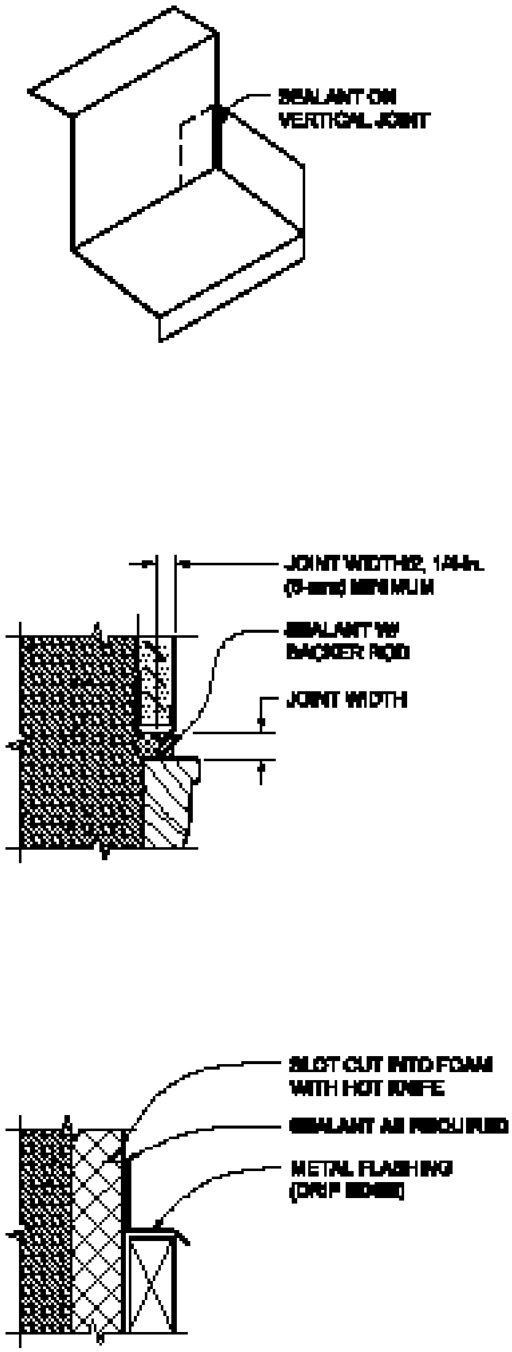

Figure B2. Typical flashing, end dam, and sealant details.

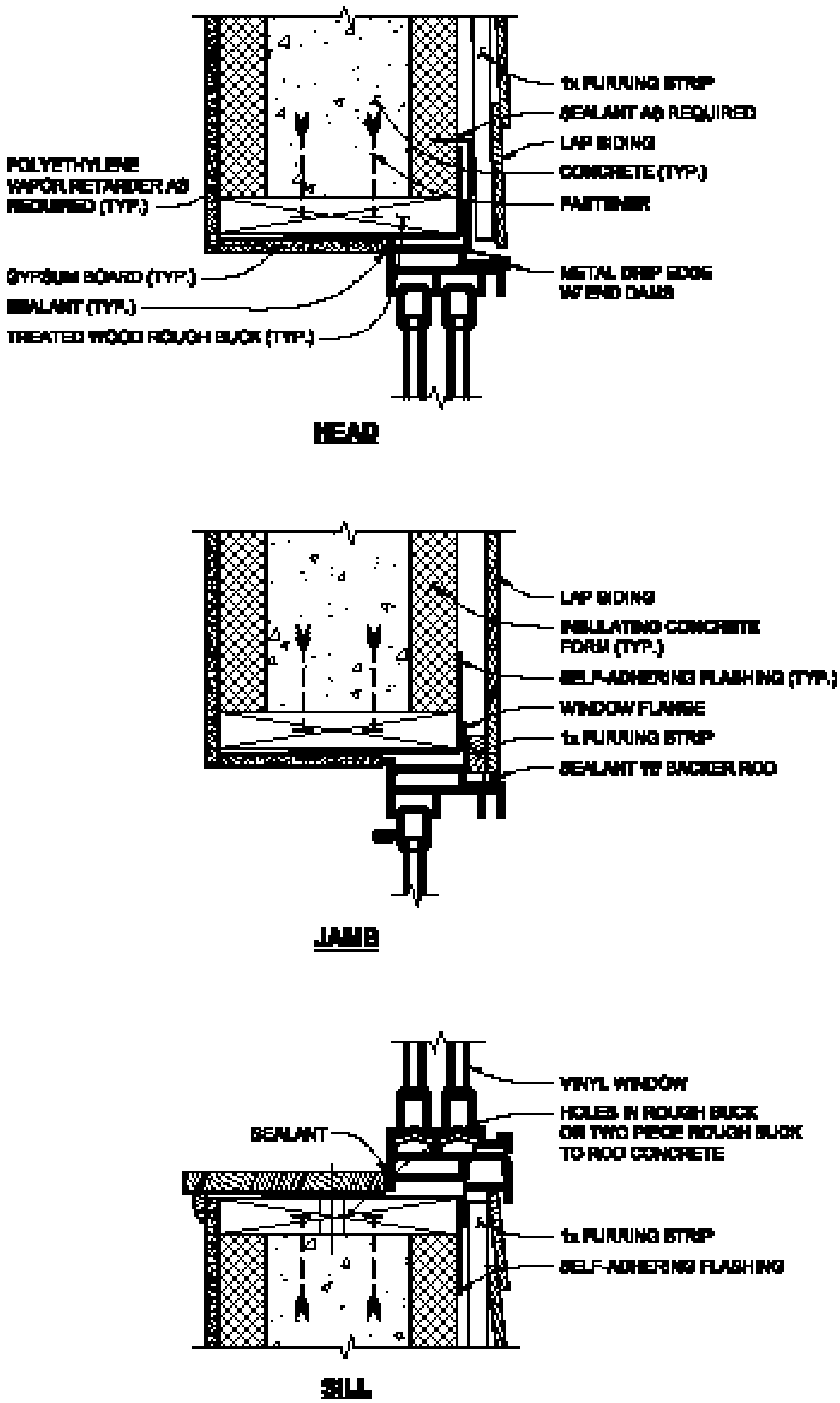

Figure B3. ICF wall with flush-mount vinyl window and lap siding.

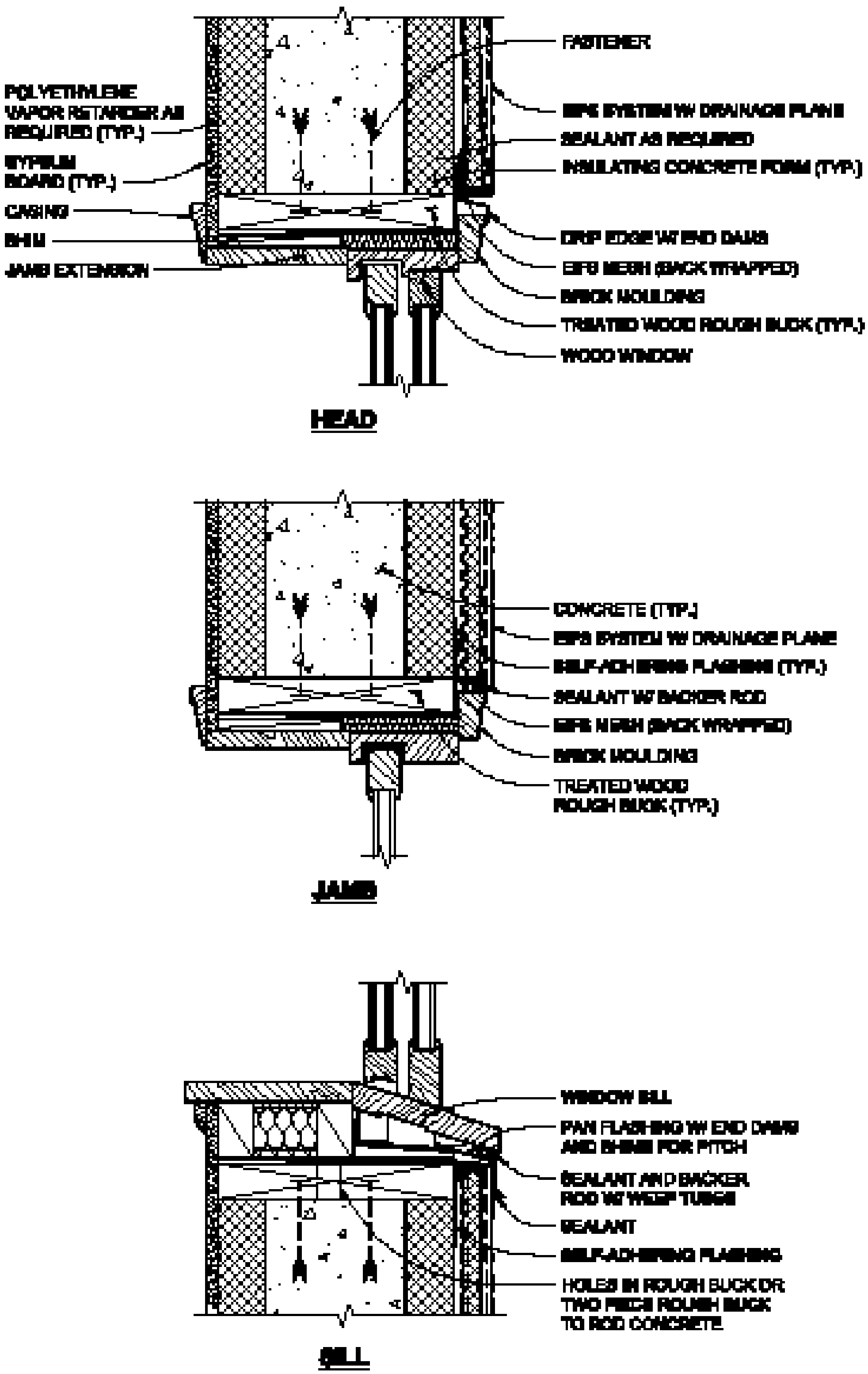

Figure B4. ICF wall with flush-mount wood window and EIFS.

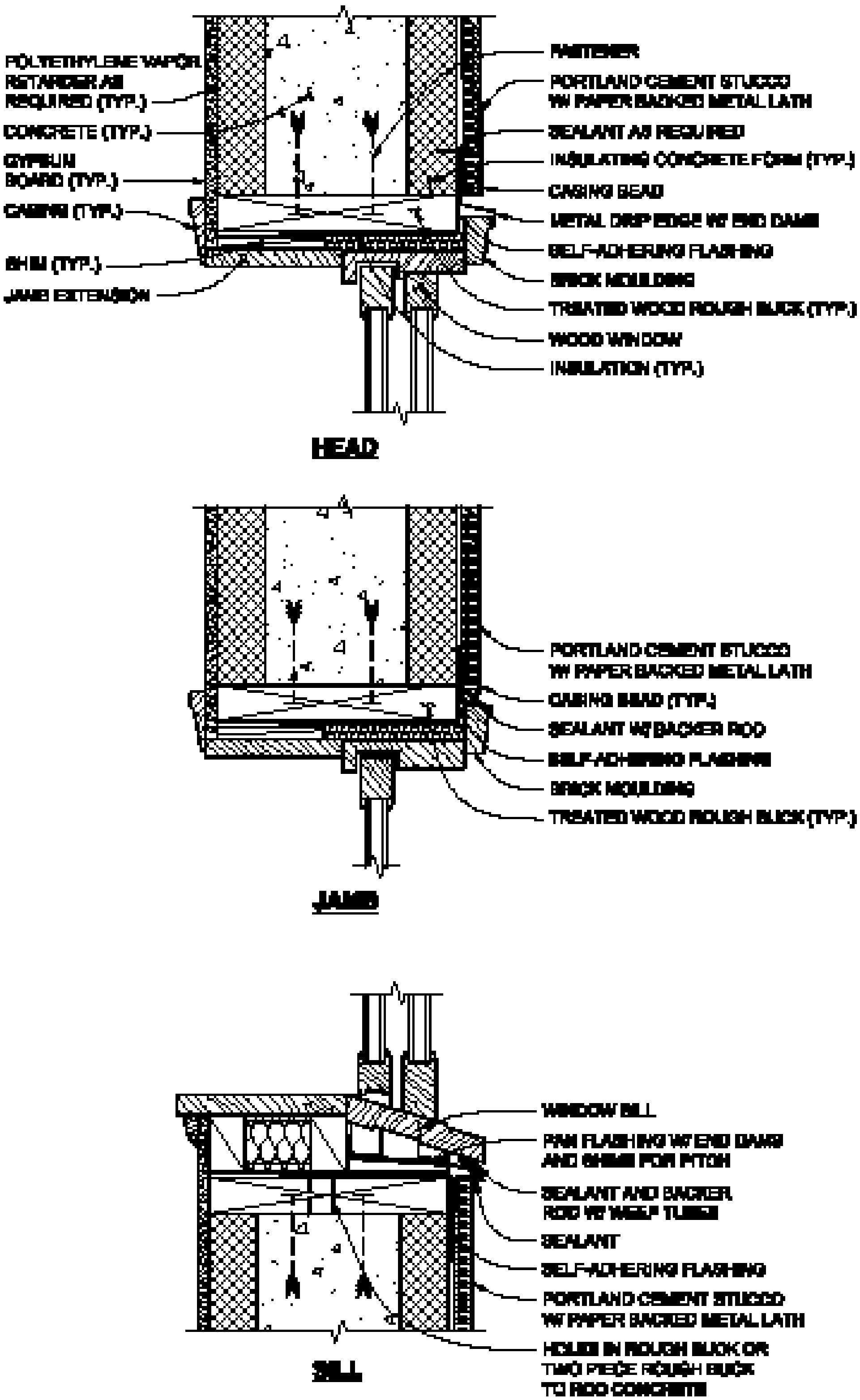

Figure B5. ICF wall with flush-mount wood window and portland cement stucco.

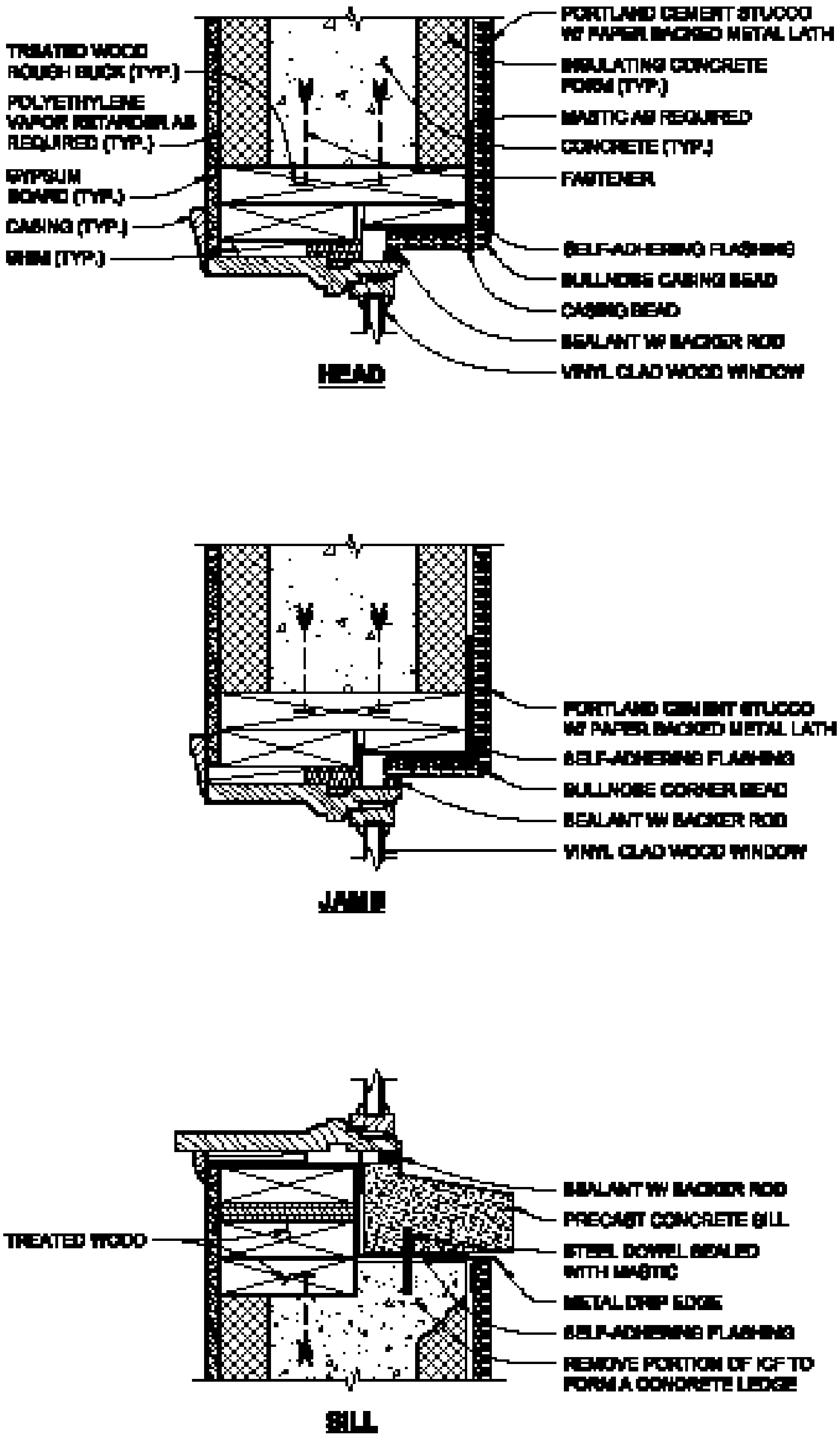

Figure B6. ICF wall with recessed vinyl-clad wood window and portland cement stucco.

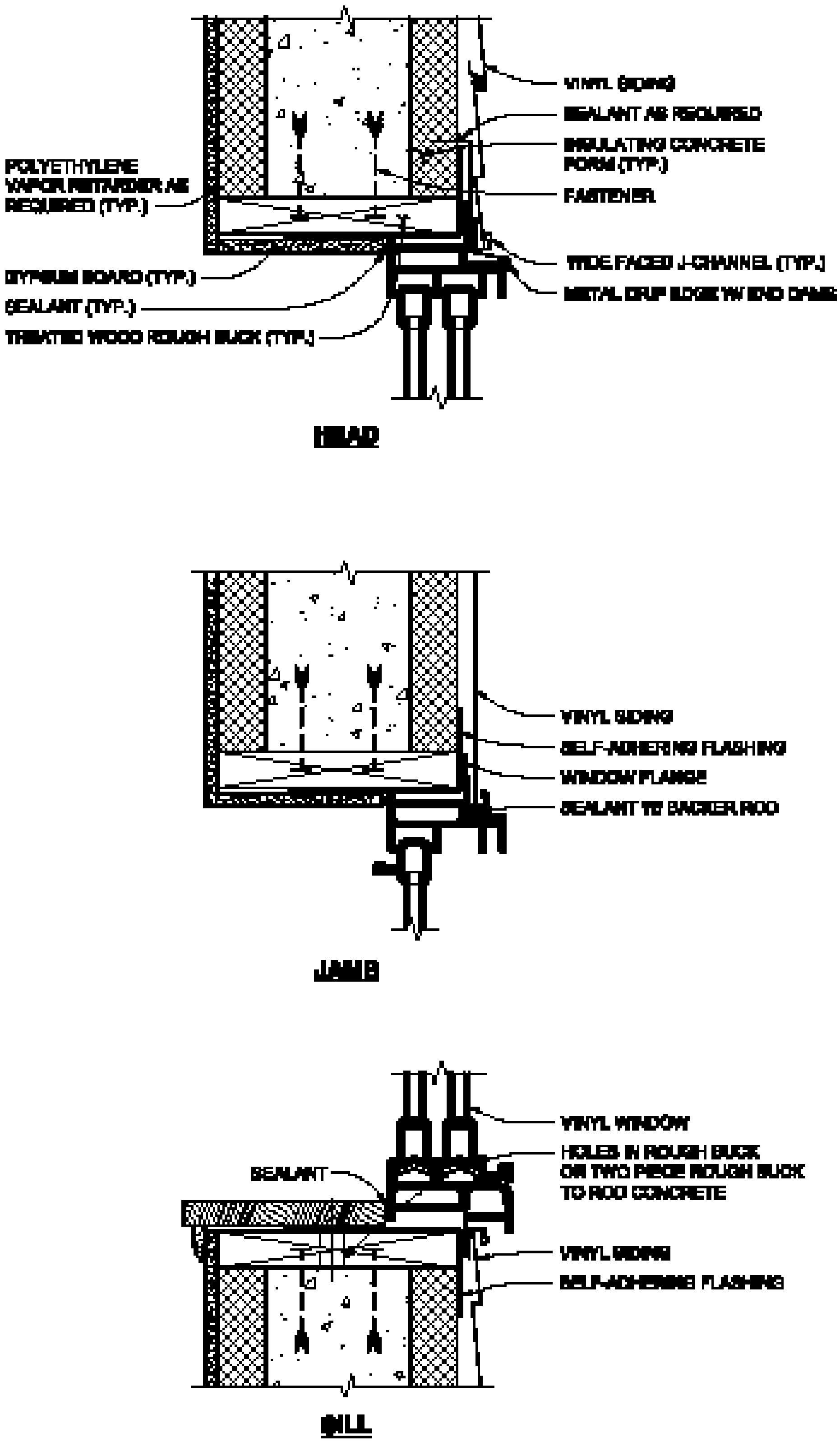

Figure B7. ICF wall with flush-mount vinyl window and vinyl siding.

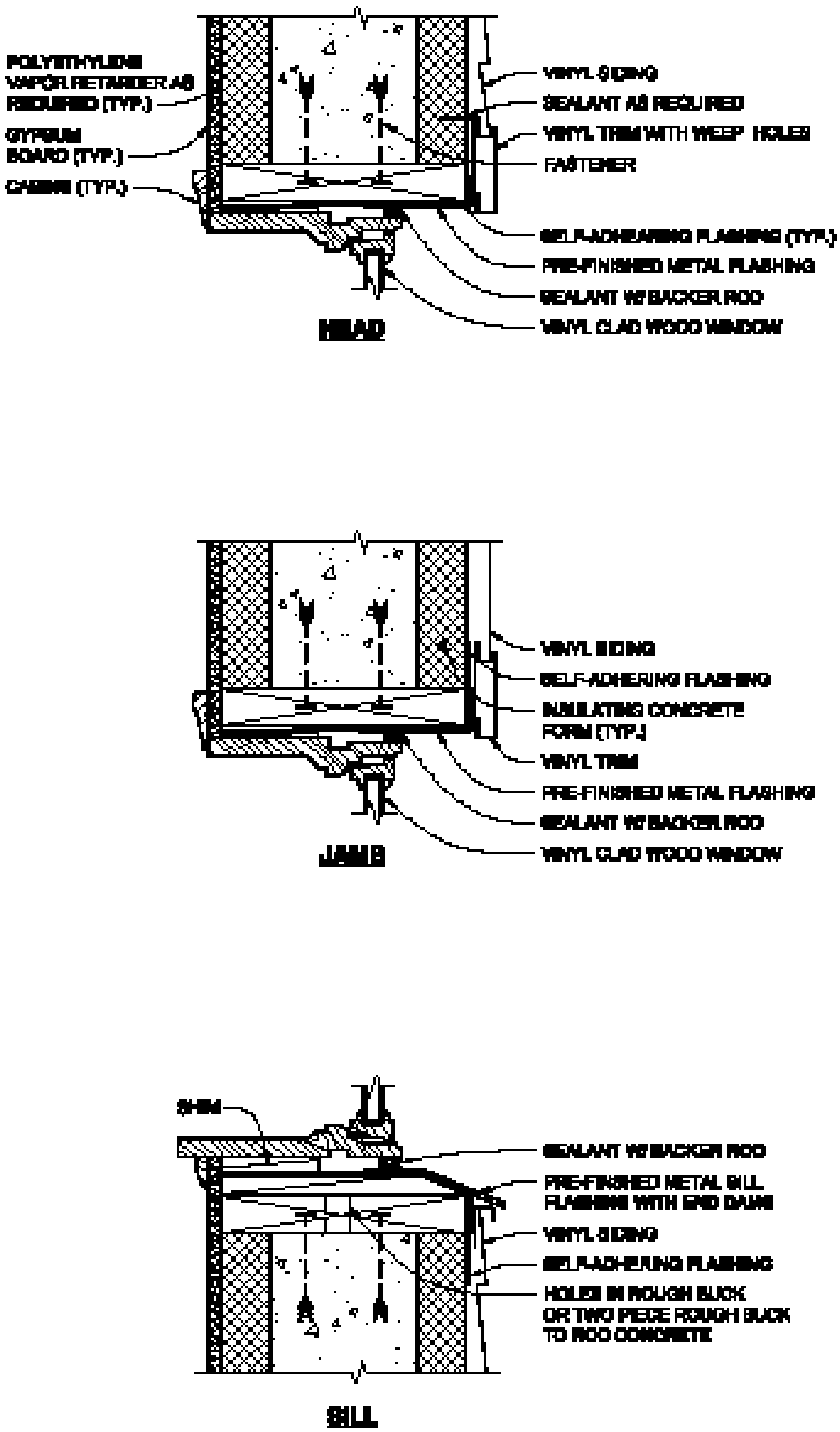

Figure B8. ICF wall with recessed vinyl-clad wood window and vinyl siding.

APPENDIX C

WHOLE WALL DETAILS

This appendix contains 16 standard details for exterior ICF walls that consider the entire wall, from the roofline to the footing. The details consider a variety of exterior finishes including vinyl siding, lap siding, portland cement stucco, and EIFS. Details also consider a variety of foundation types including ICF basement or crawlspace walls, slab-on-grade, and exterior insulated concrete basement or crawlspace walls.

Please refer to the body of the report for important notes related to the details.

<u>GENERAL NOTES</u>

Windows

- Mastic, sealant, and expanding foam should be compatible with ICF materials.
- All joints greater than -in. (3-mm) must be sealed.

Foundations and Below-Grade Walls

- Materials for subterranean insect control not shown.
- Some local building codes may not permit use of rigid foam insulation below grade or may require a combination of termiticide soil treatments and/or termite barrier methods to prevent undetected infestation. Consult with local code authorities and pest control operators for information on local requirements.
- Waterproofing materials must be compatible with ICF materials.
- Foundation detail to be engineered by others.
- Reinforcing steel to be engineered by others.
- Foundation drainage system not shown.
- Anchor bolt size, spacing, and concrete projection to be engineered by others.

Above-Grade Walls

- Reinforcing steel in walls to be engineered by others.
- Anchor bolt size and spacing to be engineered by others.
- Roof truss to be engineered by others.
- Full depth blocking (with ventilation notch) required by most building codes.

Other

- All materials including sealants, foams, self-adhering flashing, waterproofing, and dampproofing must be compatible with ICFs.

Figure C1. General notes for ICF wall details.

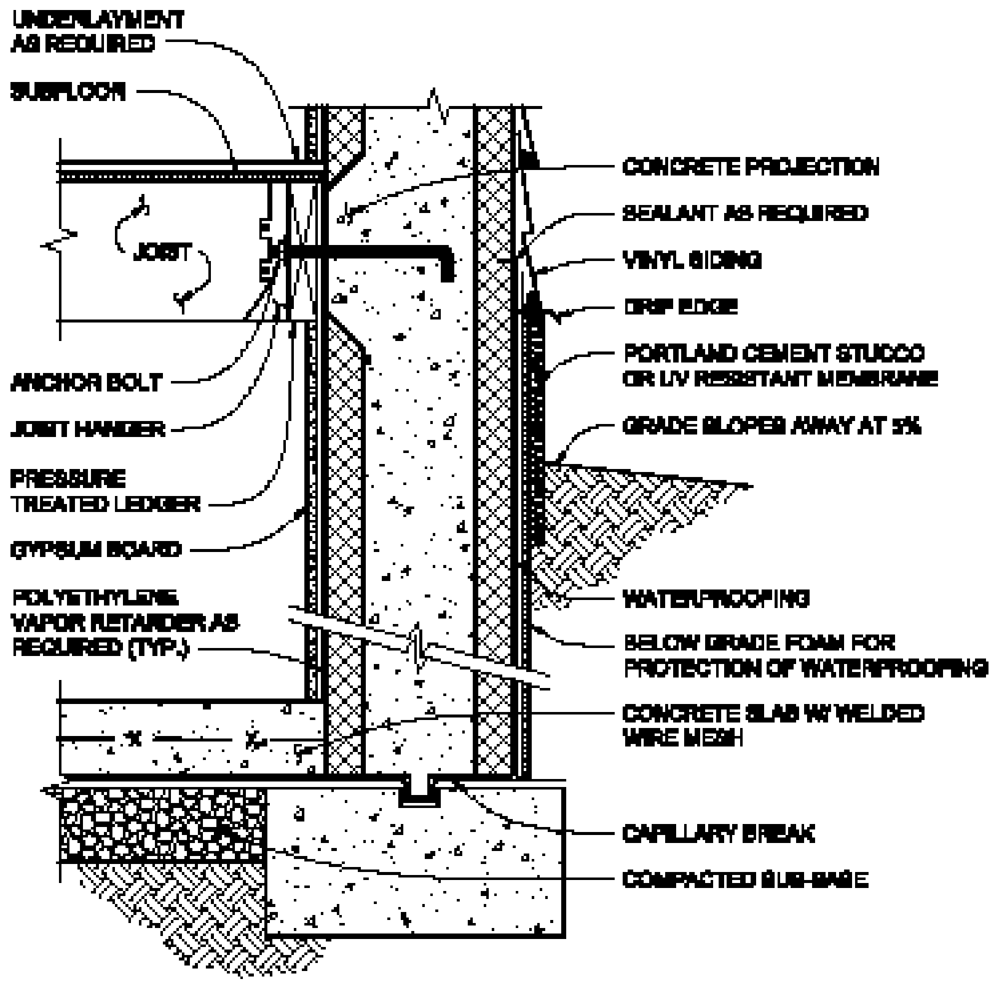

Figure C2. Above- and below-grade ICF walls with vinyl siding.

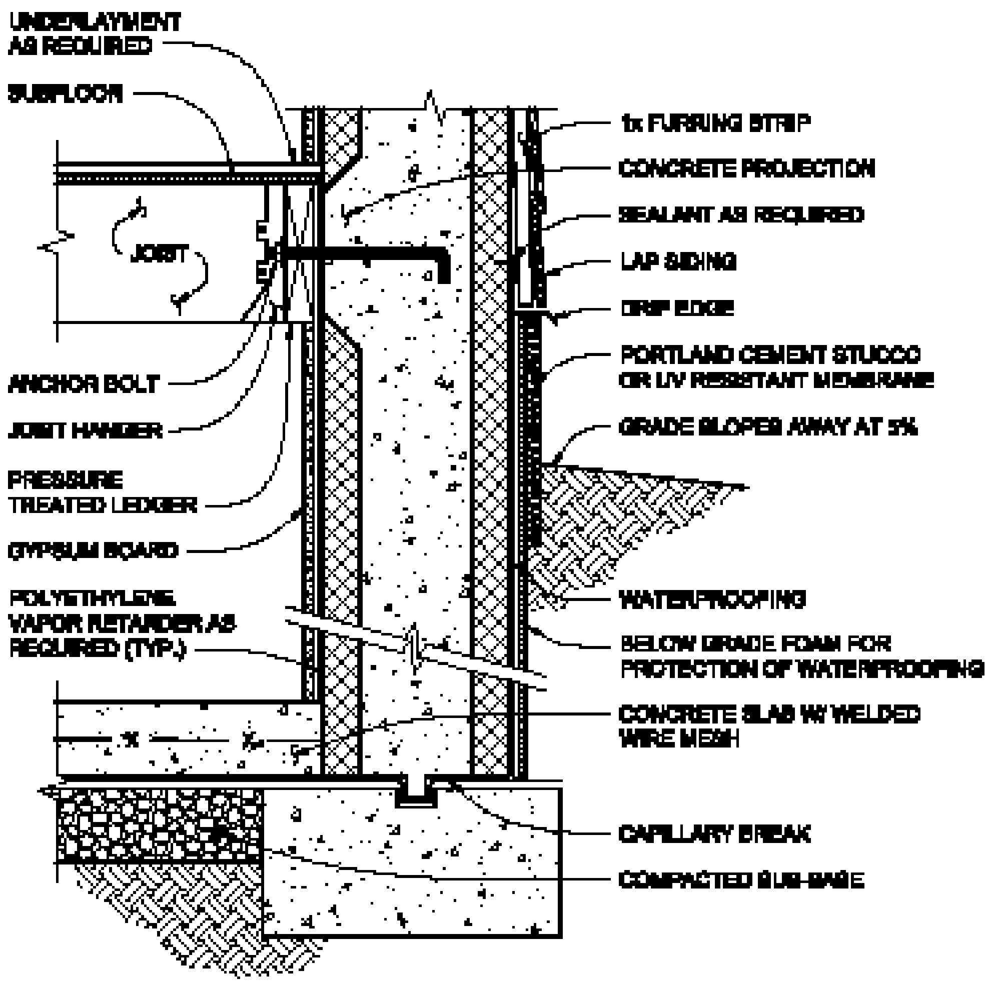

Figure C3. Above- and below-grade ICF walls with lap siding.

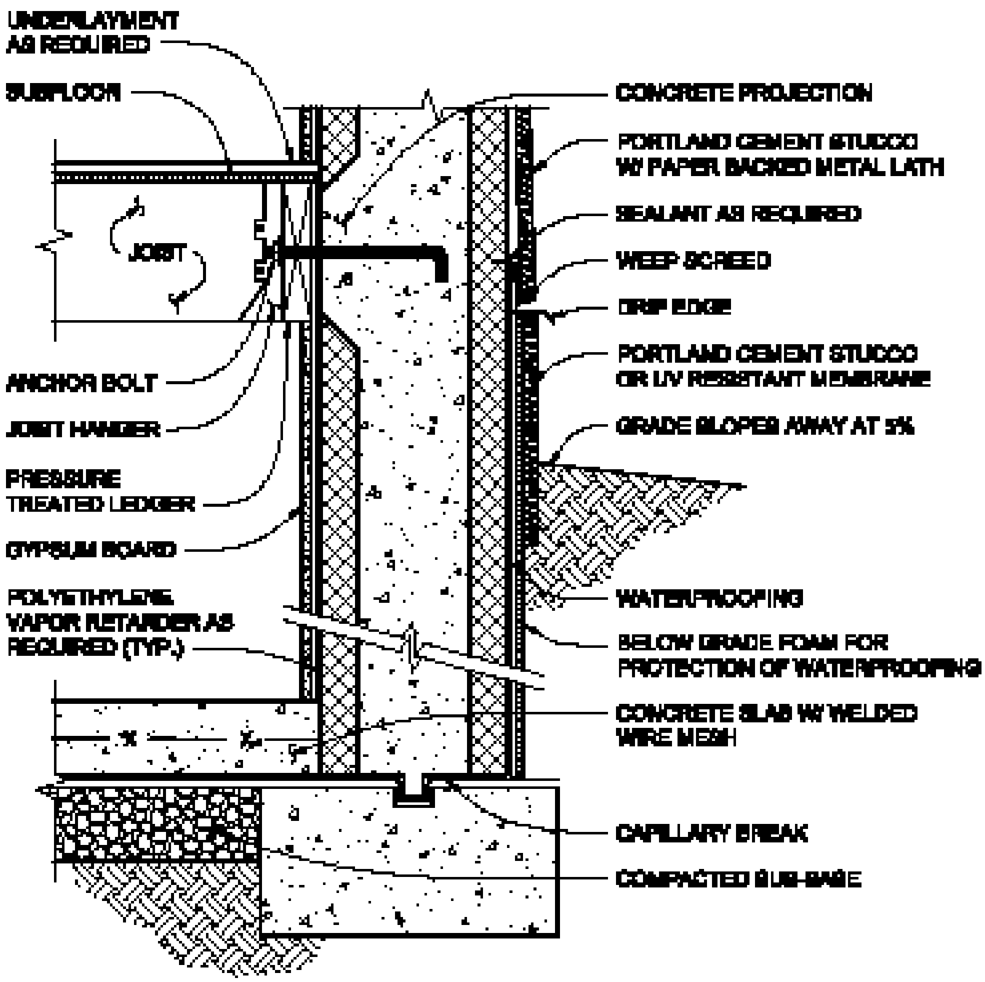

Figure C4. Above- and below-grade ICF walls with portland cement stucco.

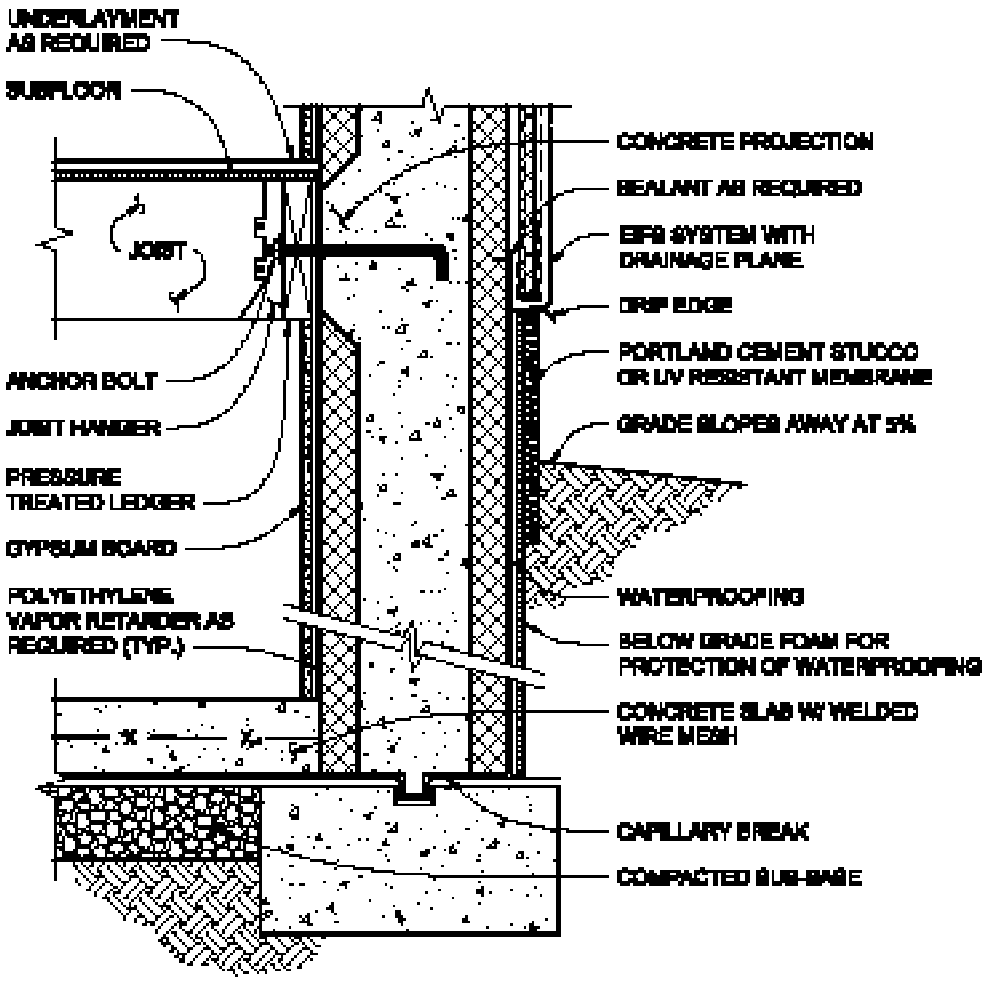

Figure C5. Above- and below-grade ICF walls with EIFS.

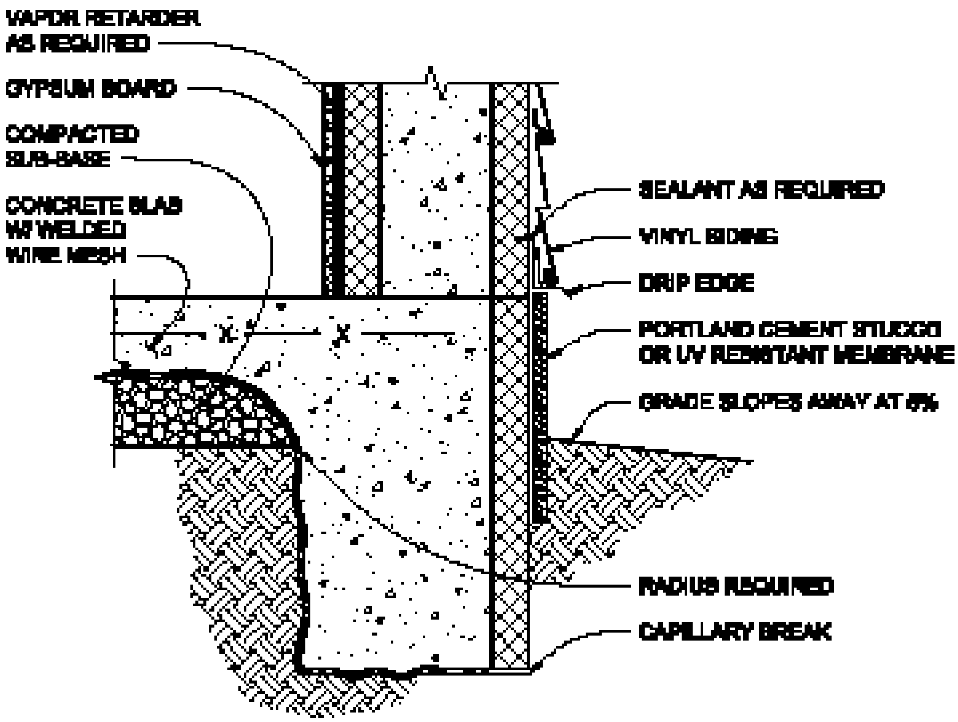

Figure C6. Above-grade ICF wall with vinyl siding on a slab-on-grade foundation.

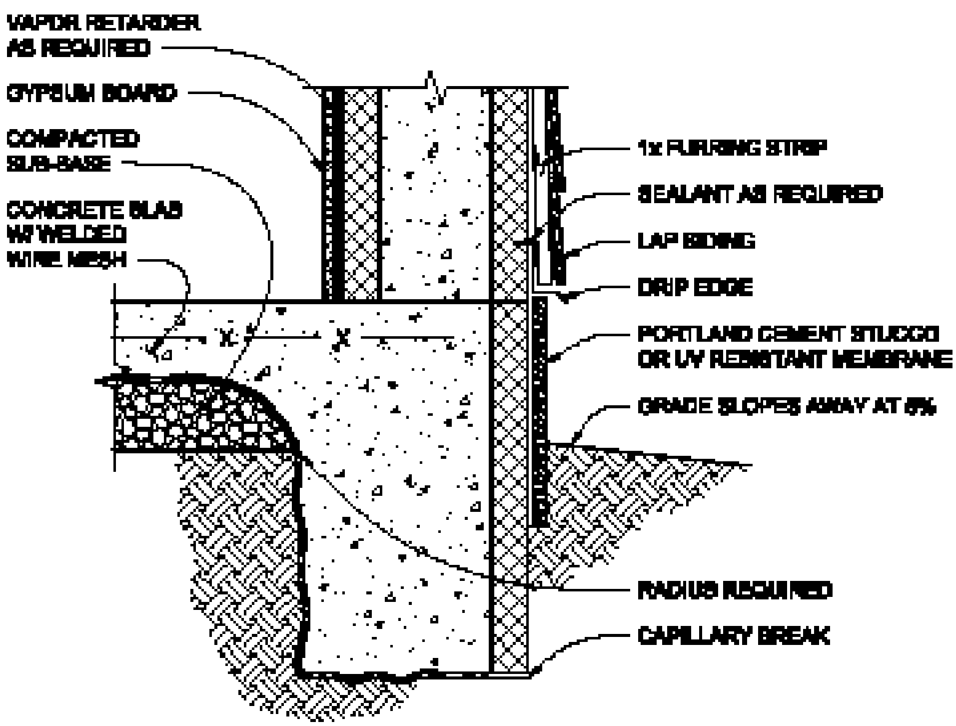

Figure C7. Above-grade ICF wall with lap siding on a slab-on-grade foundation.

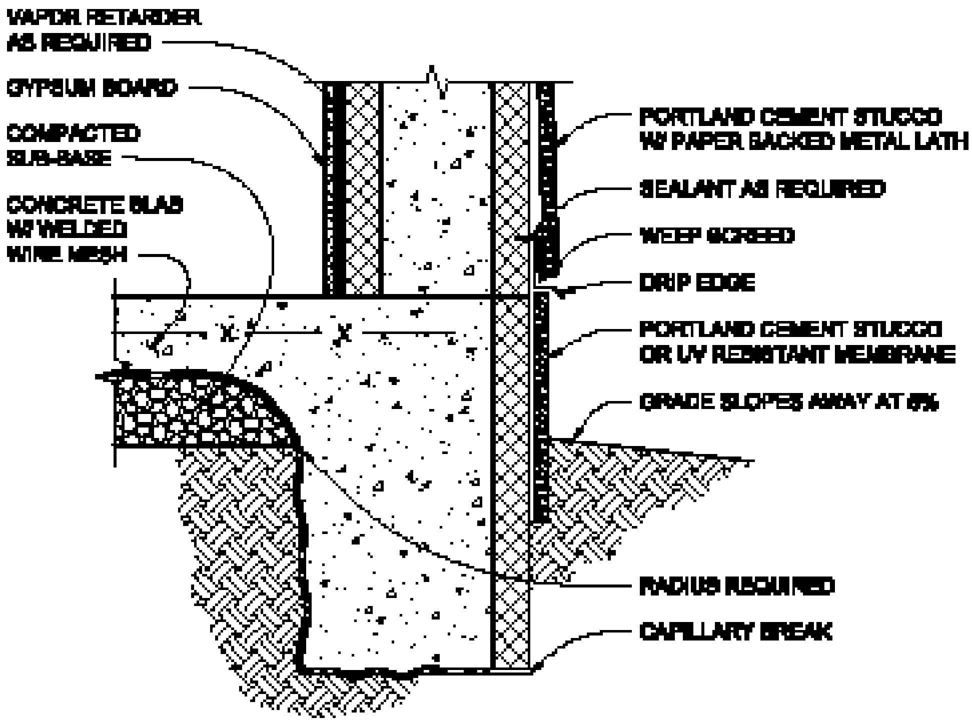

Figure C8. Above-grade ICF wall with portland cement stucco on a slab-on-grade foundation.

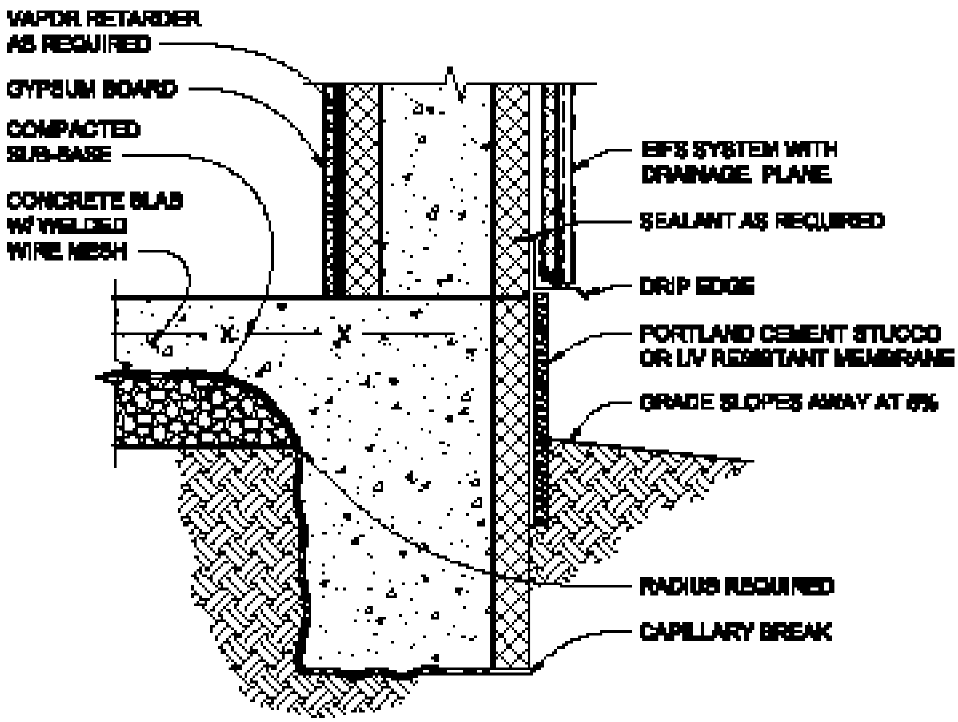

Figure C9. Above-grade ICF wall with EIFS on a slab-on-grade foundation.

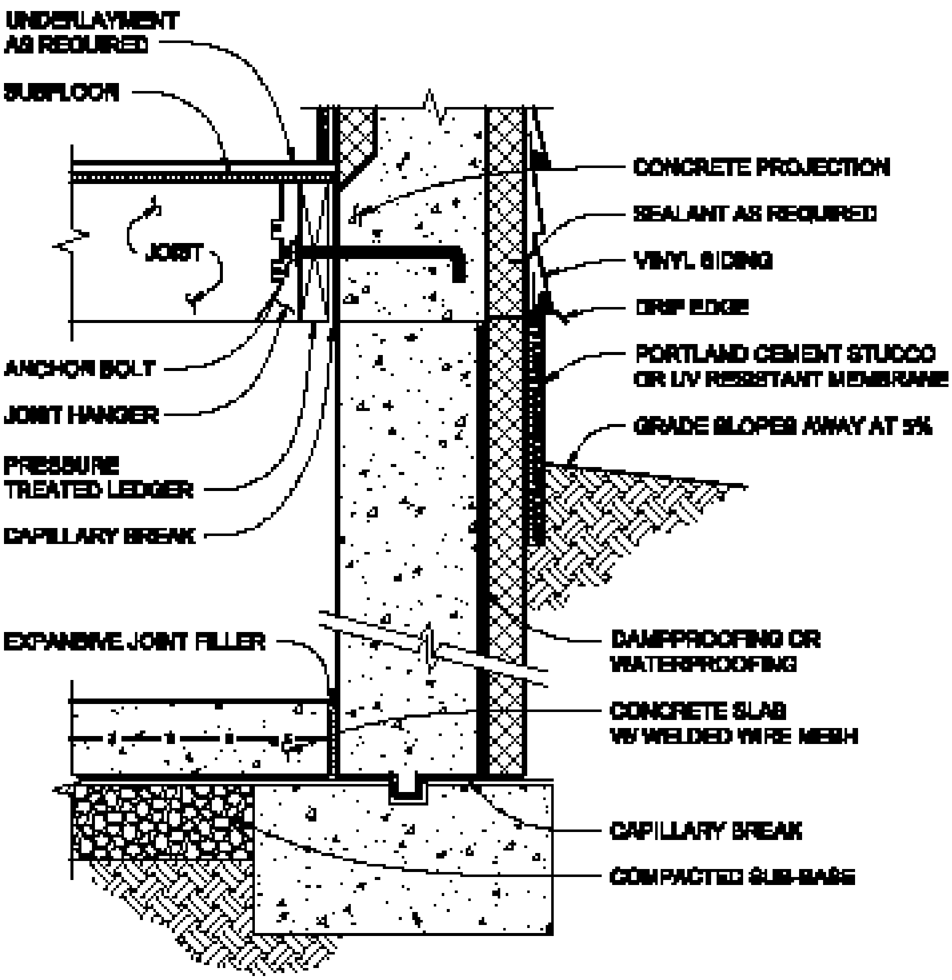

Figure C10. Above-grade ICF wall with vinyl siding on a below-grade insulated concrete wall.

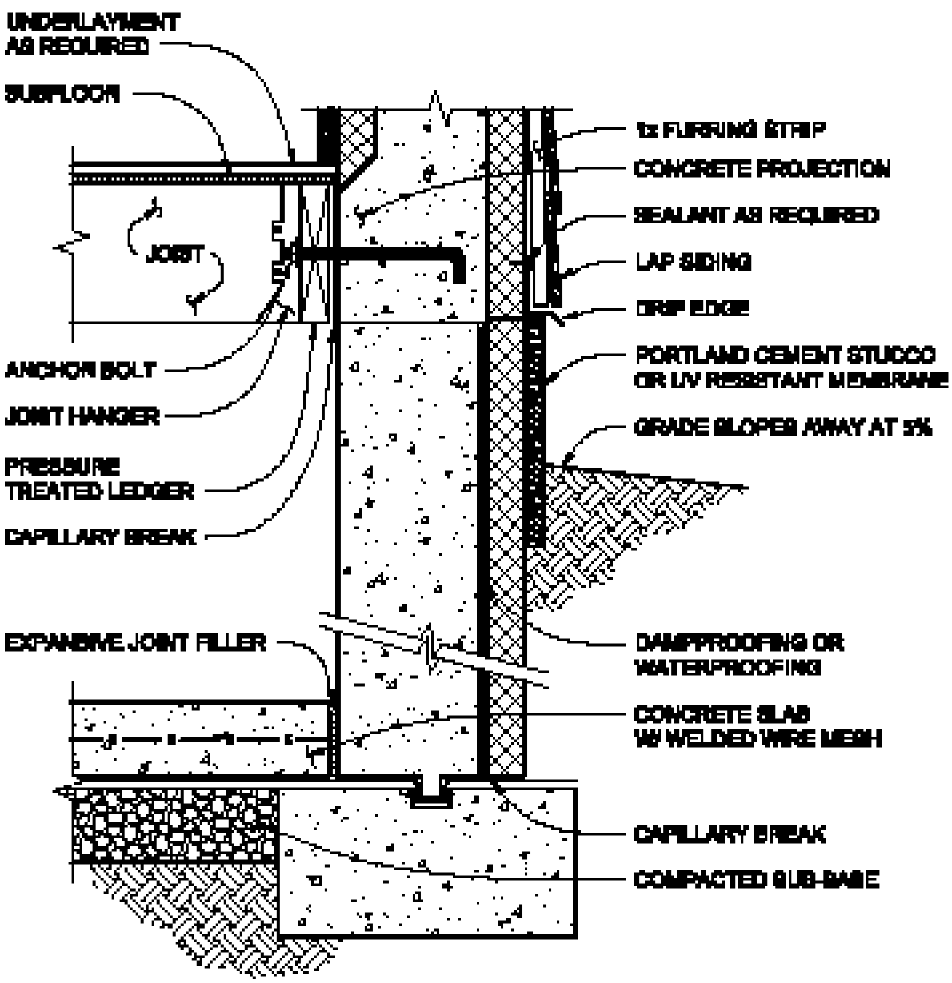

Figure C11. Above-grade ICF wall with lap siding on a below-grade insulated concrete wall.

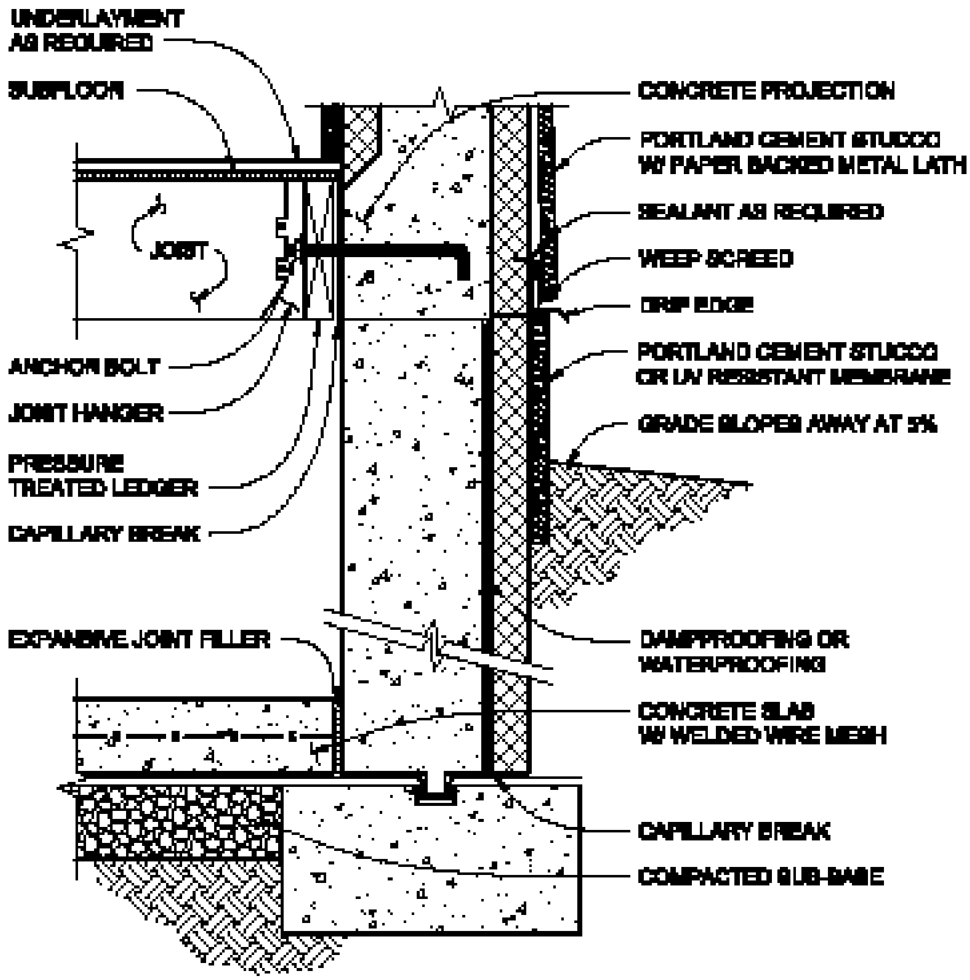

Figure C12. Above-grade ICF wall with portland cement stucco on a below-grade insulated concrete wall.

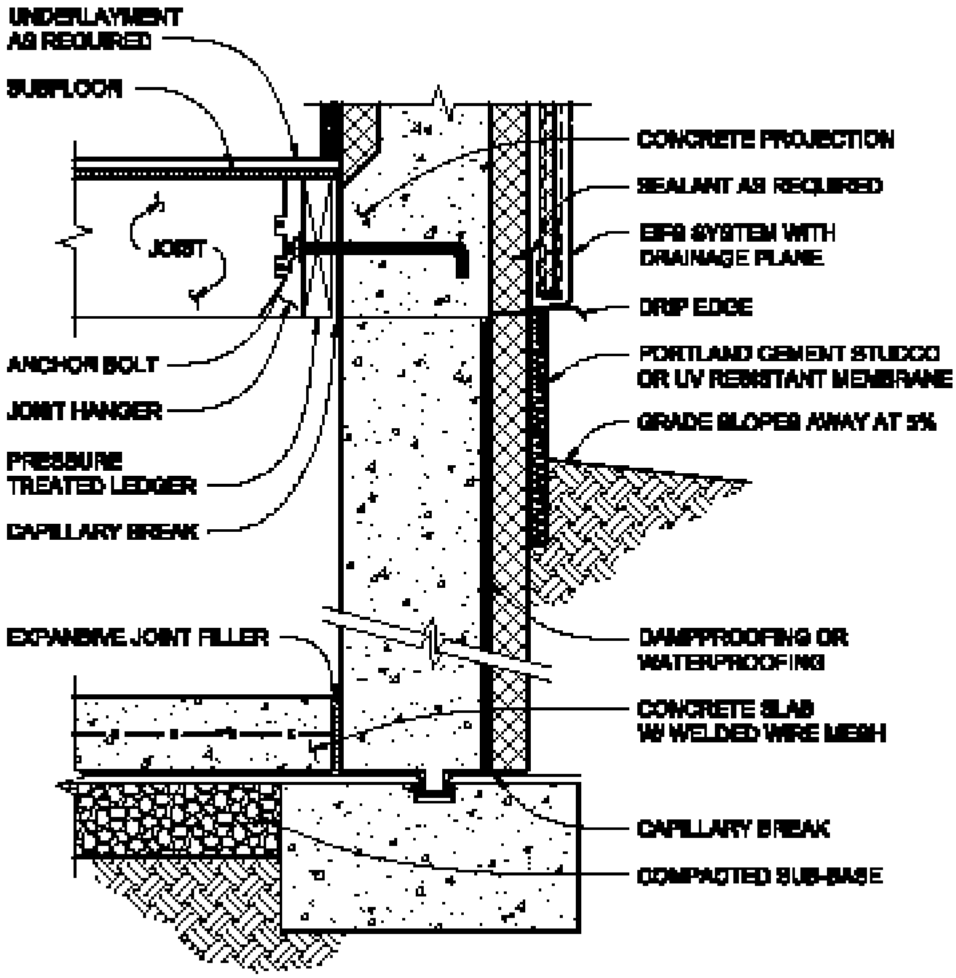

Figure C13. Above-grade ICF wall with EIFS on a below-grade insulated concrete wall.

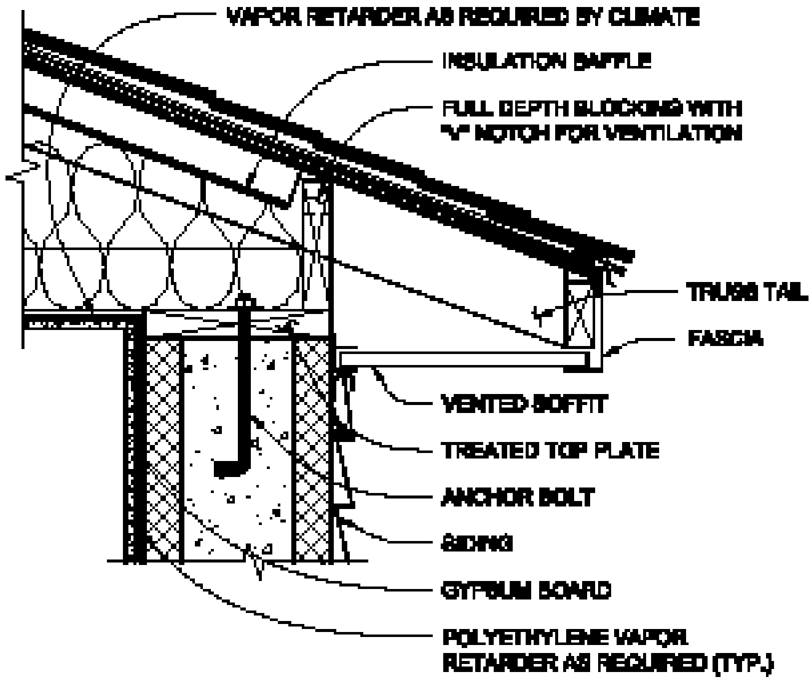

Figure C14. Above-grade ICF wall with vinyl or aluminum siding at the roofline.

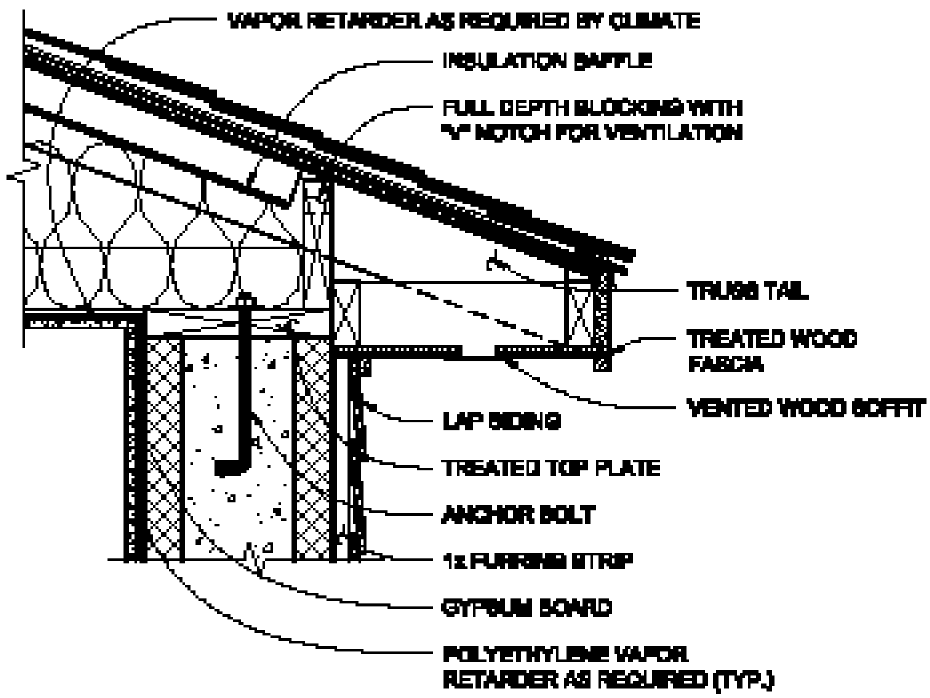

Figure C15. Above-grade ICF wall with lap siding at the roofline.

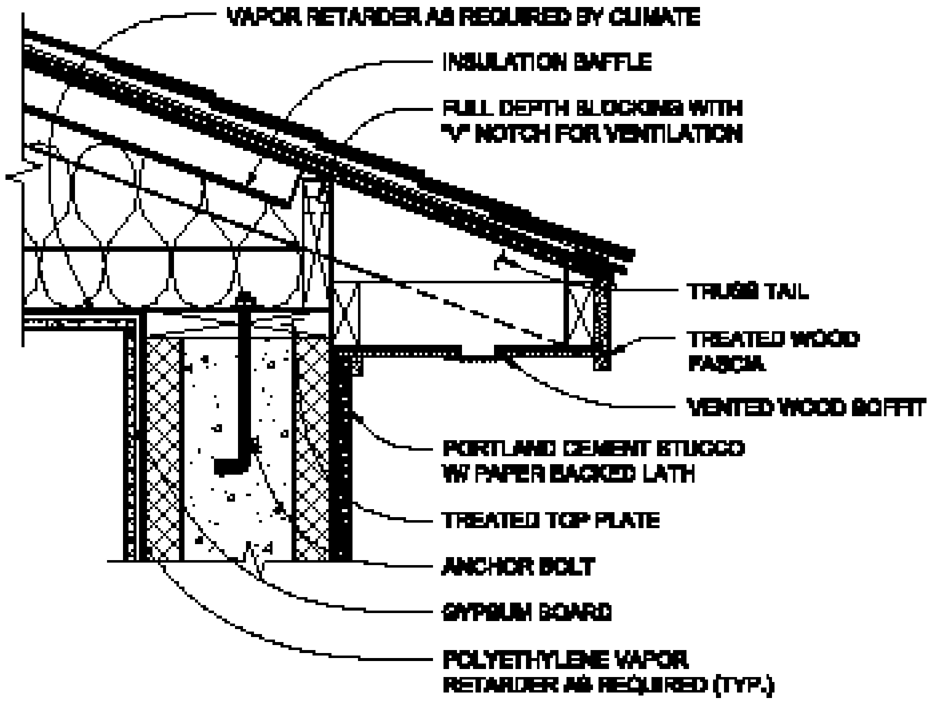

Figure C16. Above-grade ICF wall with portland cement stucco at the roofline.

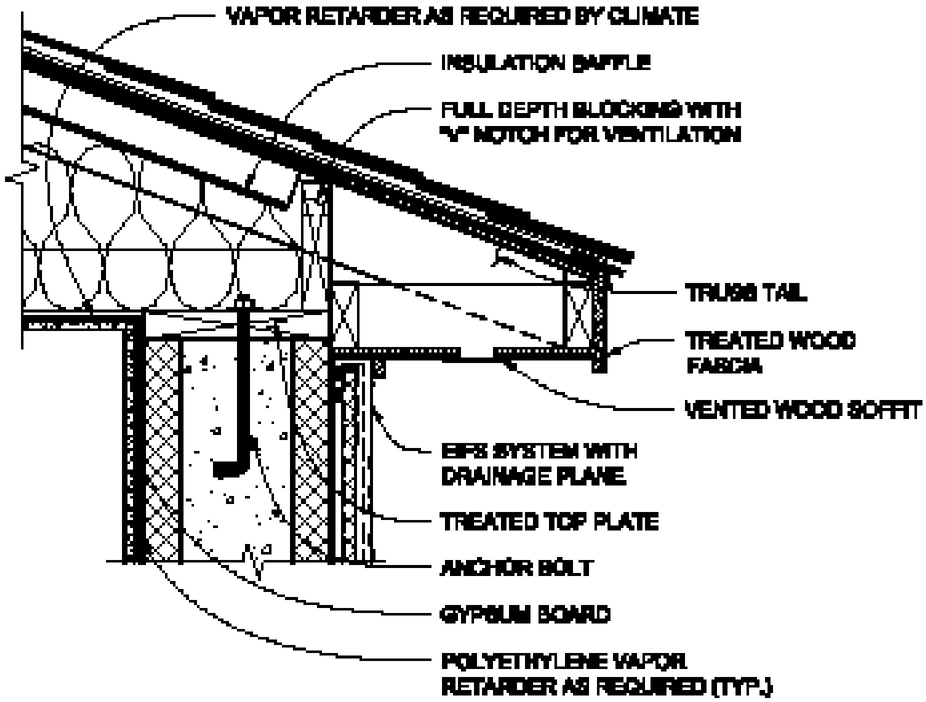

Figure C17. Above-grade ICF wall with EIFS at the roofline.