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INVESTIGATION OF MOISTURE IN INSULATING CONCRETE FORM WALLS

by John Gajda, Martha VanGeem, and Thomas Gentry

KEYWORDS

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

ABSTRACT

Insulating concrete form (ICF) wall systems are rapidly gaining market share in new housing. In the past, their use was primarily limited to custom single-family housing. Today, however, ICF wall systems are being used throughout North America 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.

ICFs, like all wall systems, require special attention to detail to avoid potential moisture problems. Standard guidelines are needed to help architects and contractors use these systems more effectively.

A project was performed to investigate the potential for moisture problems associated with ICFs and to develop standard recommendations and guidelines to avoid these problems. The project was conducted in four parts.

In the first part, six 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 systematically dissected and examined for signs of moisture-related distress.

The second part of the investigation involved analyses to evaluate 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 third part of the investigation involved gathering window installation and flashing details from ICF manufacturers and other sources. Because ICFs represent a relatively new means of above-grade construction, only limited details were found. This provided further justification of the need to develop recommended practices for ICF wall openings.

The final part of the investigation 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

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EXECUTIVE SUMMARY

Insulating concrete form (ICF) wall systems are rapidly gaining market share in new housing. In the past, their use was primarily limited to custom single-family housing. Today, however, ICF wall systems are being used throughout North America 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.

ICFs, like all wall systems, require special attention to details to avoid potential moisture problems. Standard guidelines are needed to help architects and contractors use these systems more effectively.

A project was performed to investigate the potential for moisture problems associated with ICFs and to develop standard recommendations and guidelines to avoid these problems. The project was conducted in four parts.

In the first part, six 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. The walls measured 4-ft by 4-ft (1220-mm by 1220-mm) and had a 6-in. (150-mm) concrete core. Flat-panel ICF wall systems were used with 2-in. (50-mm) of either extruded or expanded polystyrene insulation on each side of the concrete core. Interior finishes consisted of latex paint and primer on ½-in. (13-mm) drywall, with or without a polyethylene vapor retarder. Exterior finishes consisted of portland cement stucco, EIFS, and hardboard lap siding.

After one year of monitoring in a controlled atmosphere, the walls were systematically dissected and examined for signs of moisture-related distress. In general, the concrete, polystyrene, drywall, and exterior finishes performed adequately and did not show any signs of moisture-related distress. The moisture content of the various materials was found to be similar to that reported by others. Limited corrosion was noted on drywall screws removed from the wall sections. Corrosion was noted only on the portion of the screws embedded in the polystyrene. It was not possible to determine the onset or duration of corrosion, or whether corrosion is a long-term problem. Recommendations from this part of the investigation included the use of galvanized screws for fastening interior and exterior finishes. Seasonal temperature fluctuations within the wall sections suggest that heat flow through ICFs is not one-dimensional (horizontal) but also vertical. Based on this, we recommend further research to determine the effect of vertical heat flow (ground coupling) on energy savings during the winter and summer seasons.

The second part of the investigation involved analyses to evaluate the condensation potential of wall sections utilizing various interior finishes, vapor retarders, and exterior finishes. All materials utilized in the first part of the investigation were modeled in the condensation analyses. Additional conditions considered in the analyses included a vapor retarding paint, no insulation, and an exterior vapor retarder.

Steady-state condensation analyses were performed for winter and summer design conditions and average January and July conditions for twelve locations throughout North America. Locations were selected to provide a variety of climatic conditions representative of North America, with emphasis on those climates with potential moisture problems. Analyses were performed for long-term conditions of the walls and for worst-case conditions, where the interior concrete is at 100 percent relative humidity or there are gaps in the insulation.

Results of the analyses indicated that an interior vapor retarder is required in locations with average annual heating degree-days (base 65°F) of 7000 or greater. To verify results of the analytical findings recommending a vapor retarder, we recommend field studies or laboratory tests under winter conditions to determine the amount and effects of moisture accumulation between the concrete and inner layer of insulation. It was also noted that gaps between insulation boards or holes in insulation can cause condensation in locations with 1500 or greater average annual heating degree-days (base 65°F). Moisture of construction within ICF walls can initially cause condensation within walls. An exterior vapor retarder is <u>not</u> recommended in hot and humid climates.

Results of the analyses also indicated the potential for freeze-thaw damage to hardened concrete within ICF walls when the outdoor temperature is less than -15°F (-26°C). Recommendations are made for the use of air entrained concrete in locations where the outdoor temperature falls below this temperature.

The third part of the investigation involved gathering window installation and flashing details from ICF manufacturers and other sources. Three details were provided by ICF manufacturers. Additional details were provided in a PCA publication. From a review of the gathered details, a need to refine the present practice was identified. In addition, new details to cover a broader range of residential materials and finishes were warranted.

The final part of the investigation involved developing standard window details to mitigate potential water leakage 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. Caulking was not allowed to be the only barrier against moisture. The details considered both recessed and flush-mount wood and vinyl windows. Exterior finishes included EIFS, portland cement stucco, lap siding, and vinyl siding. Three-dimensional (isometric) construction-sequencing drawings were developed for recessed and flush-mount windows.

Additional details were developed to address proper practices for the whole exterior wall, from the foundation to the eave, for a variety of exterior finishes and construction types. Foundations consisted of an ICF basement or crawl space wall, a conventional exterior insulated concrete basement or crawl space wall, and slab-on-grade with a perimeter beam. Exterior finishes included EIFS, portland cement stucco, lap siding, and vinyl siding.

ACRONYMS

Various abbreviations and acronyms are used throughout this report. The list below provides definitions of the most commonly used abbreviations and acronyms.

CTL	Construction Technology Laboratories, Inc.
EIFS	Exterior insulation finish system (synthetic stucco)
EPS	Molded expanded polystyrene insulation (beadboard)
ICF	Insulating concrete form
ICFA	Insulating Concrete Form Association
ICFs	Insulating concrete forms
PCA	Portland Cement Association
pcy	Pounds per cubic yard
PVC	Polyvinyl chloride
RH	Relative humidity
XPS	Extruded polystyrene insulation

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by John Gajda, Martha VanGeem, and Thomas Gentry*

INTRODUCTION

Insulating concrete form walls are rapidly gaining popularity in the residential housing market. Initially, ICFs were utilized primarily in custom homes, but these systems are being used more and more to construct homes in a variety of sizes, price ranges, and in developments of various size. Currently, major residential homebuilders are using ICF systems in a variety of subdivisions throughout North America.

ICF manufacturers promote ICF wall systems as being superior to conventional wood-frame construction. ICF systems are being promoted as quick and easy-to-build. However, like wood-frame construction, ICF construction requires special attention to detail to avoid potential moisture problems.

Moisture problems encountered using conventional construction include condensation, peeling paint, mold, and mildew. These conditions often occur simultaneously with relatively high indoor relative humidities. 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 traditional wood-frame construction.

Although many construction practices are similar for all wall systems, ICF construction has some minor differences. Questions on ICF moisture-related issues were sometimes difficult to answer because data were not available.

To address issues specific to ICF construction and prevent potential moisture problems, standard guidelines are needed to help architects and contractors use these systems more effectively.

This project was initiated to investigate the potential for moisture problems associated with ICFs and to develop standard recommendations and guidelines to avoid problems. This project investigated the potential for selected moisture problems in these walls due to

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moisture of construction, water vapor transmission, improper placement of a vapor retarder, and window framing and flashing details. Concrete walls, at the time of construction, have large quantities of moisture. People question whether concrete contributes to moisture problems common in some climates. Concrete walls are also relatively impermeable to water vapor transmission. The effect of interior moisture was investigated by analyzing water vapor transmission in typical wall systems in numerous climates.

Walls must be effective in shedding moisture due to precipitation and inclement weather. The effect of exterior moisture sources on ICF walls was investigated by gathering and reviewing typical window flashing and framing details. Standard wall and window details were developed to implement robust, yet cost-effective means of shedding rain, preventing leakage, and preventing interior moisture problems. Standard details were developed to be applicable to a wide variety of ICF systems, and utilize a wide range of windows and exterior finishes.

SCOPE OF WORK

This project scope of work is divided into four major tasks. This report presents a section corresponding to each of these major tasks. The first section, *Drying of ICF Walls*, presents work performed to design, construct, and instrument six walls. The temperatures and internal relative humidities of the walls were monitored to determine the rate of drying for different constructions.

The second section, *Condensation Analyses*, presents the results of steady-state condensation analyses performed for numerous combinations of construction materials typically found in finished ICF walls. Analyses were performed for twelve locations throughout North America.

The third section, *Review of Existing Window Details*, documents the gathering and review of window flashing and finishing details available from ICF manufacturers and others.

The final section, *Development of ICF Window and Wall Details*, documents the design and rationale behind six typical window details. Also provided are isometric drawings that step through the construction of two installed windows. Additional details are presented which consider the whole wall as a water barrier.

DRYING OF ICF WALLS

The concrete within ICF walls, initially, has large quantities of moisture because the concrete starts out wet. As the concrete dries, water vapor (moisture) is released from the concrete and migrates through or accumulates in other building materials. High levels of accumulation may result in moisture-related problems such as rotting of wood, fungi attack, deterioration of drywall, or mold growth. Concrete is not damaged by moisture.

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 may become wet for long periods of time.

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

Six typical ICF wall sections were constructed, utilizing a variety of commercially available insulation, interior finishes, and exterior finishes. 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. Insulation materials consisted of expanded polystyrene (EPS) and extruded polystyrene (XPS). Interior finishes consisted of painted gypsum wallboard (drywall), with and without a vapor retarder. Exterior finishes consisted of synthetic stucco (EIFS), portland cement stucco, and hardboard lap siding.

For all walls constructed, the ICF wall system consisted of a flat panel system with plastic clips 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. The interior finish, drywall, was fastened directly to the plastic clips on the surface of the ICF units. Exterior stucco finishes and expanded metal lath were placed in direct contact with the polystyrene insulation. Exterior hardboard lap siding 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. Barrier materials such as asphalt saturated felt or house wrap were not used. Measurement ports were cast or cut in the wall sections for measurement of the internal relative humidity and temperature.

The base-case wall consisted of concrete, EIFS, painted interior drywall, no vapor retarder, and XPS insulation. The second wall was similar to the base case, except that it was constructed with EPS insulation. The remaining four walls had EPS insulation and either EIFS, portland cement stucco, or hardboard lap siding. Three of the walls were constructed with a vapor retarder located between the insulation board and the drywall. Table 1 presents the actual matrix of wall construction materials.

Materials. All materials utilized in this investigation were commercially available. Concrete was supplied by a local ready-mix supplier. ICF wall forms were supplied by a single manufacturer with a national distribution system. All other materials were purchased at a variety of national retail building supply stores.

The mix design for the concrete used to construct the walls is presented in Table 2. The specified compressive strength of the concrete was 3,000 psi (20.7 MPa) at 28 days. Table 3 presents the laboratory test results for the measured slump and air content of the fresh concrete and the 28-day compressive strength for the hardened concrete.

Data on ICF polystyrene insulation were supplied by the polystyrene manufacturers. XPS insulation was indicated to meet the requirements of ASTM C 578-95 - Type IV. EPS insulation was indicated to meet the requirements of ASTM C 578-87 - Type IX. Physical performance data are provided in Table 4.

Reinforcing steel utilized in the walls consisted of No. 4 (13-mm diameter) deformed bars, grade 60 (414 MPa).

Interior finishes for all walls consisted of nominal ½-in. (13-mm) drywall. The manufacturer indicated that the water vapor permeance of the drywall was 34.2 perms (1960 ng/Pa·s·m^2). The drywall was painted with one coat of a latex-based primer-sealer and one coat of latex flat wall paint. The manufacturer indicated that no data are available for the water vapor permeance of the primer or paint. Typical water vapor permanence of the primer and paint combination is approximately 4 perms (230 ng/Pa·s·m^2) [1]. The interior vapor retarder consisted of clear 6-mil (0.15-mm) polyethylene plastic. The water vapor permeance of the plastic vapor retarder is generally accepted to be 0.08 perms (5 ng/Pa·s·m^2)[1].

Exterior finishes consisted of portland cement stucco, EIFS, and 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. The nominal thickness of the hardboard lap siding was • x 12-in. (10 x 305-mm). The exterior face was factory textured and painted. Data on the manufacturer and properties are not available.

Formwork. Wall specimens were constructed to be 4-ft (1220-mm) wide by 4-ft (1220-mm) tall. Specimens were constructed in an indoor temperature-controlled environment.

Wood forms were constructed for each wall. Forms consisted of nominal 2 x 12-in. (50 x 300-mm) lumber, as shown in Figure 1. Portions of the formwork that were to be in direct contact with the concrete were temporarily lined with 6-mil (0.15-mm) polyethylene. ICF sections were placed in the formwork prior to casting as shown in Figure 2. Reinforcing steel bars were placed in the ICF sections during wall assembly. Bars were spaced at 16-in. (405-mm) on-center, as indicated in Figure 3. Reinforcing steel was attached to the plastic ties of the ICF system with steel tie wire. Completed formwork with ICFs and reinforcing steel is shown in Figures 4 and 5.

Relative humidity and temperature measurement conduits were installed in the center of the concrete and at the concrete-polystyrene interfaces. Measurement conduits were placed near the center of the 4 x 4-ft (1200 x 1220-mm) wall area to minimize edge effects. Measurement conduits were spaced approximately 12-in. (300-mm) apart, as shown in Figure 6, to minimize potential localized moisture migration effects. Conduits consisted of nominal ½-in. (13-mm) inner-diameter PVC pipes inserted through holes drilled in the polystyrene. Holes were drilled slightly smaller than the outer diameter of the PVC pipe to ensure a tight fit and to minimize moisture migration along the PVC pipe. Joints between the PVC and polystyrene were sealed with silicone sealant for additional protection against moisture migration. Steel angle irons were epoxied to the PVC pipe and the surface of the polystyrene for added stability of the PVC pipe. Figure 7 shows a wall with two relative humidity measurement conduits installed. Wall Nos. 1, 3, 4, 5, and 6 had two conduits; one located at each insulation-concrete interface. Wall No. 2 was similar to the other walls, except that it had an additional conduit located at the center of the area to be filled with concrete.

Prior to casting of the concrete, coated ½-in. (13-mm) diameter plugs were temporarily placed in the PVC conduits. Figure 8 shows two relative humidity ports with temporary plugs installed. The plugs were extended approximately ½-in. (13-mm) past the end of the conduit into the region where the concrete would be placed. The plugs were utilized to keep the conduits clear of concrete and to provide a consistent volume in the concrete for placement of the relative humidity probe. Figure 9 shows the inside of a wall with two plugs extending in an area to be filled with concrete.

Concrete. Concrete for ICF walls was supplied by a local ready-mix concrete supplier. Concrete was placed directly in the ICF forms using the discharge chute of the ready-mix truck over a period of one hour. The top surface was troweled to obtain a uniform surface. Figures 10 through 12 show the placement of the concrete in the ICF walls. After casting, concrete mix-water was observed to be leaking from joints in the ICFs. Figure 13 shows mix-water leaking from the cast ICF walls.

Finishes. Interior and exterior finishes were attached to the ICF walls 3 to 7 days after casting. Interior finishes consisted of nominal ½-in. (13-mm) drywall, one coat of latex primer, and one coat of latex paint. Drywall was attached to the plastic fastening pads of the ICF walls with 1½-in. (38-mm) drywall screws. Drywall screws were countersunk and covered with one to two coatings of drywall compound. Drywall compound, primer, and paint were applied in accordance with the manufacturers' directions. Figure 14 shows drywall attached prior to application of the drywall compound over the screws. Figure 15 shows the application of primer on the drywall.

Exterior finishes consisted of hardboard lap siding, EIFS, and portland cement stucco. Hardboard lap siding was attached to wood furring strips with drywall screws as shown in Figure 16. Portland cement stucco and EIFS finishes were applied by a professional plastering contractor.

The EIFS coating was attached directly to the polystyrene insulation of the ICF wall, in accordance with the ICF manufacturer's directions. As shown in Figure 17, the surface of the XPS insulation was roughened with a wire brush to facilitate attachment. An extra thick layer of the EIFS base-coat was used to hide the plastic pads of the ICF wall section. Fiberglass mesh and the remaining coats of the EIFS were applied in accordance with the manufacturer's directions. Figures 18 through 20 show the application of the EIFS base-coat, mesh, and topcoat.

The portland cement stucco coating consisted of a three-coat system over a metal lathe. The lathe and stucco were applied in general accordance with ASTM C 926, "Standard Specification for Application of Portland Cement-Based Plaster" and ASTM C 1063, "Standard Specification for Installation of Lathing and Furring for Portland Cement-Based Plaster". The metal lathe was screwed to the plastic pads of the ICF wall as shown in Figure 21. Figure 22 shows the application of the stucco base-coat.

Measurement Conduits. In addition to conduits in the concrete and at the concrete-insulation interfaces, additional relative humidity and temperature measurement conduits were installed at interfaces during application of interior and exterior finishes. Each wall had three additional conduits located in the drywall, at the drywall-insulation interface, and at the exterior finish-insulation interface. All conduits were capped immediately after installation to prevent moisture loss. Figure 23 shows the capped measurement conduits in a nearly finished wall.

Edge Sealing. Eight days after casting, the walls were moved to a temperature and humidity controlled room. The sides of the walls were sealed to prevent moisture from escaping and 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 had a moisture permeability of 0 perms (0 $ng/Pa \cdot s \cdot m^2$). A spray adhesive, recommended by the manufacturer of the sealing material, was used to fasten the sealing material to the sides of the walls. Figure 24 shows the application of the sealing material to the sides of the walls.

Conditioning Environment

Walls were conditioned in a temperature and humidity controlled room for a period of one year. The nominal ambient conditions in the room are 73ºF (23ºC) and 50 percent relative humidity (RH). Walls were placed in close proximity to a north exterior wall with windows. To minimize the effect of the wall and windows, the windows were covered and a ceiling mounted fan was utilized to circulate air. Figure 25 shows the layout of the walls in the room.

Data Collection

Temperature and relative humidity data for the walls and the room were measured electronically at 4 to 8 hour intervals for a period of one year. Data were collected by an electronic data logger, printed, and electronically stored. Temperature and relative humidity measurements were initiated nine days after the wall sections were cast.

Humidity and Temperature Measurement Probes. Relative humidity probes consisted of commercially available relative humidity sensors, as shown in Figure 26. Thirty-one probes were used to measure the relative humidity in the wall sections and one probe was used to measure the relative humidity of the conditioned environment.

The sensors are advertised to be factory-calibrated and ready to use. The manufacturer guaranteed the stability of the sensor to be ±2% RH over a two-year period. The operating range of the probes is 0 to 100% RH, although the accuracy of the factory-calibrated probes is guaranteed to be ±3% RH from 10 to 90% RH.

The actual sensor consisted of an active powered resistance capacitor. The relative humidity probe sensor is shown in Figure 27. The manufacturer stated that when the sensor indicates a relative humidity measurement in excess of 100 percent, condensation is present on the sensor. Manufacturer's literature also indicated that relative humidity is a linear function of the sensor output.

Type T thermocouples with special limits of error were used to measure the temperature of the walls and the storage environment. Type T thermocouples were utilized because this type of thermocouple is most accurate at room temperature. The manufacturer of the thermocouple wire indicated a deviation of -0.31°F (-0.17ºC) at 212.7°F (100.4ºC). The accuracy was indicated to be ±0.9°F (±0.5ºC) or ±0.4%.

Data Logger. Thermocouples and relativity humidity sensors were hardwired into a dedicated 40-channel data logger. The data logger was set to record data at 4 to 8 hour intervals. The logger printed humidity and temperature data to a paper tape and electronically stored the data for downloading to a computer. The accuracy of the relative humidity measurement by the data logger is stated to be ±0.005% RH. The maximum error of the compensated temperature measurement by the data logger is stated to be ±0.9ºF (0.5°C). The data logger and external power supplies were connected to a surge protector and an uninterruptible power supply to minimize the effects of power fluctuations and disruptions.

Calibration. The data logger, thermocouples, and humidity probes were calibrated in the laboratory by CTL to minimize measurement errors. It was assumed that since the probes are hardwired to the data logger, calibrating the measurement system would be more appropriate than calibrating individual components or relying on the stated accuracy of the individual components.

Calibration of the hardwired humidity probes was performed in an environmental chamber. The calibration of the chamber is second generation traceable to the National Institute of Standards and Technology (NIST). Calibration was performed by inserting the humidity sensors in the chamber and programming the chamber to remain constant at 73ºF (23°C) and at the following relative humidities in sequence: 8, 48, 68, 88, and 98% RH. The time at each relative humidity was approximately 24 hours. During this time, the data logger collected relative humidity measurements at 20-minute intervals. A linear regression was performed for each probe utilizing the measured relative humidities and the five relative humidity steps of the environmental chamber. The individual calibration coefficients (R-squared values) were in excess of 0.999 for all relative humidity probes.

The thermocouples and data logger were calibrated using a two-point calibration of ice water and boiling water. For this calibration, it was assumed that the equilibrium temperature of the ice water bath was 32°F (0ºC). The equilibrium temperature of the boiling water bath was assumed to be 211°F (99.5ºC). This temperature is the normal boiling point of water based on the ambient atmospheric pressure during the calibration. The modified value was calculated from published hourly atmospheric pressure data.

Results

Measured Results. The internal relative humidity and temperatures of the walls and the conditioned environment were monitored for a period of one year. Results are presented in Appendix A. The rates of drying of the walls are presented in Figures A1 through A6. Figure A7 presents temperature measurements of the conditioned environment and temperatures within select wall locations. Temperatures were monitored continuously only at locations presented in Figure A7. Figure A8 presents the temperature and relative humidity of the conditioned environment.

All temperature and relative humidity measurements presented in Figures A1 through A8 were corrected using the laboratory calibration and averaged to produce data on a daily basis. Relative humidity measurements in excess of 100 percent, an indication of condensation on the sensor, were corrected to 100 percent.

The mass of the walls was measured at approximately 7 days after construction, at various times during the one-year storage period, and at the end of the storage period. Measurements are presented in Table 5. Measurement error of the load cell utilized to weigh the walls is indicated to be ±5 lbs (±2.3 kg). Over a one-year period, the walls lost between 6 to 18 lbs (2.7 to 8.2 kg), or 0.5 to 1.5% of their total initial weight. This weight loss is attributable to drying of the concrete and other materials.

Visual Observations. At the end of the one-year storage period, the walls were dissected and examined for signs of moisture-related problems. Samples were also removed from the walls for moisture content and unit weight measurement. Samples were dry-cut from the walls and immediately placed in sealed polyethylene bags to minimize the change in moisture content prior to measurement.

Materials from the walls were visually examined for moisture related damage. This included visual examinations for mold, mildew, corrosion, rot, and fungi attack. Visual inspection revealed that, in general, none of the building materials from any of the walls suffered from moisture damage. The only exception was the drywall screws where corrosion (rust) was observed on portions of all screws removed from all walls. The corrosion was limited to the portion of the screw that penetrated the polystyrene insulation, as shown in Figures 28 and 29. The time of corrosion onset was not determined. However, the screws were not visually corroded prior to construction of the wall sections.

Moisture Content. The moisture content and unit weight of samples removed from the wall sections were determined. All samples were weighed upon removal from the wall sections. Samples of concrete, portland cement stucco, and EIFS were oven dried at 230°F (110°C). Samples of drywall, insulation, and hardboard lap siding were oven dried at 150°F (65°C). Unit weight of the concrete, EIFS, and portland cement stucco was calculated by the weighing the materials in air and then weighing the material in water. Unit weight of the drywall, polystyrene, and hardboard lap siding was determined by measuring and weighing representative samples of each material. All unit weights were determined on the oven-dry basis. Table 6 presents the moisture content and unit weight of the materials removed from the wall sections. Moisture content and unit weight of all materials are similar to expected results and results reported by others(2).

Discussion. Measurement of the internal relative humidity of the six ICF walls indicated the walls lose moisture over time. The rate of moisture loss, as expected, is dependent on the materials used for construction of the walls.

It is important to note that the walls were monitored in an environment where the difference in relative humidity between the interior of each wall and the surrounding environment was the only factor contributing to the drying of the walls. In this study, the temperature and relative humidity were nearly constant on both the outdoor and indoor sides of the walls. This situation illustrates the drying potential of the walls in relation to construction materials.

In actuality, indoor and outdoor temperature and humidity fluctuate on an hourly, seasonal, and annual basis. This results in a continuous change in the amount of moisture being driven into or out of walls, effecting the drying potential. Wall orientation and geographical location also complicate drying potential. Therefore, walls subject to variable indoor and outdoor temperatures and humidities in various geographical regions and orientations may dry more slowly or quickly than the walls in this study. Modeling of actual drying behavior of ICF walls is not practical because current models are overly complex and may not be accurate.

Different materials were used to construct the walls so the rate of drying, as influenced by different material configurations, could be compared. Wall Nos. 1 and 2 compared the effects of XPS and EPS insulation. Comparing Wall No. 2, with no vapor retarder, and Wall No. 3, with an interior vapor retarder, showed the effect of vapor retarder on a wall with a low permeability exterior finish. Comparing Wall No. 4, with no vapor retarder, and Wall No. 5, with an interior vapor retarder, showed the effect of vapor retarder on a wall with a high permeability exterior finish. Wall Nos. 3, 4, and 6 compared the effects of various exterior finish materials.

Comparison of Wall Nos. 1 and 2 reveals that the concrete within XPS insulation is slower to dry than concrete in EPS insulation. Figures A1 and A2 show the concrete in Wall No. 1 dried to an average of 87% RH while that in Wall No. 2 dried to 82% RH. This reflects the lower permeability (higher resistance to water vapor movement) of the XPS insulation. The relative humidity of the exterior insulation is 64% for Wall No. 1 and 61% for Wall No. 2. The relative humidity of the interior insulation is 59% for Wall No. 1 and 57% for Wall No. 2. The relative humidity of the exterior insulation is greater than that of the interior insulation for both wall sections, confirming that the EIFS coating has a lower permeability than the drywall with latex primer and paint.

The effect of a vapor retarder is illustrated by Wall Nos. 2 and 3. The concrete is slower to dry in Wall No. 3, with a vapor retarder, because a majority of the drying is occurring through the exterior finish (EIFS). Figures A2 and A3 show that the relative humidities of the concrete surface closest to the interior surfaces are 82% for Wall No. 2 and 92% for Wall No. 3. The relative humidity of the interior insulation is 57% for Wall No. 2 and 84% for Wall No. 3. The high relative humidity of the interior polystyrene also provides confirmation that a majority of the drying is occurring through the exterior finish. Comparison of the relative humidity of the drywall reveals that the relative humidity of the drywall in Wall No. 3 is close to that of the ambient conditions. Figures A2 and A3 show the relative humidity of the conditioned environment to be 47.7% and the relative humidities of the drywall in Wall Nos. 2 and 3 to be 51.5% and 50.6%, respectively. This also indicates that the interior vapor retarder forces the wall to dry to the exterior. Comparing the relative humidity of the concrete in Wall No. 3 with that of Wall No. 1 reveals that the vapor retarder slows the rate of drying of the concrete more than the XPS insulation.

The effect of the exterior finish on the rate of exterior drying is illustrated by comparing Wall Nos. 2 and 5 and Wall Nos. 3 and 4. Wall Nos. 2 and 3, respectively, are identical to Wall Nos. 5 and 4, except hardboard lap siding is substituted for EIFS in Wall Nos. 5 and 4. Relative humidities of the exterior insulation in Wall Nos. 2, 3, 4, and 5 are 61, 67, 68, and 58%, respectively, for Wall Nos. 2 and 5 without a vapor retarder. Hardboard lap siding provides less resistance to water vapor movement (higher permeability) than EIFS. Wall No. 5 indicates that the hardboard lap siding has higher permeability than the drywall with latex primer and paint. This is evident by the lower relative humidity of the exterior insulation (58%), in comparison to the interior insulation (65%).

Comparison of Wall Nos. 3, 4, and 6 reveals the relative permeability of EIFS, hardboard lap siding, and portland cement stucco. An interior vapor retarder is present in these walls, which forces a majority of the water vapor movement through the exterior finishes. Examination of the relative humidity of the concrete for the three walls indicates that the hardboard lap siding allows the concrete to dry more quickly than the stucco or EIFS. The relative humidities of the exterior-facing surface of the concrete in Wall Nos. 3, 4, and 6 are 87, 82, and 89%, respectively. The same conclusion is reached by examination of the relative humidity of the interior insulation. The relative humidities of the interior insulation in Wall Nos. 3, 4, and 6 are 84, 76, and 83%, respectively. Comparison of the relative humidity of the exterior insulation shows that the EPS behind the EIFS coating has a lower relative humidity, 67%, than that behind the stucco, 71%. This is an indication that the EIFS coating has a slightly higher permeability than the portland cement stucco.

Comparison of the relative permeability data from testing to permeability data used in the condensation analyses section reveals that the relative permeabilities of the materials appear to be consistent with available literature[1,2]. The permeability of EPS insulation is higher than that of XPS insulation. The hardboard lap siding has a higher permeability than that of EIFS and portland cement stucco. EIFS has a higher permeability than that of portland cement stucco.

Temperature fluctuations of the walls are not consistent with the air temperature of the conditioned environment. Figure A7 shows the temperatures within all walls are lower than anticipated during the period of 170 through 320 days after the wall sections were cast. This corresponds to the winter and spring months. The lowest point occurs in mid-January, with another low temperature period in early March. Although the walls were in a conditioned environment with isolation from exterior windows, the walls were in direct contact with the concrete floor. Walls were placed approximately 3 to 9-ft (0.9 to 2.7-m) from the exterior wall of the building. Inspection of the building construction plans revealed that there is little insulation between the concrete floor deck and the exterior. The concrete floor cooled the walls during the winter. Comparison of the temperature variations to the relative humidity measurements revealed little-to-no overall influence on the relative humidity of the wall components; relative humidity plots did not show similar long-term drops. Daily variability of the relative humidity measurements is explained by the daily temperature fluctuations.

The inadvertent cooling of the ICF wall sections during the winter months illustrates the importance of continuous exterior thermal insulation on concrete buildings. The lack of exterior insulation on the building containing the conditioned environment affected the temperature within the ICF wall sections to a distance of 9-ft (2.7-m) or more from the outdoor environment. This also supports the concept that heat flow through ICFs is not one-dimensional (horizontal) but also vertical. This indicates the need for further research to determine if the vertical heat flow (ground coupling) saves energy in the summer or winter seasons.

Wall Nos. 1 through 6 were conditioned in an environment of constant temperature, 73°F (23°C), one each side. Actual exterior walls would be subjected to temperature gradients, which would produce greater vapor pressure differentials across the walls. In most climates, this would result in more drying than shown in these tests. Exceptions are hot and humid climates where walls are wetted.

Recommendations. Based on the rate of drying measurements, no recommendations are made regarding the use of vapor retarders, concrete, polystyrene insulation, exterior finishes, or interior finishes. These materials all performed adequately and did not show any signs of moisture-related distress after the one-year period.

Corrosion products were observed on the portion of the drywall screws within the polystyrene insulation. Since it is not possible to determine when the corrosion initiated or propagated, it is recommended that galvanized screws be used to attach both exterior and interior finishes to the ICF walls. Additional research may be advisable to examine the long-term effects of corrosion on all metal fasteners within the ICF walls. Such fasteners include metal fastening pads, metal webs joining insulation panels, fasteners for treated wood bucks (for window attachment), metal electrical conduit and plumbing, and lag bolts for suspended floor and roof attachments.

CONDENSATION ANALYSES

Typical ICF walls with various exterior finishes were modeled for twelve climates throughout North America to determine the potential for moisture problems or condensation within walls. Condensation problems can potentially lead to degradation of the effective insulation R-value[3], deterioration of drywall or finishes, and mold or mildew. The steady state vapor transmission was modeled for the summer and winter seasons for twelve climates throughout North America. All exterior and interior finishes described in the *Drying of ICF Walls* section of this report were analyzed in all climates. Analyses take into account the differences between XPS and EPS insulation, and walls with and without a vapor retarder. The ultimate goal of the analyses was to develop a standard specification 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 modeling. These locations were selected to represent a wide range of climates, with a bias towards those with known moisture problems. Selected climates include eleven locations in the U.S. and one location in Canada. Locations in the U.S. included Fairbanks, AK; Seattle, WA; Minneapolis, MN; Madison, WI; Cincinnati, OH; Washington, DC; Miami, FL; Lake Charles, LA; Charlotte, NC; Phoenix, AZ; and Los Angeles, CA. Edmonton, AB was selected as the location in Canada. Historical data for the U.S. locations was provided by the NOAA[4]. Historical climatic data for Edmonton, AB was provided by the climate services unit of *Environment Canada*[5]. Design conditions were provided by ASHRAE[1].

Analyses required the use of constant indoor and outdoor temperatures and relative humidity conditions. The following outdoor temperature conditions were utilized in the analyses:

• 97.5% Winter Design	ASHRAE[1]
• Average January	NOAA[4] and *Environment Canada*[5]
• 2.5% Summer Design	ASHRAE[1]
• Average July	NOAA[4] and *Environment Canada*[5]

Analyses utilized average monthly relative humidities for January and July from NOAA[4]. Outdoor climatic data utilized in the analyses are presented in Table 7. 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.

The various indoor and outdoor conditions resulted in a matrix of six different conditions for each wall section analyzed.

Wall Sections and Construction

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. Analyses considered the effects of interior finishes, insulation type, vapor retarder placement, and exterior finishes. Interior finishes included latex paint and vapor retarding paint. Vapor retarders included interior (those between the insulation and the drywall), exterior (those between the insulation and the exterior finish) and 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. Table 8 presents thermal and water vapor resistance properties of materials used in the analyses. Data on the material properties were obtained from a variety of sources, and are also provided in the table.

The combination of materials resulted in a matrix of thirty-six different wall sections. Although each combination of materials in the matrix is not appropriate for each climate, for ease of analysis all wall sections were analyzed for all climates. It should be noted that it <u>not</u> advisable to place an interior vapor retarder in a wall in a warm and humid climate. Likewise, an exterior vapor retarder should <u>not</u> be placed in a wall in a cold weather climate. This is because a vapor retarder should be placed on the side of the wall where the majority of the water vapor flow, on an annual basis, originates. In cool climates, during the majority of the typical year, water vapor flows from the interior of the building to the exterior. Therefore the vapor retarder should be placed on the indoor portion of the wall. The opposite is true in hot-humid climates.

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, "Standard Practice for Selection of Vapor Retarders for Thermal Insulation". The analyses provided the location of the surfaces on which condensation potentially occurs. Analyses were performed with an automated spreadsheet calculation. An example calculation is presented in Table B1 of Appendix B.

It is important to note that calculation assumptions may not replicate actual conditions. The analysis method utilized is a first-order steady-state method used to show the potential for condensation. The method does not consider the dynamic effects of daily temperature change, solar effects, thermal mass, ground coupling, or material absorption. Therefore, results are a first-order estimate of the potential for condensation and where it is likely to occur. Condensation analyses do not consider the effect of freezing conditions within the wall sections.

Dynamic analyses were not used because adequate models for drying of concrete do not exist, material property data required dynamic analyses is very limited, and the models are not user-friendly.

Results

Results of the steady-state water vapor diffusion analyses are presented in Appendix B in Tables B2 through B19. The tables provide information of the location analyzed, the wall construction, and the indoor / outdoor conditions. The tables also provide information regarding the location of the first surface (from the indoor side of the wall) to accumulate condensation (if any) within the wall sections.

The tables are divided into three groups. Tables B2 through B7 are results for the whole wall, with the relative humidity of the concrete core of the walls at steady-state equilibrium with the indoor and outdoor conditions. For the analyses, the concrete core assumed to be near the average of the indoor and outdoor relative humidities. These analyses are typical of the long-term equilibrium condition of the walls. Condensation analyses are typically performed for this situation.

Tables B8 through B13 are results for analyses from the concrete center to the exterior surface of the wall, assuming the relative humidity of the concrete is forced to 100 percent.

Tables B14 through B19 are results for analyses from the concrete center to the interior surface of the wall, assuming the relative humidity of the concrete is again forced to 100 percent. Tables B8 through B19 consider a worst-case situation, where the wall is recently cast, or never dries out.

Figure A2 indicates that the relative humidity at the center of the concrete wall was approximately 87 percent after a period of one year in a 50% RH steady-state environment. In reality, the relative humidity of the concrete in ICF walls would, most likely for many years, be in excess of the equilibrium case assumed for the water vapor transmission analyses. However, the relative humidity would be lower than the 100 percent assumed for new concrete.

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

Winter design conditions used in this report are predicted to occur 54 hours per year, but occasionally occur for continuous periods of 3 to 5 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 and do not exhibit potential condensation in the average January condition. Recommendations regarding the use of vapor retarders in this report are conservative. The utilization of less stringent criteria may result in condensation problems and long-term moisture damage to walls.

Whole Wall Analyses. Using the winter design conditions as criteria for vapor retarder placement, results from Tables B2 through B7 show that an interior vapor retarder is necessary to prevent condensation in cold-weather climates such as Edmonton, Minneapolis, Madison, Cincinnati, and Washington DC. A vapor retarder in Fairbanks does not prevent condensation at the insulation-concrete surface on the interior side. Application of a vapor retarding paint provides adequate resistance against condensation only in Washington DC. Warmer climates do not require an interior vapor retarder for winter design conditions.

Using the average January conditions as a criterion for vapor retarder placement, the results are similar to those for winter design conditions, except that Cincinnati and Washington DC do not require an interior vapor retarder. Also, condensation does not occur in Fairbanks when a typical vapor retarder is used. Again, a vapor retarding paint is not sufficient for most climates.

Vapor retarder placement requirements for the winter design and average January conditions do not cause condensation in the summer design and average July conditions.

Vapor retarders are not required nor recommended on the exterior of ICF walls in hot and humid climates. Condensation is likely to occur if a vapor retarder is placed between the insulation and exterior finish in hot and humid climates.

Lack of Insulation. Analyses considering walls with no insulation, in Tables B2 through B7, indicate that condensation is present in all climates except Miami and Los Angeles during winter design conditions. Interior vapor retarders do not provide resistance to condensation when no insulation is present. Condensation typically occurs on the interior finish because the lack of insulation keeps the interior finish cold. Similar condensation also occurs in all climates except Los Angeles, Miami, Phoenix, Lake Charles, and Charlotte during average January conditions. These analyses indicate the need to keep insulation intact and free of holes or gaps.

Wet Concrete. Analyses performed with the concrete at 100 percent relative humidity, in Tables B8 through B19, indicate that the majority of the condensation problems will occur on the interior portion of the wall section. Analyses indicate that, during winter design conditions, condensation occurs for vapor retarder placement locations developed as a result of the whole wall analyses, for all locations except Los Angeles, Phoenix, and Miami.

Analyses using average January conditions reveal that condensation is predicted to occur in Fairbanks, Edmonton, Minneapolis, and Madison. Analyses also indicate that a vapor retarder is required in Cincinnati. Condensation for these wall sections and climates is within the wall section, between the insulation and concrete. In cases where a vapor retarder is recommended, condensation also occurs between the vapor retarder and insulation during summer design conditions. Analyses indicate that condensation is not present during the average July conditions, indicating that the walls have the potential to dry. These analyses, assuming that concrete is at 100% RH, are for conditions that typically occur only during the first year after construction.

Additional Analyses. Limited additional analyses were performed to test the sensitivity of select material properties and relative humidities. Analyses were performed using whole wall analyses and winter design conditions, except as noted below.

The first analysis was performed to determine the maximum indoor relative humidity if a vapor retarding paint is utilized instead of a traditional vapor retarder. For this analysis, the vapor retarding paint was assumed to have a permeance of 0.4 perms (23 ng/Pa·s·m^2). This permeance is typical of some high-quality vapor retarding paints. Results of the analysis are presented in Table B20. Results indicate that a vapor retarding paint is not viable in Fairbanks or Edmonton. The maximum indoor relative humidity to prevent condensation in all locations analyzed was found to be 38 percent. This relative humidity is lower than the recommended indoor relative humidity of 45 to 60 percent[(2)].

The second analysis was performed to determine the maximum indoor relative humidity to avoid condensation for walls with interior vapor retarders in Edmonton. The results of the analysis are presented in Table B21. Results for the winter design condition indicate that the maximum indoor relative humidity is 42 percent. This relative humidity is also lower than the recommended indoor relative humidity of 45 to 60 percent[(2)]. The analysis also indicated that 42 percent indoor relative humidity still causes condensation in Fairbanks. Further analyses for Fairbanks indicated that, for all practical purposes, condensation cannot be avoided with the selected materials. Table B22 indicates that an indoor relative humidity of 21 percent is required to eliminate condensation in walls with exterior hardboard lap siding. Condensation was still present in wall sections with portland cement stucco and EIFS.

A fourth analysis was performed to determine the maximum indoor relative humidity where an interior vapor retarder is not required for winter design conditions in Cincinnati. Table B23 indicates that an indoor relative humidity of 38 percent is required to eliminate condensation in walls without a vapor retarder.

The final analysis used average January conditions to determine if a 1 perm (57 ng/Pa·s·m^2) interior vapor retarder is sufficient, or if a vapor retarder with a low permeance such as polyethylene is required to prevent condensation within the ICF walls. Results indicated that the 1 perm (57 ng/Pa·s·m^2) vapor retarder is sufficient to prevent condensation in the ICF walls for locations analyzed in the continental United States. A 0.1 perm (6 ng/Pa·s·m^2) vapor retarder is required to prevent condensation in all locations analyzed.

Potential Freeze-Thaw Damage. Analyses were performed to determine the outdoor temperature required to freeze the hardened concrete within the modeled ICF walls. These analyses used steady-state temperature data generated in the condensation potential analyses. These analyses are not applicable to the potential for freezing of concrete during or immediately after placement.

For these analyses, concrete was assumed to freeze when the exterior surface of the concrete within the ICF walls was 26°F (-3°C) or below. Although concrete freezes over a broad temperature range, this temperature is commonly used as a freezing point in analyses for freezing and thawing of concrete. Repeated cycling above and below this temperature causes freeze-thaw damage to non-air-entrained concrete. Analyses considered all 36 wall configurations presented in Table B2. Analyses calculated the maximum outdoor temperature that causes the concrete to reach a temperature of 26°F (-3°C) for steady-state temperature conditions.

Results of the analyses indicate that freeze/thaw damage to non- or improperly air entrained concrete may occur if the outdoor temperature regularly falls below -15°F (-26°C). If large gaps or holes exist in the insulation, localized freeze/thaw damage may occur when the outdoor temperatures are in the range of 10 to 20°F (-12 to -7°C).

Analyses represent only the modeled flat panel ICF wall system. Indoor temperature fluctuations, changes in the insulation thickness, and density may significantly change the outdoor temperature required to freeze the concrete. It is important to note that the freezing analyses were simplified and may not represent actual freeze-thaw behavior.

Recommendations

Results of the condensation analyses indicate that for worst-case situations, where the initial moisture in the wall never dries or when the wall is initially cast, condensation occurs during winter design conditions for all locations analyzed except Los Angeles, Miami, and Phoenix. If the average January conditions are utilized, condensation occurs within the walls in the cold-weather climates. Analyses utilizing average July condition indicate that the walls have the potential to dry.

Analyses performed for the long-term condensation potential of wall sections indicate that, to prevent condensation, a vapor retarder is required between the insulation and interior finish (drywall) for Madison, WI, and colder climates. Therefore, vapor retarders are recommended for climates with 7000 or more heating degree-days, base 65°F (HDD65). A vapor retarder with a maximum permeance of 0.1 perm (6 ng/Pa·s·m^2) is required. To verify results of the analytical findings recommending a vapor retarder, we recommend field studies or laboratory tests under winter conditions to determine the amount and effects of moisture accumulation between the concrete and inner layer of insulation.

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

Vapor retarder recommendations are based on results of analyses utilizing average January and winter design conditions. It is assumed that any condensation that occurs during winter design conditions but not during average January conditions will evaporate readily when temperatures are warmer.

Figure C1 and Table C1 indicate locations where a vapor retarder is recommended between the insulation and interior finish (drywall). Figure C1 should be used as a general guide. Recommendations are based on analyses of twelve locations. Analyses for other locations may provide slightly different results.

Gaps between insulation boards or holes in insulation can cause condensation on walls in locations with 1500 HDD65 or above. Figure C1 and Table C1 also indicate locations where this may occur. 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.

Freeze-thaw damage can cause significant damage to unprotected hardened concrete. Therefore, the use of adequately air entrained concrete is recommended for locations where the outdoor temperature regularly falls below -15°F (-26°C). Table C1 indicates locations where air entrained concrete is recommended.

REVIEW OF EXISTING WINDOW DETAILS

ICF distributors and manufacturers were surveyed to develop a database of typical window framing and flashing details for ICF walls. Details from other sources were reviewed for inclusion into the database. The goal of developing the database was to collect all of the existing details so that the details could be reviewed for adequacy in protecting the walls and indoor environment from moisture due to exterior weather conditions. The best details would be developed into a standard detail or set of details applicable to all ICF wall systems.

Request for Details

A listing of all ICF manufacturers and distributors was obtained from the Insulating Concrete Form Association (ICFA). Additional manufacturers and/or distributors were obtained from industry publications. A total of 26 manufacturers and distributors were contacted in an effort to gather typical window framing and flashing details for ICF walls. Second requests were made to facilitate a better response to the survey.

As a result of the survey, a total of 14 responses were received. Only a few of the responses received contained complete window framing and flashing details. Most manufacturers indicated the method of framing a window by including instructions for constructing and installing a wood buck. Three manufacturers included drawings that showed windows with exterior and interior finishes. None of the details for window installation included enough information to ensure long-term water resistance.

Additional details were found in a PCA publication(6) entitled, "Insulating Concrete Forms for Residential Design and Construction". Like the most developed of the manufacturer details, there was more information needed to enable the installation to function most effectively. Furthermore, these details on illustrated the installation of wood windows in an exterior wall with stucco finish or wood clapboard siding. Current market trends are toward vinyl windows with vinyl siding.

As a result of the survey of existing details for ICF construction, it is evident that sufficiently developed details, covering the full range of the most commonly used exterior residential finishes do not exist. The details that do exist provided the basis for the design of fully developed details that utilize a variety of materials and windows. These details and their rationale are presented in the following section.

DEVELOPMENT OF ICF WINDOW AND WALL DETAILS

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. The details were developed to work with currently available ICF wall systems. Details for specific systems should be used if available from the manufacturer.

In the following sections, six window details are presented. These details consider a variety of exterior finishes including vinyl siding, lap siding, portland cement stucco, and EIFS. The details also consider recessed and flush-mount vinyl and vinyl-clad wood windows. Two of the window details, a recessed window and a flush-mount window, are presented in a series of three-dimensional (isometric) sequenced drawings. These drawings provide the reader with step-by-step directions for installing windows in ICF walls.

Also presented are a series of details that consider the entire exterior ICF 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 conditions including slab-on-grade, exterior insulated concrete basement or crawlspace walls, and ICF basement or crawlspace walls.

Window Details

Six window details were developed from the available details and 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. More information on various types of ICF systems is presented in Reference 6. Consideration was given to developing cost effective designs that are constructible.

Design Philosophy. The window details developed as part of this project are designed to provide robust, cost-effective details that utilize common construction practices. The details utilize the exterior finish as the first defense against moisture intrusion. This barrier stops a majority of the moisture. 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. Use of the complete EIFS system minimizes potential liability concerns for ICF manufacturers, in the event that moisture penetrates the EIFS surface.

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. This type of buck does not work with all types of ICF systems. For this reason, 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. Screws are fastened to the rough buck before the buck is placed in the ICFs. Galvanized screws are required because moisture from the concrete will corrode non-galvanized screws in a short period of time. Screws, rather than nails, are required for resistance to pullout during the life of the structure. 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 window 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.

All details show an interior vapor retarder with the note that it may not be required. Geographical regions where this vapor retarder is required are indicated in Table C1 and Figure C1.

Six Details. Six details utilizing the stated design philosophy are presented in Appendix D. General notes regarding all of the window and wall details are provided in Figure D1.

Figure D2 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 is often not properly installed.

Figure D3 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 D4 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 D5 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 D6 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 masonry sills be supported by concrete.

Figure D7 presents an ICF wall with a flush-mount vinyl window and vinyl siding. Figure D8 presents a recessed vinyl-clad window and vinyl siding. Details presented in Figures D7 and D8 are anticipated to be the most common details for use in production housing.

Construction Details (Isometric)

Two of the window details described above, a recessed window condition and a flush-mount window condition are presented in a series of isometric drawings. These drawings provide the reader with step-by-step directions for installing windows in ICF wall systems. The sequenced drawings are provided in Appendix E.

Recessed Window with Stucco. Figures E1 though E10 are based on the recessed vinyl-clad wood window with portland cement stucco presented in Figure D6. The figures present a step-by-step process for installing windows in ICF walls. In all of the figures, items highlighted in gray are the specific items being installed or discussed.

Figure E1 shows installation of the partial buck in the partially constructed ICF wall. Note that the galvanized screws are attached to the buck prior to installation in the wall. Also note that a portion of the ICF has been removed to form a concrete ledge for the precast concrete sill. Figure E2 presents the completed buck in the partially constructed ICF wall. Figure E3 presents the ICF wall with the concrete placed and the temporary portion of the buck removed. Figure E4 the inside portion of the buck built-up for attachment of the window. Figure E5 shows the installation of the self-adhering flashing at the sill. If one continuous piece is not used, care should be taken to provide positive drainage to the exterior. Note that the self-adhering flashing must be compatible with the ICFs. Figure E6 shows the installation of the window. Manufacturer's directions should be followed during the installation. This includes the use of sealant (if required) between the nailing fin and rough buck. Figure E7 shows the installation of self-adhering flashing at the jambs and the head. Note the required minimum widths of the flashing. Figure E8 shows the installation of the pre-cast concrete sill on steel dowels. Dowels holes in the self-adhering flashing should be sealed with a compatible material. Figure E9 shows the installation of the paper backed metal lathe and accessories. Proper practice should be followed in installation of the lathe and accessories. This includes, but is not limited to, anchoring the accessories to the lathe, not the substructure. A ½-in. (13-mm) space should be provided for all areas requiring backer rod and sealant. Figure E10 shows the installation of portland cement stucco, backer rod, and sealant. Installation of all materials should be in accordance with manufacturers' directions.

Flush-mount Window with Vinyl Siding. Figures E11 through E16 are based on the flush-mount vinyl window with vinyl siding presented in Figure D7. The figures present a step-by-step process for installing windows in ICF walls. In all of the figures, items shaded in gray are the specific items being installed or discussed.

Figure E11 shows the installation of the rough buck in the partially constructed ICF wall. Note that the galvanized screws are attached to the buck prior to installation in the wall. Figure E12 presents the completed ICF wall with the concrete placed. Figure E13 shows the installation of the window. Manufacturer's directions should be followed during the installation. This includes the use of sealant (if required) between the nailing fin and rough buck. Figure E14 shows the installation of the self-adhering flashing at the sill, jambs, and head. Care should be taken to provide positive drainage to the exterior. Note that the self-adhering flashing must be compatible with the ICFs. Also note the required minimum widths of the flashing. Figure E15 shows the installation head flashing. This flashing should contain the end dam detail presented in Figure D2. Figure E16 shows the installation of the vinyl siding. Installation of vinyl siding and accessories should be in accordance with manufacturers' directions.

Whole Wall Details

Standard details for exterior ICF walls are presented that consider the entire wall, from the roof line 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.

Design Philosophy. The design philosophy behind the whole-wall details is similar to that of the window details; to provide robust cost-effective details that utilize common construction practices. The details utilize the exterior finish as the first defense against moisture intrusion. This barrier stops a majority of the moisture. The exterior polystyrene surface of the ICFs is utilized as a secondary rain-screen barrier to protect the interior of the home from water that passes through the exterior finish.

As previously discussed, the 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. Any holes or other defects in the ICFs should be sealed with water-resistant materials that are compatible with the ICFs. These 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.

Proper drainage away from the building is essential for long-term successful performance. In all of these details, foundation drainage systems have <u>not</u> 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.

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.

All details show an interior vapor retarder with the note that it may not be required. Geographical regions where this vapor retarder is required are indicated in Table C1 and Figure C1.

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

Termites have been known to tunnel through foam insulation materials in search of wood products. Presently, the Southern Building Code (SBC) and the CABO One and Two Family Dwelling Code restrict the use of rigid insulation board to 6 in. (150 mm) or more above grade in areas where the probability of termite infestation is very heavy. However, the 1998 CABO code allows foam insulation below grade if the home has no untreated wood in the structure.

ICF walls can be extended to the footing in homes built with treated wood, steel framing, or concrete under the CABO requirements. While not detrimental to the structural integrity of the concrete wall assembly, the tunneling from below grade foam to above grade foam makes detection of infestation difficult.

The Insulating Concrete Form Association (ICFA) has been working closely with the pest control industry to identify a combination of treatment methods and barriers that will prevent infestation and permit detection.

The ICFA recommends owners building new homes in locations designated as heavy termite infestation areas consult with an established local pest control operator throughout the construction process. Very likely, the home mortgage lender will require a termite guarantee from the operator. The operator will most likely require preventative termite soil treatment under all concrete slabs on grade before construction, and all soil in contact with walls after construction. Continuous barriers such as stainless steel mesh or concrete will most likely be required to isolate the above grade insulation from the below grade insulation. The pest control guarantee should include a maintenance program with periodic inspection and appropriate follow up treatment.

Details. Sixteen figures are presented in Appendix F. The figures are divided into four groups. The first group considers above-grade ICF walls constructed on below-grade ICF walls. The second group of figures considers above-grade ICF walls constructed on a concrete slab-on-grade with an integral perimeter beam. The third set of figures considers above-grade ICF walls constructed on below-grade insulated concrete walls. The final group of figures 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 figures are provided to complement the window details presented in Figures D3 though D8.

ICF Walls on Below-Grade ICF Walls. Figures F1 through F4 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 all 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 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.

A prefabricated metal flashing is utilized to drain moisture that reached the ICF surface (the secondary rain-screen barrier) out of the wall.

An elastomeric waterproofing is required 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 recommend 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 an 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 F1, F2, F3, and F4, respectively, show the vinyl siding, lap siding, portland cement stucco, and the EIFS variations.

ICF Walls on a Concrete Slab-on-Grade. Figures F5 through F8 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 protection from the environment. Portland cement stucco or an UV resistant membrane is required.

Figures F4, F5, F6, and F7, respectively, show the vinyl siding, lap siding, portland cement stucco, and the EIFS variations.

ICF Walls on Below-Grade Insulated Concrete Walls. Figures F9 through F12 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 an 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 F9, F10, F11, and F12, respectively, show the vinyl siding, lap siding, portland cement stucco, and the EIFS variations.

ICF Walls at the Roofline. Figures F13 through F16 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.

Figures F13, F14, F15, and F16, respectively, show the vinyl siding, lap siding, portland cement stucco, and the EIFS variations.

SUMMARY AND CONCLUSIONS

Insulating concrete form (ICF) wall systems are rapidly gaining market share in new housing. In the past, their use was primarily limited to custom single-family housing. Today, however, ICF wall systems are being used throughout North America 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.

ICFs, like all wall systems, require special attention to details to avoid potential moisture problems. Standard guidelines are needed to help architects and contractors use these systems more effectively.

This project was performed to investigate the potential for moisture problems associated with ICFs and to develop standard recommendations and guidelines to avoid problems. The project was conducted in four parts.

In the first part, six 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. The walls measured 4-ft by 4-ft (1220-mm by 1220-mm) and had a 6-in. (150-mm) concrete core. Flat-panel ICF wall systems were used with 2-in. (50-mm) of either XPS or EPS insulation. Interior finishes consisted of latex paint and primer on ½-in. (13-mm) drywall, with or without a polyethylene vapor retarder. Exterior finishes consisted of portland cement stucco, EIFS, and hardboard lap siding.

The second part of the investigation involved analyses 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 twelve locations throughout North America.

The third part of the investigation involved gathering window installation and flashing details from ICF manufacturers and other sources.

The final part of the investigation involved developing standard window details 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. Three-dimensional (isometric) construction sequencing drawings were developed for recessed and flush-mount 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. After one year of drying, the relative humidity within ICF walls varied from 77 to 92 percent. This indicates that the ICF walls are drying. The range is due to different exterior finishes and the presence or absence of a vapor retarder.

2. After one year of drying in a controlled atmosphere, the concrete, polystyrene, drywall, and exterior finishes performed adequately and did not show any signs of moisture-related distress.

3. The moisture content of the various materials in finished ICF walls dried for one year was found to be similar to equilibrium moisture contents reported by others.

4. When walls were dissected after one year of drying, corrosion was noted on the portion of drywall screws embedded in the polystyrene. It was not possible to determine the onset or duration of corrosion, or whether corrosion is a long-term problem. As a result of this finding, galvanized screws are recommended for fastening interior and exterior finishes.

5. Temperature fluctuations within the wall sections during the one year of laboratory monitoring suggest that heat flow through the wall is not one-dimensional (horizontal) but also vertical. This indicates that potential energy savings through vertical heat flow (ground coupling) may be substantial and that further research into the potential for energy savings during summer and winter seasons is needed.

6. 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. Locations where this may be a potential problem are presented in Appendix C.

7. To verify results of the analytical findings recommending a vapor retarder, we recommend field studies or laboratory tests under winter conditions to determine the amount and effects of moisture accumulation between the concrete and inner layer of insulation.

8. Analyses indicated that gaps between insulation boards or holes in insulation can cause condensation on walls in locations with 1500 HDD65 or above. Locations where this may be a potential problem are presented in Appendix C.

9. Analyses indicated that moisture of construction within ICF walls can initially cause condensation within walls. However, ICF walls will eventually dry if guidelines are followed and walls are not subjected to other sources of moisture.

10. 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.

11. 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 C.

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DISCLAIMER

The recommendations and ideas presented in this report are based on a specific laboratory program and analyses, engineering judgement, 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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Table 1. ICF Wall Construction Matrix

Wall No.	Interior Finish	Vapor Retarder	Insulation Type	Exterior Finish
1	Painted Drywall	None	XPS	EIFS
2	Painted Drywall	None	EPS	EIFS
3	Painted Drywall	Interior	EPS	EIFS
4	Painted Drywall	Interior	EPS	Hardboard Lap Siding
5	Painted Drywall	None	EPS	Hardboard Lap Siding
6	Painted Drywall	Interior	EPS	Portland Cement Stucco

Table 2. Concrete Mix Design

Constituent	Quantity	
Cement	564 pcy	335 kg/m^3
Sand	1405 pcy	834 kg/m^3
Pea Gravel, • -in. (10-mm)	1550 pcy	920 kg/m^3
Water	250 pcy	148 kg/m^3
Air Entraining Admixture	8 oz.	237 ml

Table 3. Measured Concrete Properties

Property	Measured Value	
Slump	6½ in.	165 mm
Air Content	7%	7%
28-day Compressive Strength	3,600 psi	24.8 MPa

Table 4. Physical Properties of Insulation[7,8]

Property	EPS	XPS
Density, pcf (kg/m^3)	1.8 to 2.2 (29 to 35)	1.7 (27)
Water Vapor Permeability, perm·in. (ng/Pa·s·m)	0.6 to 2.0 (2.6 to 3.2)	1.1 (2.5)
Water Absorption, maximum	< 2.0 percent	< 0.10 percent
Thermal Conductivity*, Btu/hr·ft^2·°F (W/m·K)	0.23 (0.033)	0.194 (0.028)

* Thermal conductivity at 75°F (24°C)

Table 5. Mass of ICF Wall Sections

Day	Weight, lbs (kg)					
	Wall No. 1	Wall No. 2	Wall No. 3	Wall No. 4	Wall No. 5	Wall No. 6
0	—	—	—	—	—	—
7	1239 (562)	1236 (561)	1238 (561)	1232 (559)	1249 (566)	1330 (603)
43	1230 (558)	1234 (560)	1234 (560)	1230 (558)	1240 (562)	1321 (599)
70	1241 (563)	1243 (564)	1238 (561)	1235 (560)	1250 (567)	1332 (604)
379	1230 (558)	1226 (556)	1220 (553)	1222 (554)	1236 (561)	1324 (600)

Note: The accuracy of the measurements is ±5 lbs (±2.3 kg)

Table 6. Moisture Content of Materials from ICF Wall Sections

Material	Surface	Wall No.	Ovendry Density pcf	Ovendry Density kg/m^3	Moisture Content, %
Concrete	Interior	1	132	2120	4.5%
		2	131	2100	4.5%
		3	130	2080	5.0%
		4	130	2080	5.1%
		5	130	2090	4.7%
		6	129	2070	5.2%
	Exterior	1	132	2110	4.9%
		2	132	2230	4.3%
		3	131	2100	5.2%
		4	133	2130	4.6%
		5	131	2090	4.9%
		6	134	2140	4.6%
	Average		**131**	**2110**	**4.8%**
Drywall	Interior	1	40	640	0.7%
		2	40	640	0.8%
		3	40	640	0.7%
		4	40	640	0.7%
		5	40	640	0.4%
		6	40	640	0.5%
	Average		**40**	**640**	**0.6%**
EIFS	Exterior	1	107	1710	1.7%
		2	113	1820	1.9%
		3	111	1770	3.5%
	Average		**110**	**1770**	**2.4%**
EPS	Interior	2	1.9	31	0.0%
		3	1.9	31	0.0%
		4	1.9	31	0.0%
		5	1.9	31	0.0%
		6	1.9	31	0.0%
	Exterior	2	1.9	31	0.0%
		3	1.9	31	0.0%
		4	1.9	31	0.0%
		5	1.9	31	0.0%
		6	1.9	31	0.0%
	Average		**1.9**	**31**	**0.0%**

Table 6 (continued). Moisture Content of Materials from ICF Wall Sections

Material	Surface	Wall No.	Ovendry Density		Moisture Content, %
			pcf	kg/m^3	
XPS	Inside	1	1.8	29	0.0%
	Outside	1	1.8	29	0.0%
	Average		**1.8**	**29**	**0.0%**
Stucco	Outside	6	135	216	2.9%
Hardboard Siding	Outside	4	49	780	6.3%
	Outside	5	49	780	6.2%
	Average		**49**	**780**	**6.2%**

Table 7. Outdoor Ambient Conditions Used for the Condensation Analyses

City	State/ Province	Winter Design			Average January			Summer Design			Average July		
		Temperature		RH, %	Temperature		RH, %	Temperature		RH, %	Temperature		RH, %
		°F	°C		°F	°C		°F	°C		°F	°C	
Fairbanks	AL	-47	-44	67	-12.8	-24.9	67	78	26	60.5	61.5	16.4	60.5
Edmonton	AB	-25	-32	73	9.5	-12.5	73	82	28	66	60.1	15.6	66
Minneapolis	MN	-12	-24	69	11.2	-11.6	69	89	32	67	73.1	22.8	67
Madison	WI	-7	-22	73.5	15.6	-9.1	73.5	88	31	71	70.6	21.4	71
Cincinnati	OH	6	-14	73	28.9	-1.7	73	90	32	71	75.4	24.1	71
Seattle	WA	26	-3	77	39.1	3.9	77	80	27	65	64.8	18.2	65
Washington	DC	17	-8	61	35.2	1.8	61	91	33	64.5	78.9	26.1	64.5
Charlotte	NC	22	-6	67	40.5	4.7	67	93	34	73	78.5	25.8	73
L. Charles	LA	31	-1	78	51.5	10.8	78	93	34	78.5	82.3	27.9	78.5
Los Angeles	CA	43	6	64.5	56.0	13.3	64.5	80	27	76.5	69.0	20.6	76.5
Phoenix	AZ	34	1	50	52.3	11.3	50	107	42	32.5	92.3	33.5	32.5
Miami	FL	47	8	71.5	67.1	19.5	71.5	90	32	74	82.4	28.0	74

Table 8. Physical Properties of Materials Used in the Condensation Analyses

Material Property	Normal Paint	Vapor Retarder Paint	Drywall	Vapor Retarder	XPS	EPS	Concrete	Portland Cement Stucco	Hardboard Siding	EIFS
Thickness, in. (mm)	0.002[B] (0.05)	0.002[B] (0.05)	0.5[A] (13)	0.004[D] (0.1)	1.94[D] (49.3)	2.00[D] (50.8)	6[D] (150)	0.5[D] (13)	0.375[C] (9.5)	0.15[A] (3.8)
Permeance, perm (ng/Pa·s·m^2)	5[E] (290)	1[E] (57)	34.2[A] (1960)	0.08[C] (5)						8.4[A] (480)
Permeability, perm·in. (ng/Pa·s·m)					1.1[F] (1.6)	2.0[G] (2.9)	3.2[C] (4.6)	3.2[C] (4.6)	2.95[C] (4.3)	
Thermal Conductance, Btu/hr·ft^2·°F (W/m^2·K)			2.22[C] (12.6)							
Thermal Conductivity, Btu·in./hr·ft^2·°F (W/m·K)					0.193[F] (0.028)	0.230[G] (0.033)	16[C] (2.3)	9.7[C] (1.4)	1.06[C] (0.15)	10[B] (1.4)
R-Value, hr·ft^2·°F/Btu (m^2·K/W)	0[B] (0)	0[B] (0)		0[B] (0)						

Source:
A. United States Gypsum Company
B. Estimated
C. ASHRAE Handbook of Fundamentals, 1993 Edition
D. Measured from Constructed ICF Wall Sections
E. IC Industries, Inc.(Reference 8)
F. Benchmark Foam, Inc. (Reference 7)
G. General Rule of Thumb

Figure 1. Wood form for ICF wall section.

Figure 2. Wood form with ICFs.

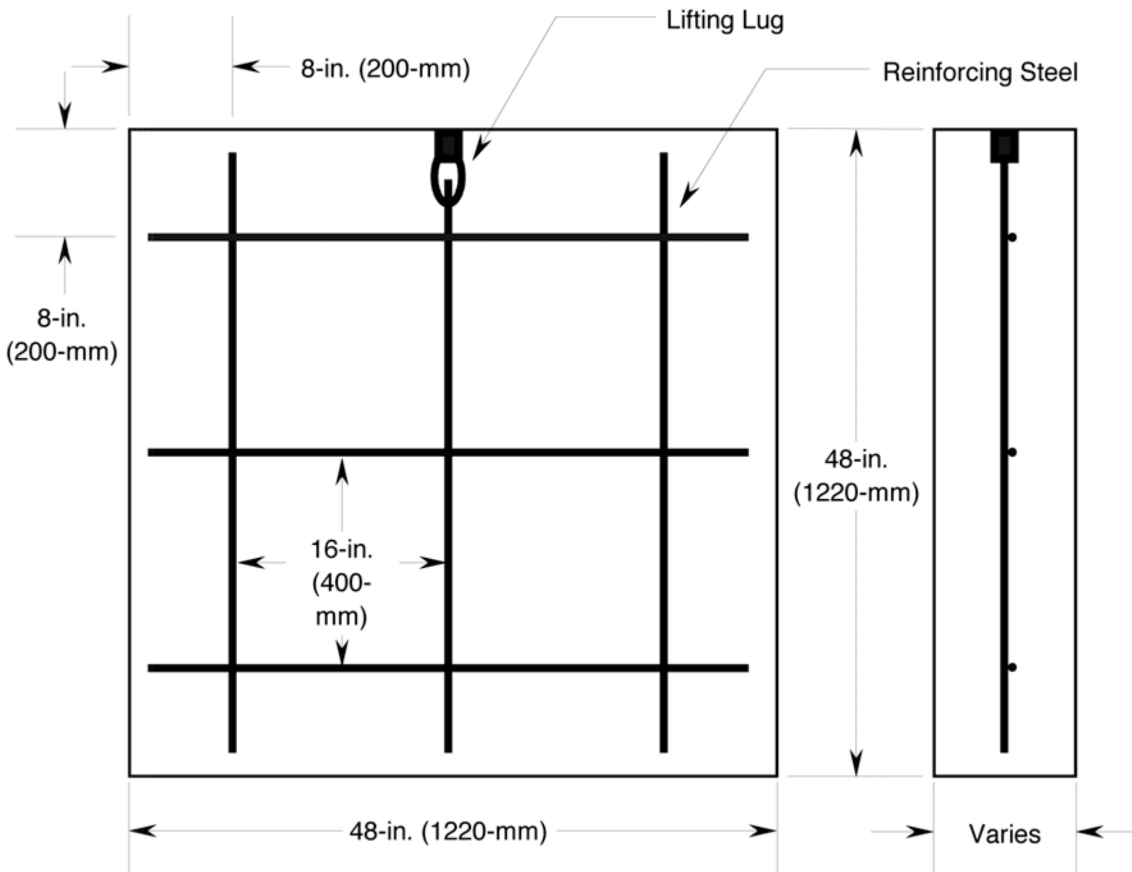


Figure 3. Layout of reinforcing steel in the ICF walls.

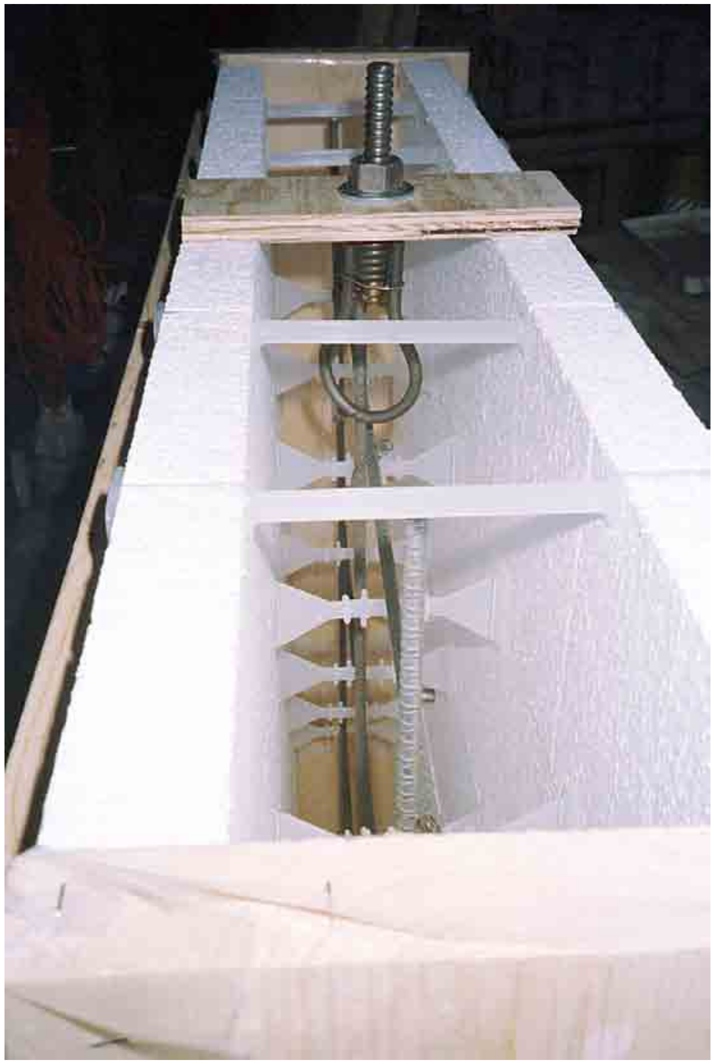


Figure 4. ICF wall section with reinforcing steel and lifting lug installed.

Figure 5. ICF wall sections in wood forms with reinforcing steel installed.

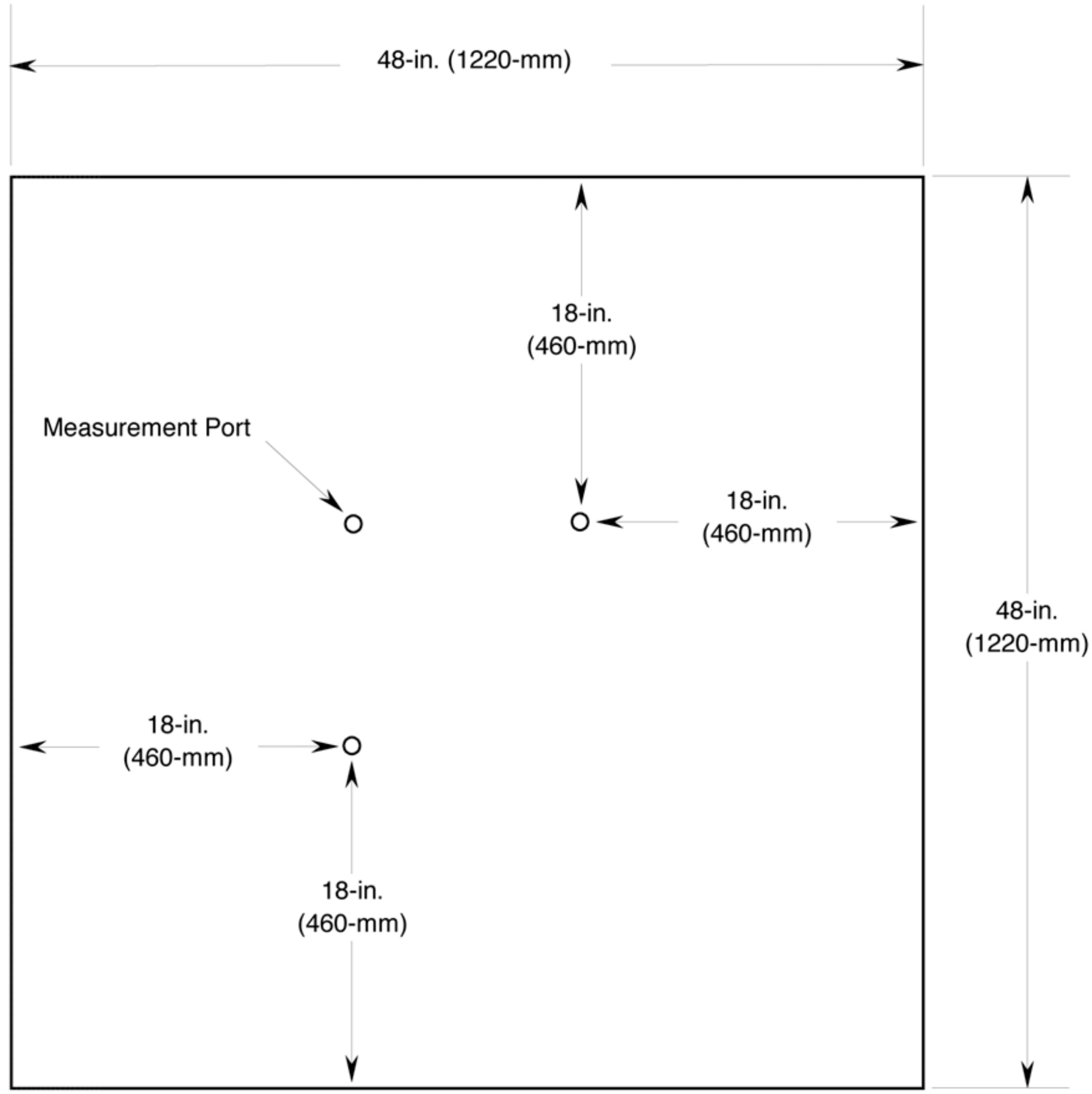


Figure 6. Generalized layout of relative humidity ports in walls.

Figure 7. Relative humidity ports installed in Wall No. 6.

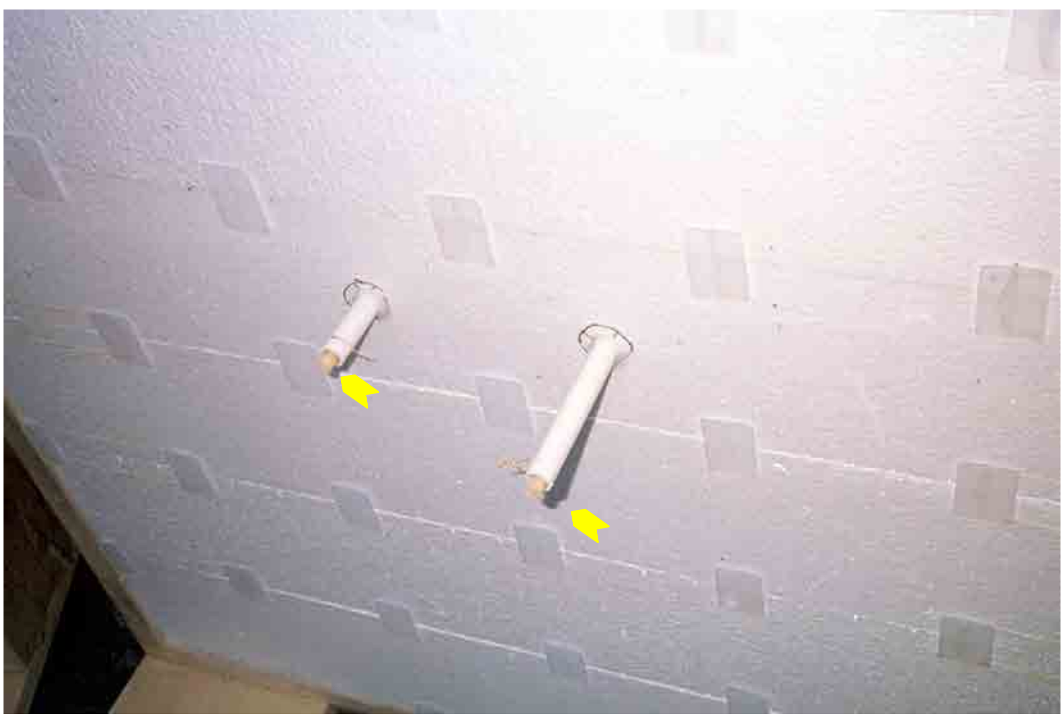


Figure 8. Temporary plugs installed in relative humidity measurement ports.

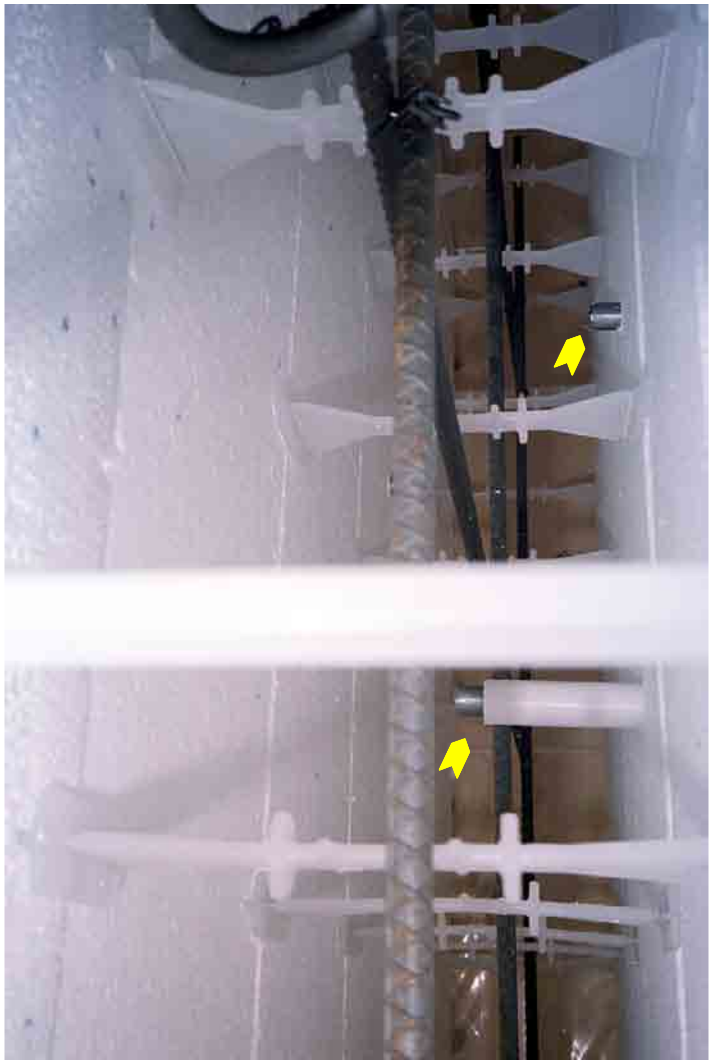


Figure 9. Temporary plugs installed in the relative humidity measurement ports at the concrete–insulation interface and center of concrete in Wall No. 1.

Figure 10. Placement of concrete into ICF.

Figure 11. Close-up of placement of concrete into ICF.

Figure 12. Strike-off of concrete.

Figure 13. Mix water leaking from ICF walls immediately after casting.

Figure 14. Wall No. 4 with drywall installed prior to application of drywall compound.

Figure 15. Application of latex primer on finished drywall.

Figure 16. Installation of hardboard lap siding on wood furring.

Figure 17. Roughening of XPS insulation prior to application of the EIFS base coat on Wall No. 1 (NOT A RECOMMENDED PRACTICE).

Figure 18. Application of the EIFS base coat on EPS insulation of Wall No. 3.

Figure 19. Application of fiberglass mesh into the EIFS scratch coat.

Figure 20. Application of the EIFS top coat.

Figure 21. Application of metal lathe prior to portland cement stucco.

Figure 22. Application of portland cement stucco base-coat.

Figure 23. Temporary caps on relative humidity ports in Wall No. 2.

Figure 24. Application of edge sealing material.

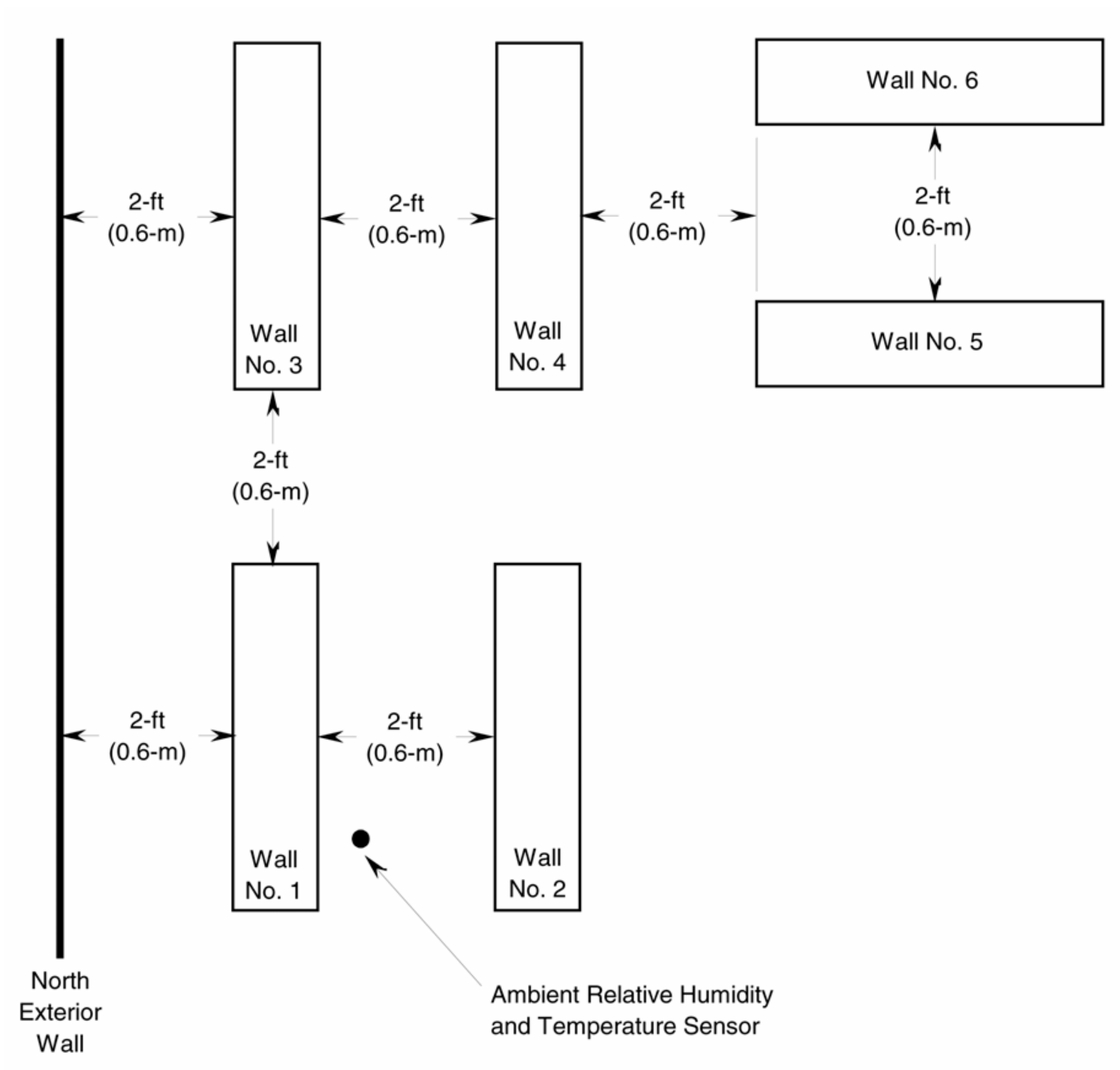


Figure 25. Layout of wall sections in storage environment.

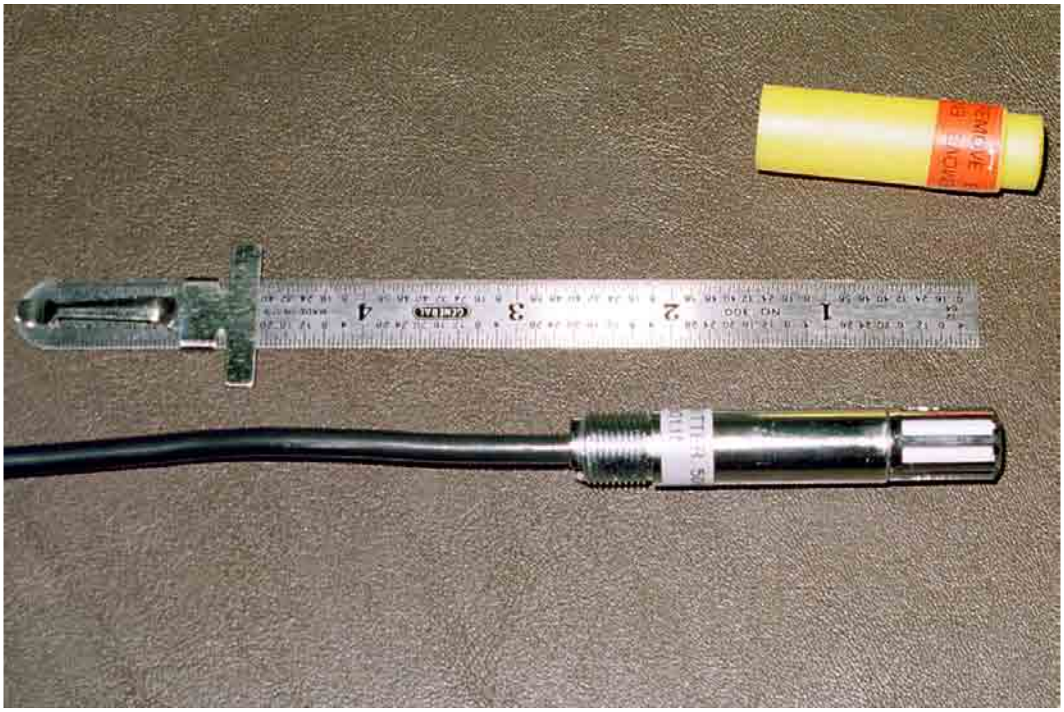


Figure 26. Relative humidity probe.

Figure 27. Relative humidity probe with the protective housing of the relative humidity sensor removed.

Figure 28. Close-up of drywall screw showing corrosion.

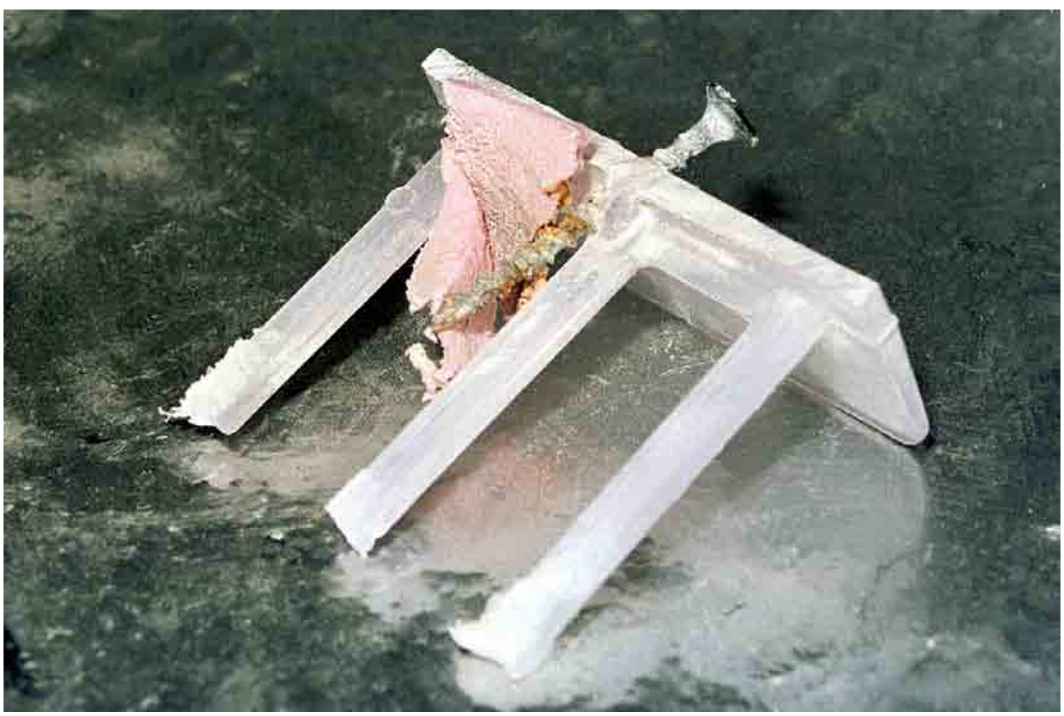


Figure 29. Close-up of a corroded drywall screw showing corrosion only occurs on the portion of the screw embedded in the polystyrene.

APPENDIX A. DRYING OF ICF WALLS

This appendix presents results of the rates of drying of the six ICF walls. Figures A1 through A6 present the relative humilities within Wall Nos. 1 through 6. Figure A7 presents temperatures within ICF walls. Figure A8 presents the temperature and relative humidity of the conditioned environment.

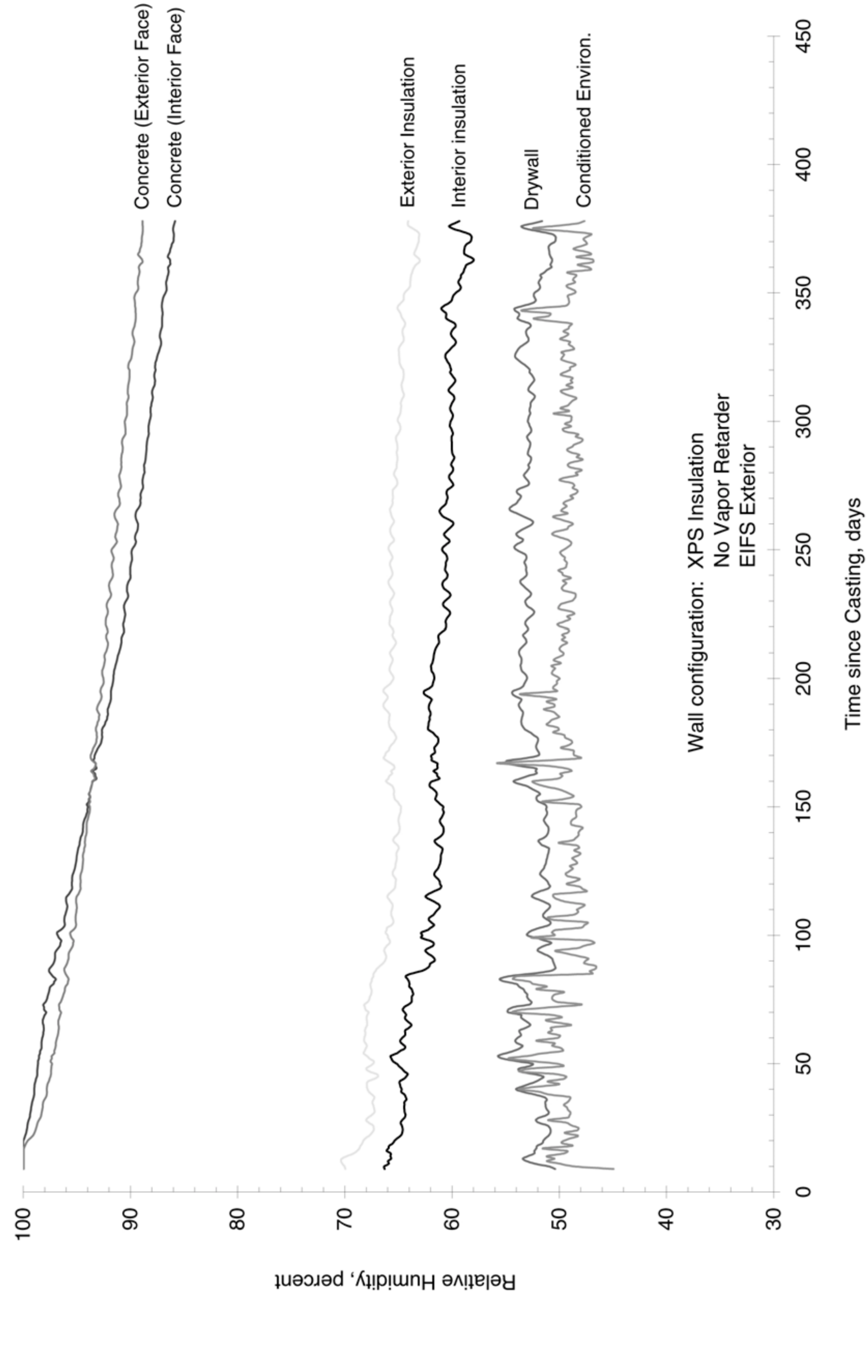


Figure A1. Internal relative humidities for Wall No. 1.

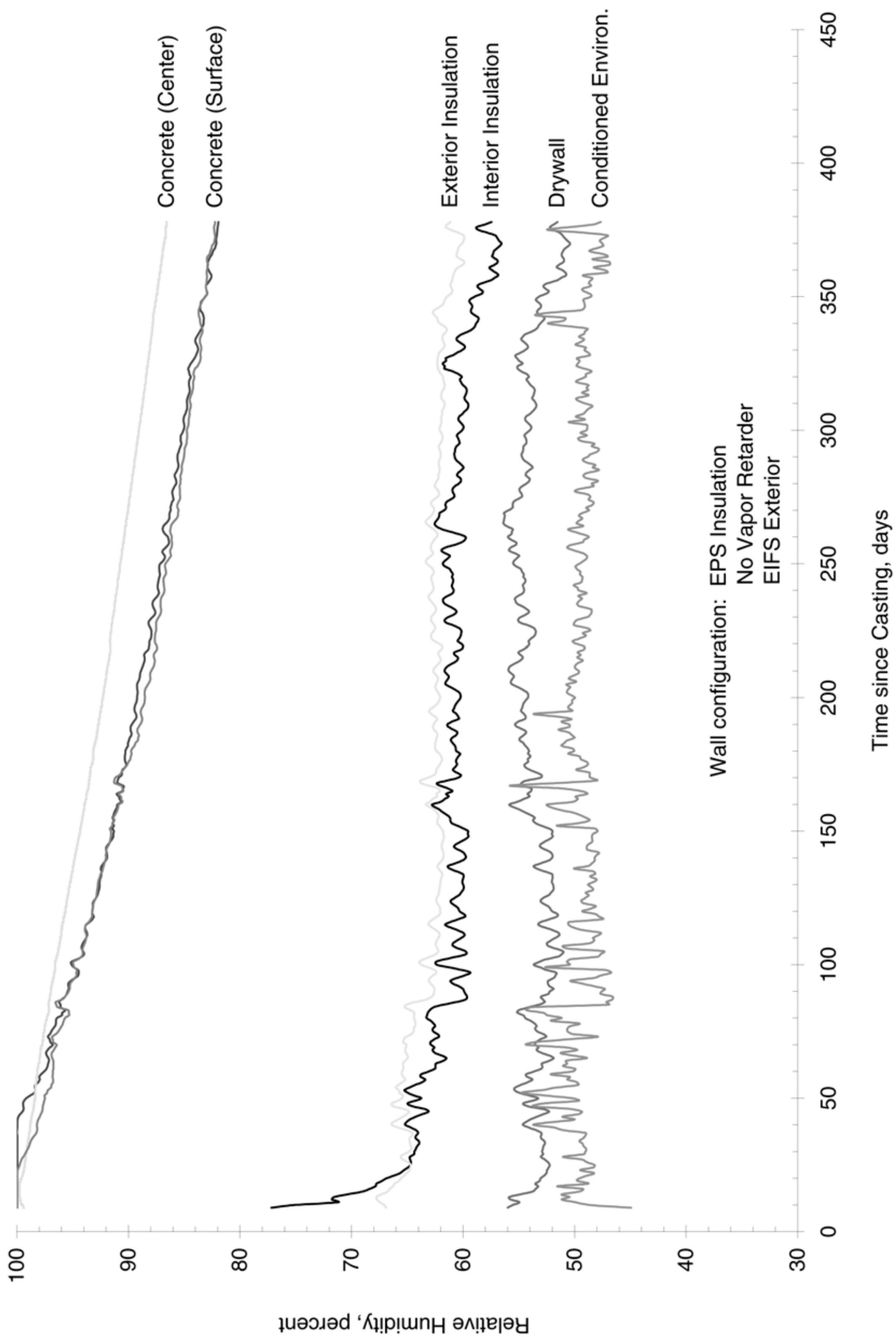


Figure A2. Internal relative humidities for Wall No. 2.

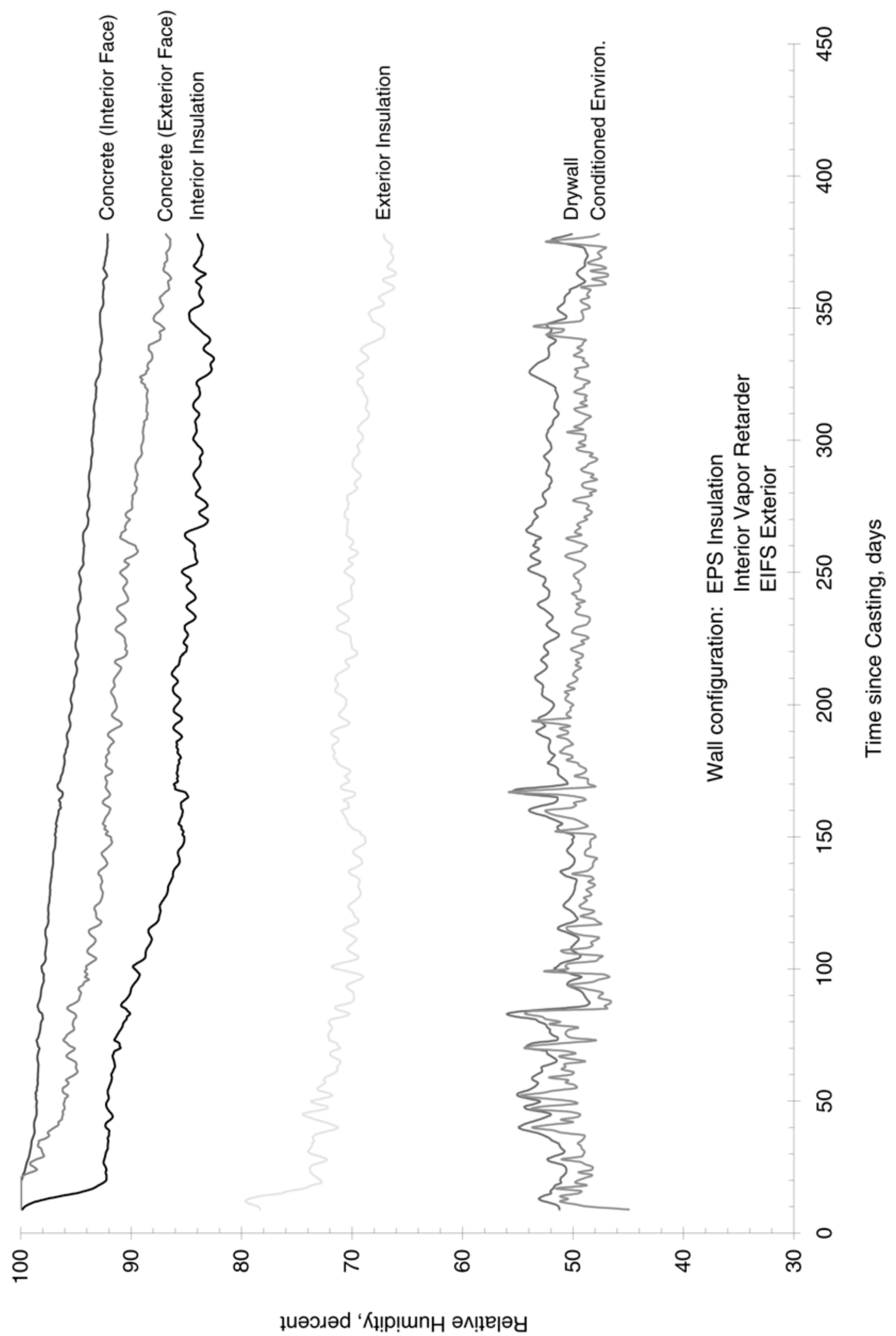


Figure A3. Internal relative humidities for Wall No. 3.

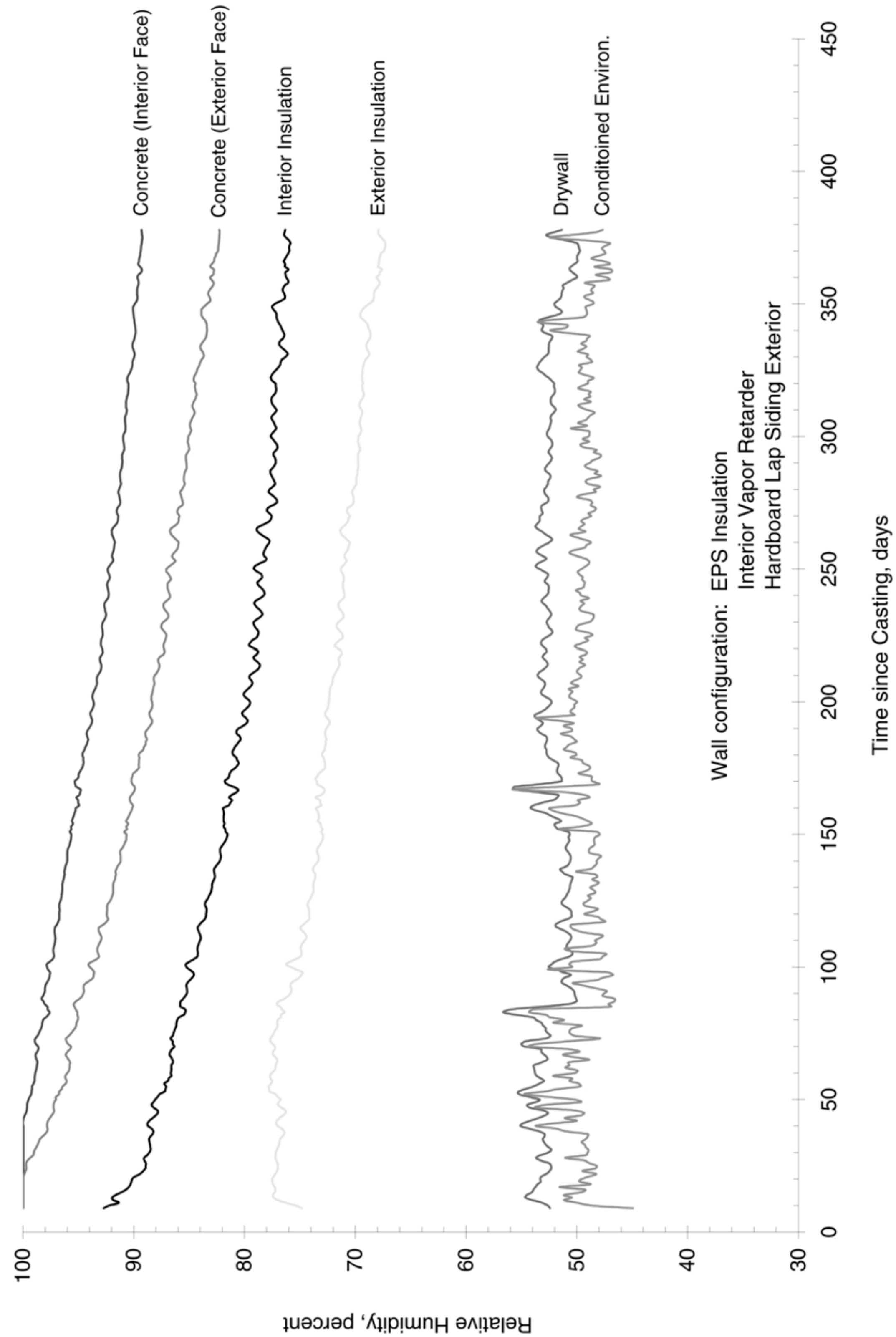


Figure A4. Internal relative humidities for Wall No. 4.

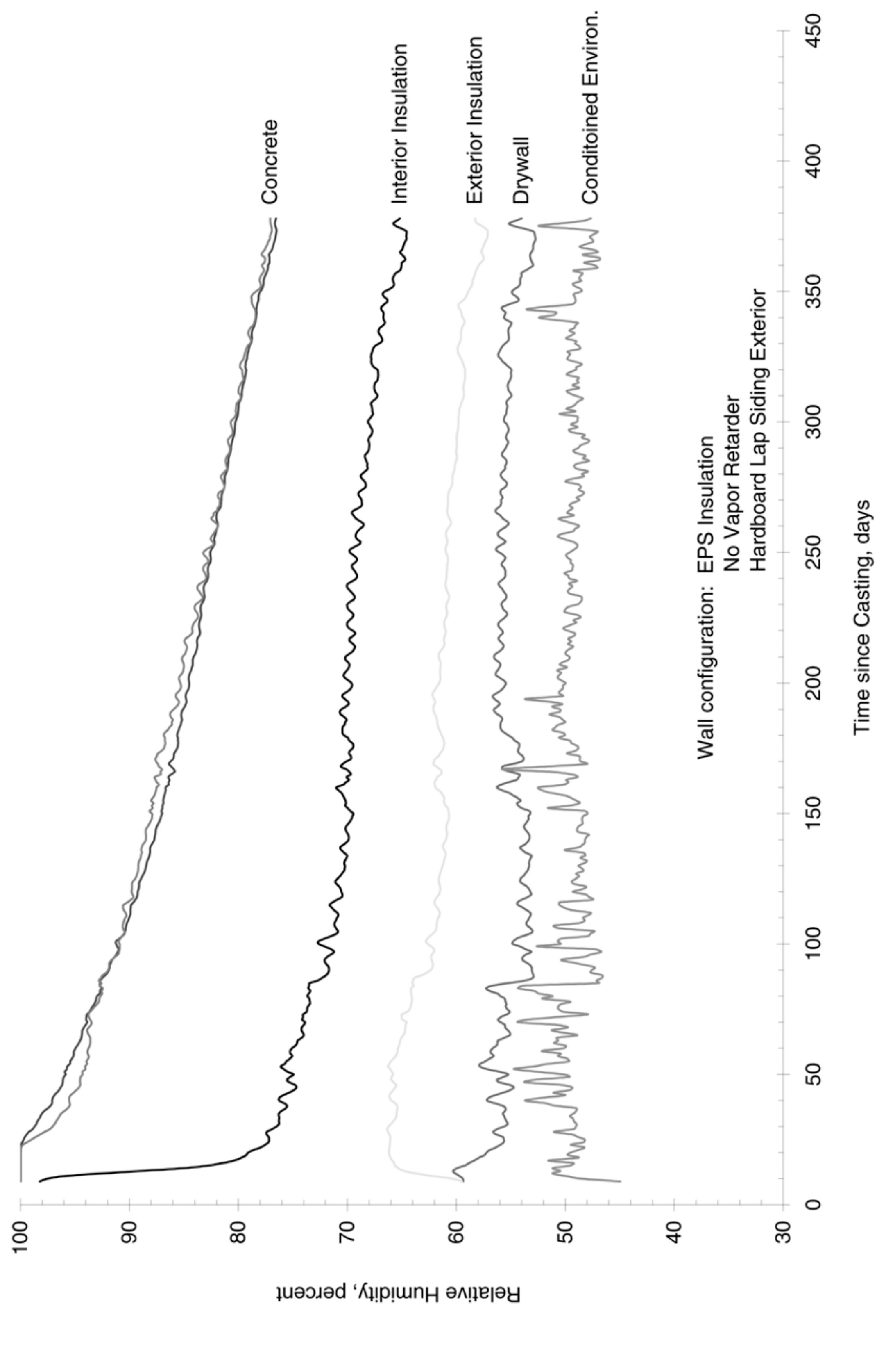


Figure A5. Internal relative humidities for Wall No. 5.

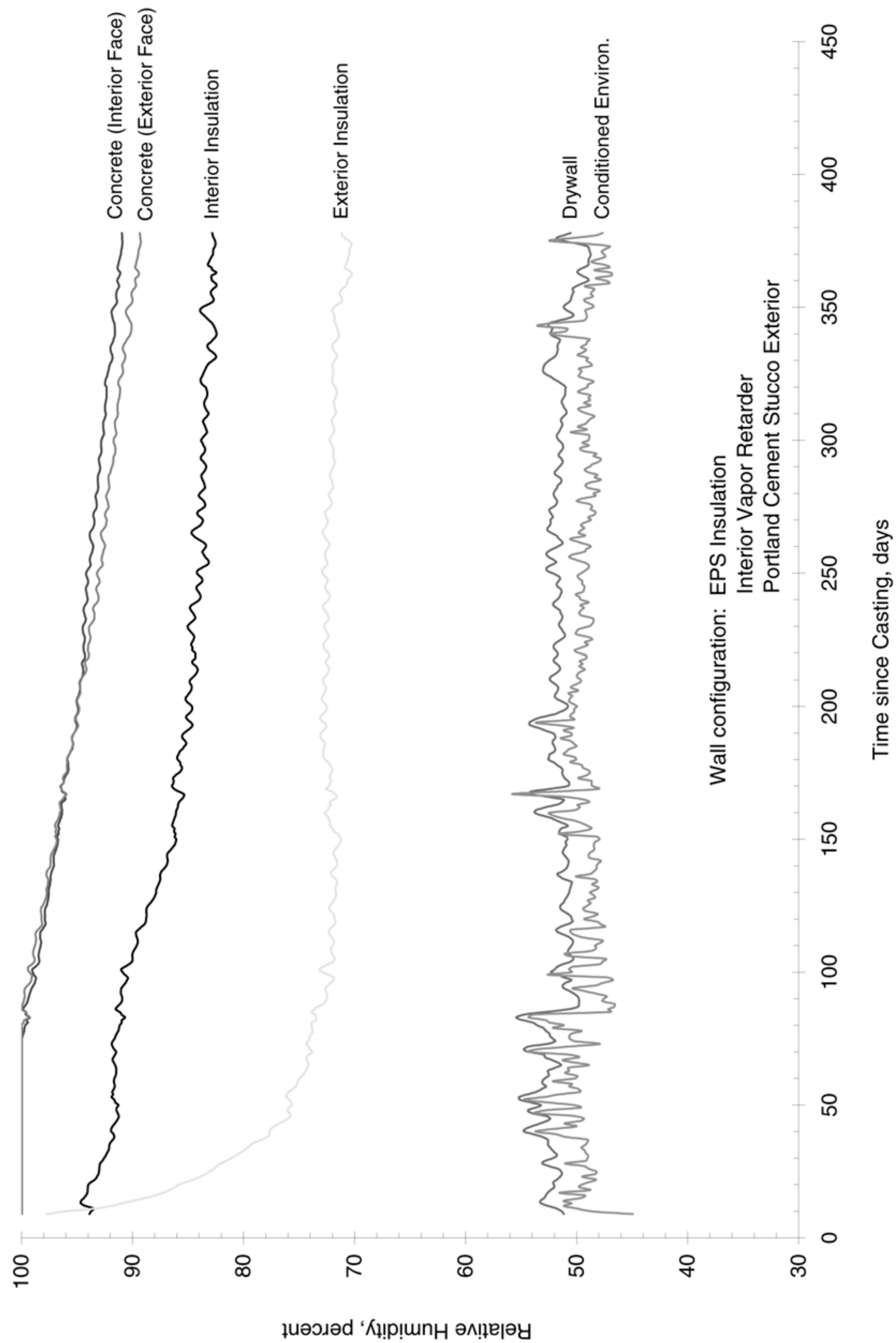


Figure A6. Internal relative humidities for Wall No. 6.

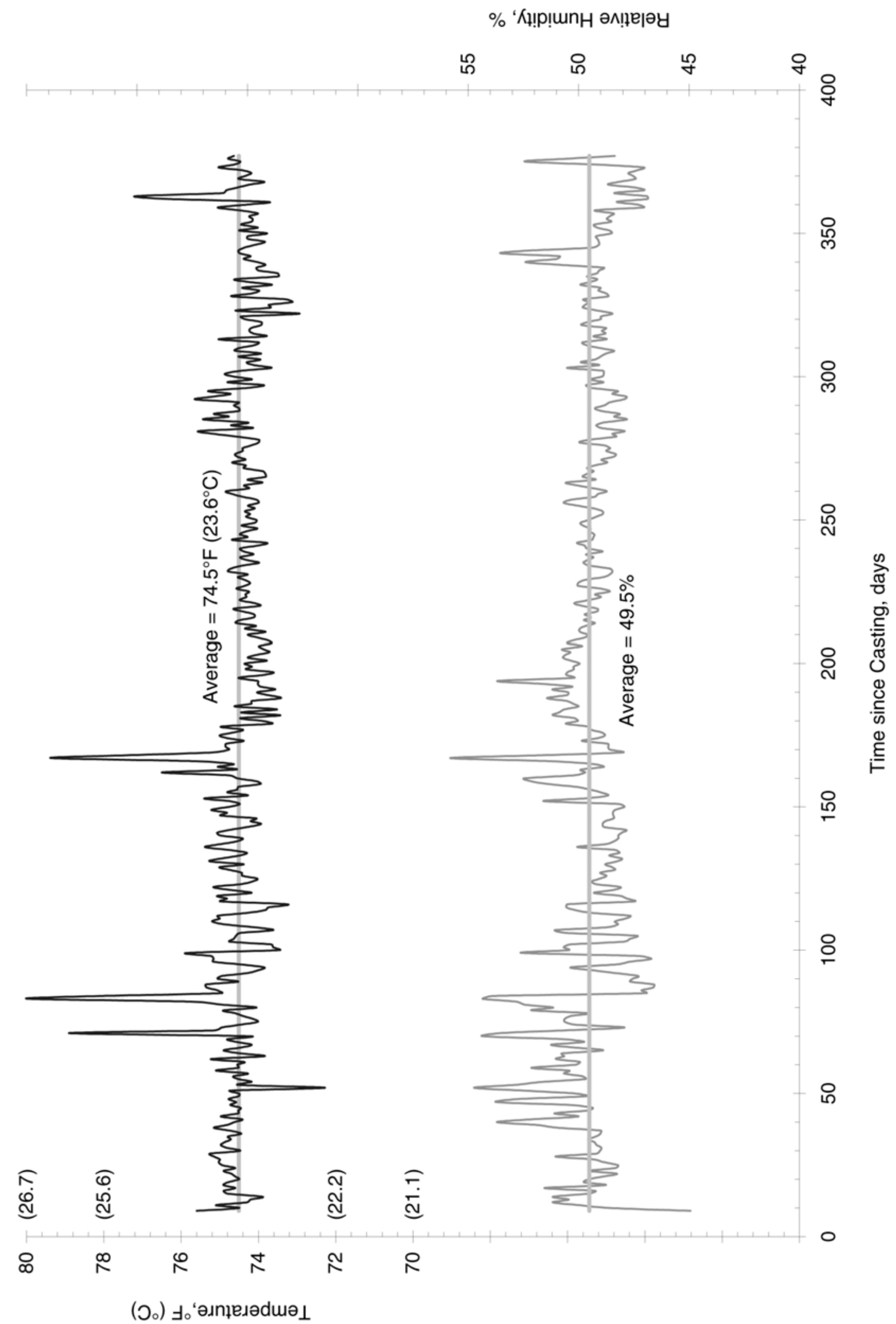


Figure A7. Temperatures within ICF wall sections.

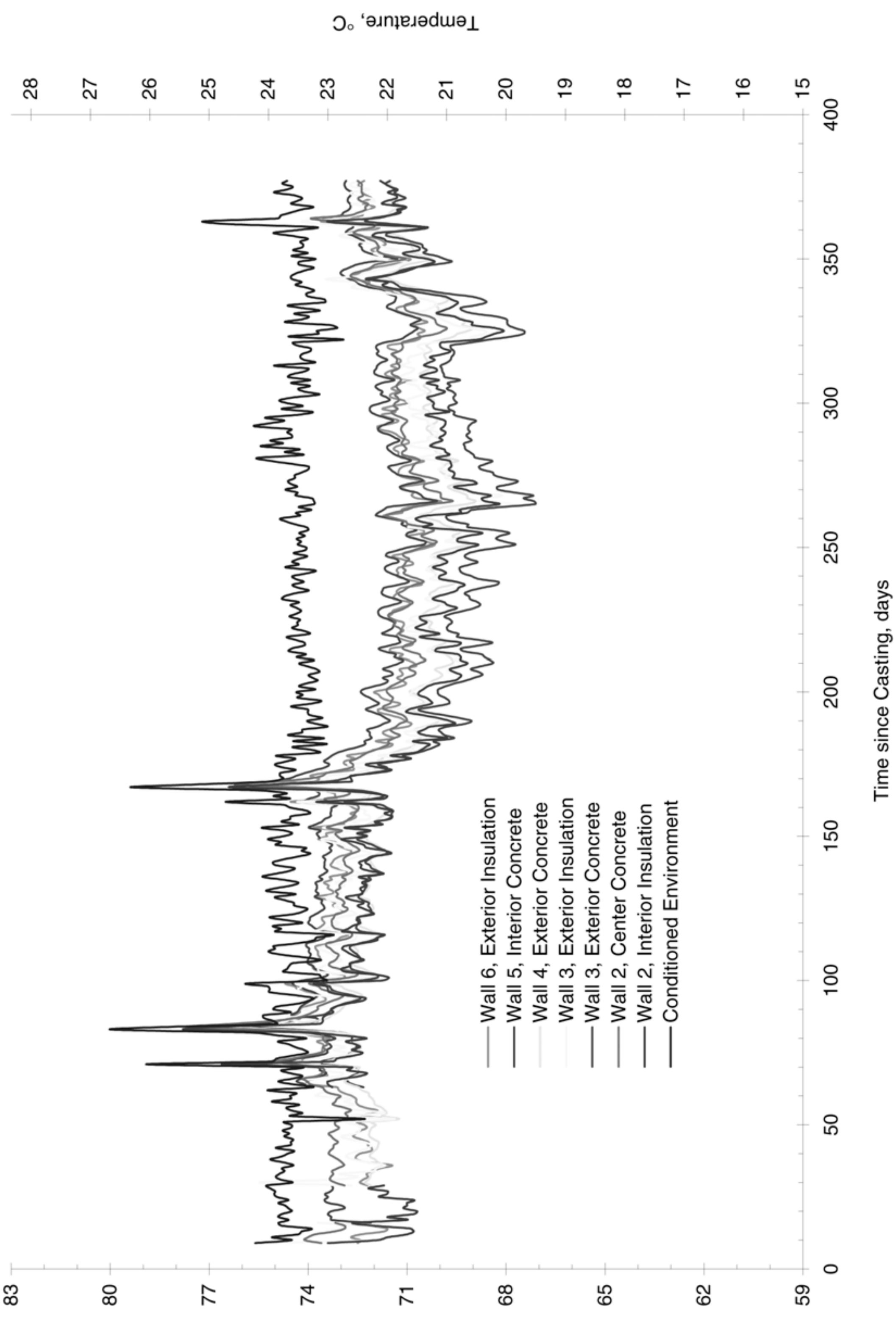


Figure A8. Ambient conditions of the conditioned environment.

APPENDIX B. CONDENSATION POTENTIAL OF ICF WALLS

This appendix contains the results of the condensation analyses of typical ICF walls with various exterior finishes modeled for twelve climates throughout North America. The analyses were performed to determine the potential for moisture problems or condensation within walls.

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, "Standard Practice for Selection of Vapor Retarders for Thermal Insulation". The analyses provided the location of the surfaces on which condensation potentially occurs.

Data are presented as a series of tables. Tables are divided into three groups. Each group of tables represents different analyses. The first group of tables, Tables B2 through B7, represent whole-wall long-term conditions. The relative humidity of the concrete core of the walls is less than 100 percent, near the average of the indoor and outdoor relative humidities. These analyses are typical of the long-term equilibrium condition of the walls. Condensation analyses are typically performed for this situation.

The second group of tables, Tables B8 through B13, consider the center of the concrete to exterior surface of the walls. The relative humidity of the concrete is forced to 100 percent. The third group of tables, Tables B14 through B19 consider the center of the concrete to interior surface of the wall. The relative humidity of the concrete is again forced to 100 percent. The Tables B8 through B19 consider a worst-case situation, where the wall is recently cast, or never dries out.

Within each group, six tables consider a variety of indoor and outdoor conditions for typical and design winter and summer conditions. These conditions are described in detail within the body of this report.

Each of the tables provides information of the location analyzed, the wall construction, and the indoor / outdoor conditions. The tables also provide information regarding the location of condensation (if present) within the wall sections. In these analyses, condensation always occurs on material interfaces, such as the drywall-vapor retarder interface. Due to space limitations, codes were used to represent the first location of condensation, if present, as measured from the indoor surface of the ICF wall. No data represents no condensation. Codes were chosen to minimize confusion of the reader and are presented in the table below.

Code	Material
VR	Vapor Retarder
Interior	Paint*
PCC	Portland Cement Concrete
Ext	Exterior Surface
Dry	Drywall
Insul	Polystyrene Insulation

* Condensation appears on the interior surface of the wall.

Codes indicate the indoor-most location of condensation; "Insul/PCC" indicates condensation between the *indoor* insulation and the concrete core, while "PCC/Insul" indicates condensation between the concrete and the *outdoor* insulation.

Tables B2 through B17 contain all combinations of materials analyzed, a total of thirty-six different wall sections. Although each combination of materials in the matrix is not appropriate for each climate, for ease of analysis all wall sections were analyzed for all climates. Shaded areas of the tables indicate rows with recommended wall construction materials. A vapor retarder between the insulation and the interior finish (drywall) is recommended in ICF walls in cold weather climates, with annual heating degree days (base 65) in excess of 7000. A vapor retarder is not recommended in all other climates.

It should be noted that it not advisable to place an interior vapor retarder on a wall in a warm and humid climate. Likewise, an exterior vapor retarder should not be placed in a wall in a cold weather climate. This is because a vapor retarder should be placed on the side of the wall where the majority of the water vapor flow, on an annual basis, originates. In cool climates, during the majority of the typical year, water vapor flows from the interior of the building to the exterior. Therefore the vapor retarder should be placed on the indoor portion of the wall. The opposite is true in hot-humid climates.

Table B1. ASTM C 755 Steady-State Water Vapor Difussion Analysis Example Calculation (English Units)

	Indoor	Air Film		Normal Paint		1/2-in. Drywall		EPS Insulation		Concrete		EPS Insulation		EIFS Finish		Air Film	Outdoor	Total
Thickness, in.				0.002		0.5		2.0		6.0		2.0		0.15				
Permeance, perm		160		5.0		34.2								8.4		1000		
Permeability, perm•in.								2.0		3.2		2.0						
Vapor resistance, $perm^{-1}$		0.006		0.200		0.029		1.000		1.875		1.000		0.119		0.001		4.231
Vapor pressure drop, in. Hg		0.001		0.017		0.002		0.083		0.155		0.083		0.010		0.000		0.350
Vapor pressure for continuity, in. Hg	0.396		0.396		0.379		0.377		0.294		0.139		0.057		0.047		0.046	
Thermal Conductance, $Btu/hr•ft^2•°F$		1.46				2.22										6		
Thermal Conductivity, $Btu•in./hr•ft^2•°F$								0.2299		16		0.2299		10				
R-Value, $hr•ft^2•°F/Btu$		0.685		0.000		0.450		8.700		0.375		8.700		0.015		0.167		19.092
Temperature drop, °F		2.2		0.0		1.4		27.7		1.2		27.7		0.0		0.5		60.8
Temperature, °F	72		69.8		69.8		68.4		40.7		39.5		11.8		11.7		11.2	60.8
Saturation vapor pressure, in. Hg	0.792		0.735		0.735		0.700		0.254		0.243		0.069		0.069		0.067	
Actual vapor pressure, in. Hg	0.396		0.396		0.379		0.377		0.254		0.139		0.057		0.047		0.046	
Vapor Flow from outside					0.083		0.083		0.070		0.083		0.087		0.599			
Vapor Flow from inside					0.080		0.080		0.114		0.082		0.082		0.083			
Condensation Rate																		
$g/day/m^2$									0.752									
$gr/hr/ft^2$									0.045									

Indoor conditions: 72°F, 50% RH
Outdoor conditions: 11.2°F, 69% RH

Table B2. Condensation Potential for ICF Walls using ASHRAE 97.5% Winter Design Conditions

No.	Construction Materials				Location											
	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC		Insul / PCC					
2	EIFS	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
3	EIFS	EPS	Inside	normal	Insul / PCC											
4	EIFS	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR
5	EIFS	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
6	EIFS	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
7	EIFS	XPS	Inside	normal	Insul / PCC											
8	EIFS	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR
9	EIFS	none	none	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC		Dry / PCC	
10	EIFS	none	none	VR	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC			
11	EIFS	none	Inside	normal	Interior	Interior	Interior	Interior	Interior	Dry / VR	Interior	Interior	Dry / VR		Dry / VR	
12	EIFS	none	Outside	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC	PCC / VR	Dry / PCC	PCC / VR
13	Stucco	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC		Insul / PCC					
14	Stucco	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
15	Stucco	EPS	Inside	normal	Insul / PCC	Insul / Ext										
16	Stucco	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR
17	Stucco	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
18	Stucco	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
19	Stucco	XPS	Inside	normal	Insul / PCC	Insul / Ext										
20	Stucco	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR
21	Stucco	none	none	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC		Dry / PCC	
22	Stucco	none	none	VR	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC			
23	Stucco	none	Inside	normal	Interior	Interior	Interior	Interior	Interior	Dry / VR	Interior	Interior	Dry / VR		Dry / VR	
24	Stucco	none	Outside	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC	PCC / VR	Dry / PCC	PCC / VR
25	Wood	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC		Insul / PCC					
26	Wood	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
27	Wood	EPS	Inside	normal	Insul / PCC											
28	Wood	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR
29	Wood	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
30	Wood	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
31	Wood	XPS	Inside	normal	Insul / PCC											
32	Wood	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR
33	Wood	none	none	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC			
34	Wood	none	none	VR	Interior	Interior	Interior	Interior	Interior		Dry / PCC					
35	Wood	none	Inside	normal	Interior	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR		Dry / VR	
36	Wood	none	Outside	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC		Dry / PCC	
Outdoor Temperature, °F					-47	-25	-12	-7	6	26	17	22	31	43	34	47
Outdoor Temperature, °C					-44	-32	-24	-22	-14	-3	-8	-6	-1	6	1	8
Outdoor Relative Humidity, %					67	73	69	73.5	73	77	61	67	78	64.5	50	71.5
Indoor Temperature, °F					72	72	72	72	72	72	72	72	72	72	72	72
Indoor Temperature, °C					22	22	22	22	22	22	22	22	22	22	22	22
Indoor Relative Humidity, %					50	50	50	50	50	50	50	50	50	50	50	50

Table B3. Condensation Potential for ICF Walls using NOAA Average January Conditions

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
2	EIFS	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC									
3	EIFS	EPS	Inside	normal												
4	EIFS	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR				
5	EIFS	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
6	EIFS	XPS	none	VR	Insul / PCC											
7	EIFS	XPS	Inside	normal												
8	EIFS	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR				
9	EIFS	none	none	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC					
10	EIFS	none	none	VR	Interior	Interior	Interior	Interior	Dry / PCC							
11	EIFS	none	Inside	normal	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR				
12	EIFS	none	Outside	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC				
13	Stucco	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
14	Stucco	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC									
15	Stucco	EPS	Inside	normal												
16	Stucco	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR				
17	Stucco	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
18	Stucco	XPS	none	VR	Insul / PCC											
19	Stucco	XPS	Inside	normal												
20	Stucco	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR				
21	Stucco	none	none	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC					
22	Stucco	none	none	VR	Interior	Interior	Interior	Interior	Dry / PCC							
23	Stucco	none	Inside	normal	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR				
24	Stucco	none	Outside	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC				
25	Wood	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
26	Wood	EPS	none	VR	Insul / PCC	Insul / PCC										
27	Wood	EPS	Inside	normal												
28	Wood	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR				
29	Wood	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC									
30	Wood	XPS	none	VR	Insul / PCC											
31	Wood	XPS	Inside	normal												
32	Wood	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR				
33	Wood	none	none	normal	Interior	Interior	Interior	Dry / PCC	Dry / PCC							
34	Wood	none	none	VR	Interior	Interior	Interior	Dry / PCC								
35	Wood	none	Inside	normal	Interior	Interior	Interior	Dry / VR	Dry / VR		Dry / VR					
36	Wood	none	Outside	normal	Interior	Interior	Interior	Dry / PCC	Dry / PCC	PCC / VR	Dry / PCC	PCC / VR				
Outdoor Temperature, °F					-12.8	9.5	11.2	15.6	28.9	39.1	35.2	40.5	51.5	56	52.3	67.1
Outdoor Temperature, °C					-24.9	-12.5	-11.6	-9.1	-1.7	3.9	1.8	4.7	10.8	13.3	11.3	19.5
Outdoor Relative Humidity, %					67	73	69	73.5	73	77	61	67	78	64.5	50	71.5
Indoor Temperature, °F					72	72	72	72	72	72	72	72	72	72	72	72
Indoor Temperature, °C					22	22	22	22	22	22	22	22	22	22	22	22
Indoor Relative Humidity, %					50	50	50	50	50	50	50	50	50	50	50	50

Table B4. Condensation Potential for ICF Walls using ASHRAE 2.5% Summer Design Conditions without Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal												
2	EIFS	EPS	none	VR												
3	EIFS	EPS	Inside	normal					VR / Insul			VR / Insul	VR / Insul			VR / Insul
4	EIFS	EPS	Outside	normal												
5	EIFS	XPS	none	normal												
6	EIFS	XPS	none	VR												
7	EIFS	XPS	Inside	normal					VR / Insul			VR / Insul	VR / Insul			VR / Insul
8	EIFS	XPS	Outside	normal												
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal												
12	EIFS	none	Outside	normal												
13	Stucco	EPS	none	normal												
14	Stucco	EPS	none	VR												
15	Stucco	EPS	Inside	normal					VR / Insul			VR / Insul	VR / Insul			VR / Insul
16	Stucco	EPS	Outside	normal												
17	Stucco	XPS	none	normal												
18	Stucco	XPS	none	VR												
19	Stucco	XPS	Inside	normal					VR / Insul			VR / Insul	VR / Insul			VR / Insul
20	Stucco	XPS	Outside	normal												
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal												
24	Stucco	none	Outside	normal												
25	Wood	EPS	none	normal												
26	Wood	EPS	none	VR												
27	Wood	EPS	Inside	normal					VR / Insul			VR / Insul	VR / Insul			VR / Insul
28	Wood	EPS	Outside	normal												
29	Wood	XPS	none	normal												
30	Wood	XPS	none	VR												
31	Wood	XPS	Inside	normal					VR / Insul			VR / Insul	VR / Insul			VR / Insul
32	Wood	XPS	Outside	normal												
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal												
36	Wood	none	Outside	normal												
Outdoor Temperature, °F					78	82	89	88	90	80	91	93	93	80	107	90
Outdoor Temperature, °C					26	28	32	31	32	27	33	34	34	27	42	32
Outdoor Relative Humidity, %					60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
Indoor Temperature, °F					75	75	75	75	75	75	75	75	75	75	75	75
Indoor Temperature, °C					24	24	24	24	24	24	24	24	24	24	24	24
Indoor Relative Humidity, %					80	80	80	80	80	80	80	80	80	80	80	80

Table B5. Condensation Potential for ICF Walls using NOAA Average July Conditions without Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal												
2	EIFS	EPS	none	VR												
3	EIFS	EPS	Inside	normal												
4	EIFS	EPS	Outside	normal	Insul / VR	Insul / VR				Insul / VR						
5	EIFS	XPS	none	normal												
6	EIFS	XPS	none	VR												
7	EIFS	XPS	Inside	normal												
8	EIFS	XPS	Outside	normal	Insul / VR	Insul / VR										
9	EIFS	none	none	normal	Dry / PCC	Dry / PCC										
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal	Dry / VR	Dry / VR										
12	EIFS	none	Outside	normal	Dry / PCC	Dry / PCC				PCC / VR						
13	Stucco	EPS	none	normal												
14	Stucco	EPS	none	VR												
15	Stucco	EPS	Inside	normal												
16	Stucco	EPS	Outside	normal	Insul / VR	Insul / VR				Insul / VR						
17	Stucco	XPS	none	normal												
18	Stucco	XPS	none	VR												
19	Stucco	XPS	Inside	normal												
20	Stucco	XPS	Outside	normal	Insul / VR	Insul / VR										
21	Stucco	none	none	normal	Dry / PCC	Dry / PCC										
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal	Dry / VR	Dry / VR										
24	Stucco	none	Outside	normal	Dry / PCC	Dry / PCC				PCC / VR						
25	Wood	EPS	none	normal												
26	Wood	EPS	none	VR												
27	Wood	EPS	Inside	normal												
28	Wood	EPS	Outside	normal	Insul / VR	Insul / VR				Insul / VR						
29	Wood	XPS	none	normal												
30	Wood	XPS	none	VR												
31	Wood	XPS	Inside	normal												
32	Wood	XPS	Outside	normal	Insul / VR	Insul / VR										
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal	Dry / VR	Dry / VR										
36	Wood	none	Outside	normal	Dry / PCC	Dry / PCC										
Outdoor Temperature, °F					61.5	60.1	73.1	70.6	75.4	64.8	78.9	78.5	82.3	69	92.3	82.4
Outdoor Temperature, °C					16.4	15.6	22.8	21.4	24.1	18.2	26.1	25.8	27.9	20.6	33.5	28.0
Outdoor Relative Humidity, %					60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
Indoor Temperature, °F					75	75	75	75	75	75	75	75	75	75	75	75
Indoor Temperature, °C					24	24	24	24	24	24	24	24	24	24	24	24
Indoor Relative Humidity, %					80	80	80	80	80	80	80	80	80	80	80	80

Table B6. Condensation Potential for ICF Walls using ASHRAE 2.5% Summer Design Conditions with Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal												
2	EIFS	EPS	none	VR												
3	EIFS	EPS	Inside	normal					VR / Insul			VR / Insul	PCC / Insul			VR / Insul
4	EIFS	EPS	Outside	normal												
5	EIFS	XPS	none	normal												
6	EIFS	XPS	none	VR												
7	EIFS	XPS	Inside	normal					VR / Insul			VR / Insul	VR / Insul			VR / Insul
8	EIFS	XPS	Outside	normal												
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal												
12	EIFS	none	Outside	normal												
13	Stucco	EPS	none	normal												
14	Stucco	EPS	none	VR												
15	Stucco	EPS	Inside	normal					VR / Insul			VR / Insul	PCC / Insul			VR / Insul
16	Stucco	EPS	Outside	normal												
17	Stucco	XPS	none	normal												
18	Stucco	XPS	none	VR												
19	Stucco	XPS	Inside	normal					VR / Insul			VR / Insul	VR / Insul			VR / Insul
20	Stucco	XPS	Outside	normal												
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal												
24	Stucco	none	Outside	normal												
25	Wood	EPS	none	normal												
26	Wood	EPS	none	VR												
27	Wood	EPS	Inside	normal					VR / Insul			VR / Insul	PCC / Insul			VR / Insul
28	Wood	EPS	Outside	normal												
29	Wood	XPS	none	normal												
30	Wood	XPS	none	VR												
31	Wood	XPS	Inside	normal					VR / Insul			VR / Insul	VR / Insul			VR / Insul
32	Wood	XPS	Outside	normal												
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal												
36	Wood	none	Outside	normal												
Outdoor Temperature, °F					78	82	89	88	90	80	91	93	93	80	107	90
Outdoor Temperature, °C					26	28	32	31	32	27	33	34	34	27	42	32
Outdoor Relative Humidity, %					60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
Indoor Temperature, °F					73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5
Indoor Temperature, °C					23	23	23	23	23	23	23	23	23	23	23	23
Indoor Relative Humidity, %					65	65	65	65	65	65	65	65	65	65	65	65

Table B7. Condensation Potential for ICF Walls using NOAA Average July Conditions with Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal												
2	EIFS	EPS	none	VR												
3	EIFS	EPS	Inside	normal												
4	EIFS	EPS	Outside	normal												
5	EIFS	XPS	none	normal												
6	EIFS	XPS	none	VR												
7	EIFS	XPS	Inside	normal												
8	EIFS	XPS	Outside	normal												
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal												
12	EIFS	none	Outside	normal												
13	Stucco	EPS	none	normal												
14	Stucco	EPS	none	VR												
15	Stucco	EPS	Inside	normal												
16	Stucco	EPS	Outside	normal												
17	Stucco	XPS	none	normal												
18	Stucco	XPS	none	VR												
19	Stucco	XPS	Inside	normal												
20	Stucco	XPS	Outside	normal												
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal												
24	Stucco	none	Outside	normal												
25	Wood	EPS	none	normal												
26	Wood	EPS	none	VR												
27	Wood	EPS	Inside	normal												
28	Wood	EPS	Outside	normal												
29	Wood	XPS	none	normal												
30	Wood	XPS	none	VR												
31	Wood	XPS	Inside	normal												
32	Wood	XPS	Outside	normal												
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal												
36	Wood	none	Outside	normal												
Outdoor Temperature, °F					61.5	60.1	73.1	70.6	75.4	64.8	78.9	78.5	82.3	69	92.3	82.4
Outdoor Temperature, °C					16.4	15.6	22.8	21.4	24.1	18.2	26.1	25.8	27.9	20.6	33.5	28.0
Outdoor Relative Humidity, %					60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
Indoor Temperature, °F					73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5
Indoor Temperature, °C					23	23	23	23	23	23	23	23	23	23	23	23
Indoor Relative Humidity, %					65	65	65	65	65	65	65	65	65	65	65	65

Table B8. Condensation Potential for the Outer Portion of Wet ICF Walls using ASHRAE 97.5% Winter Design Conditions

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal	Ext / Insul	Ext / Insul	Ext / Insul	Ext / Insul								
2	EIFS	EPS	none	VR	Ext / Insul	Ext / Insul	Ext / Insul	Ext / Insul								
3	EIFS	EPS	Inside	normal	Ext / Insul	Ext / Insul	Ext / Insul	Ext / Insul								
4	EIFS	EPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
5	EIFS	XPS	none	normal	Ext / Insul	Ext / Insul										
6	EIFS	XPS	none	VR	Ext / Insul	Ext / Insul										
7	EIFS	XPS	Inside	normal	Ext / Insul	Ext / Insul										
8	EIFS	XPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal												
12	EIFS	none	Outside	normal	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC
13	Stucco	EPS	none	normal	Ext / Insul	Ext / Insul	Ext / Insul	Ext / Insul								
14	Stucco	EPS	none	VR	Ext / Insul	Ext / Insul	Ext / Insul	Ext / Insul								
15	Stucco	EPS	Inside	normal	Ext / Insul	Ext / Insul	Ext / Insul	Ext / Insul								
16	Stucco	EPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
17	Stucco	XPS	none	normal	Ext / Insul	Ext / Insul	Ext / Insul	Ext / Insul								
18	Stucco	XPS	none	VR	Ext / Insul	Ext / Insul	Ext / Insul	Ext / Insul								
19	Stucco	XPS	Inside	normal	Ext / Insul	Ext / Insul	Ext / Insul	Ext / Insul								
20	Stucco	XPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal												
24	Stucco	none	Outside	normal	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC
25	Wood	EPS	none	normal	Ext / Insul	Ext / Insul										
26	Wood	EPS	none	VR	Ext / Insul	Ext / Insul										
27	Wood	EPS	Inside	normal	Ext / Insul	Ext / Insul										
28	Wood	EPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
29	Wood	XPS	none	normal	Ext / Insul	Ext / Insul										
30	Wood	XPS	none	VR	Ext / Insul	Ext / Insul										
31	Wood	XPS	Inside	normal	Ext / Insul	Ext / Insul										
32	Wood	XPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal												
36	Wood	none	Outside	normal	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC
Outdoor Temperature, °F					-47	-25	-12	-7	6	26	17	22	31	43	34	47
Outdoor Temperature, °C					-44	-32	-24	-22	-14	-3	-8	-6	-1	6	1	8
Outdoor Relative Humidity, %					67	73	69	73.5	73	77	61	67	78	64.5	50	71.5
Indoor Temperature, °F					72	72	72	72	72	72	72	72	72	72	72	72
Indoor Temperature, °C					22	22	22	22	22	22	22	22	22	22	22	22
Indoor Relative Humidity, %					50	50	50	50	50	50	50	50	50	50	50	50

Table B9. Condensation Potential for the Outer Portion of Wet ICF Walls using NOAA Average January Conditions

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal	Ext / Insul											
2	EIFS	EPS	none	VR	Ext / Insul											
3	EIFS	EPS	Inside	normal	Ext / Insul											
4	EIFS	EPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
5	EIFS	XPS	none	normal												
6	EIFS	XPS	none	VR												
7	EIFS	XPS	Inside	normal												
8	EIFS	XPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal												
12	EIFS	none	Outside	normal	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	
13	Stucco	EPS	none	normal	Ext / Insul											
14	Stucco	EPS	none	VR	Ext / Insul											
15	Stucco	EPS	Inside	normal	Ext / Insul											
16	Stucco	EPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
17	Stucco	XPS	none	normal	Ext / Insul											
18	Stucco	XPS	none	VR	Ext / Insul											
19	Stucco	XPS	Inside	normal	Ext / Insul											
20	Stucco	XPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal												
24	Stucco	none	Outside	normal	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	
25	Wood	EPS	none	normal												
26	Wood	EPS	none	VR												
27	Wood	EPS	Inside	normal												
28	Wood	EPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
29	Wood	XPS	none	normal												
30	Wood	XPS	none	VR												
31	Wood	XPS	Inside	normal												
32	Wood	XPS	Outside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal												
36	Wood	none	Outside	normal	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	VR / PCC	
Outdoor Temperature, °F					-12.8	9.5	11.2	15.6	28.9	39.1	35.2	40.5	51.5	56	52.3	67.1
Outdoor Temperature, °C					-24.9	-12.5	-11.6	-9.1	-1.7	3.9	1.8	4.7	10.8	13.3	11.3	19.5
Outdoor Relative Humidity, %					67	73	69	73.5	73	77	61	67	78	64.5	50	71.5
Indoor Temperature, °F					72	72	72	72	72	72	72	72	72	72	72	72
Indoor Temperature, °C					22	22	22	22	22	22	22	22	22	22	22	22
Indoor Relative Humidity, %					50	50	50	50	50	50	50	50	50	50	50	50

Table B10. Condensation Potential for the Outer Portion of Wet ICF Walls using ASHRAE 2.5% Summer Design Conditions without Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal									Insul / PCC			
2	EIFS	EPS	none	VR									Insul / PCC			
3	EIFS	EPS	Inside	normal									Insul / PCC			
4	EIFS	EPS	Outside	normal												
5	EIFS	XPS	none	normal									Insul / PCC			
6	EIFS	XPS	none	VR									Insul / PCC			
7	EIFS	XPS	Inside	normal									Insul / PCC			
8	EIFS	XPS	Outside	normal												
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal												
12	EIFS	none	Outside	normal												
13	Stucco	EPS	none	normal									Insul / PCC			
14	Stucco	EPS	none	VR									Insul / PCC			
15	Stucco	EPS	Inside	normal									Insul / PCC			
16	Stucco	EPS	Outside	normal												
17	Stucco	XPS	none	normal									Insul / PCC			
18	Stucco	XPS	none	VR									Insul / PCC			
19	Stucco	XPS	Inside	normal									Insul / PCC			
20	Stucco	XPS	Outside	normal												
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal												
24	Stucco	none	Outside	normal												
25	Wood	EPS	none	normal									Insul / PCC			
26	Wood	EPS	none	VR									Insul / PCC			
27	Wood	EPS	Inside	normal									Insul / PCC			
28	Wood	EPS	Outside	normal												
29	Wood	XPS	none	normal									Insul / PCC			
30	Wood	XPS	none	VR									Insul / PCC			
31	Wood	XPS	Inside	normal									Insul / PCC			
32	Wood	XPS	Outside	normal												
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal												
36	Wood	none	Outside	normal												
				Outdoor Temperature, °F	78	82	89	88	90	80	91	93	93	80	107	90
				Outdoor Temperature, °C	26	28	32	31	32	27	33	34	34	27	42	32
				Outdoor Relative Humidity, %	60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
				Indoor Temperature, °F	75	75	75	75	75	75	75	75	75	75	75	75
				Indoor Temperature, °C	24	24	24	24	24	24	24	24	24	24	24	24
				Indoor Relative Humidity, %	80	80	80	80	80	80	80	80	80	80	80	80

Table B11. Condensation Potential for the Outer Portion of Wet ICF Walls using NOAA Average July Conditions without Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal												
2	EIFS	EPS	none	VR												
3	EIFS	EPS	Inside	normal												
4	EIFS	EPS	Outside	normal	VR / Insul	VR / Insul		VR / Insul		VR / Insul				VR / Insul		
5	EIFS	XPS	none	normal												
6	EIFS	XPS	none	VR												
7	EIFS	XPS	Inside	normal												
8	EIFS	XPS	Outside	normal	VR / Insul	VR / Insul		VR / Insul		VR / Insul				VR / Insul		
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal												
12	EIFS	none	Outside	normal	VR / PCC	VR / PCC				VR / PCC				VR / PCC		
13	Stucco	EPS	none	normal												
14	Stucco	EPS	none	VR												
15	Stucco	EPS	Inside	normal												
16	Stucco	EPS	Outside	normal	VR / Insul	VR / Insul		VR / Insul		VR / Insul				VR / Insul		
17	Stucco	XPS	none	normal												
18	Stucco	XPS	none	VR												
19	Stucco	XPS	Inside	normal												
20	Stucco	XPS	Outside	normal	VR / Insul	VR / Insul		VR / Insul		VR / Insul				VR / Insul		
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal												
24	Stucco	none	Outside	normal	VR / PCC	VR / PCC				VR / PCC				VR / PCC		
25	Wood	EPS	none	normal												
26	Wood	EPS	none	VR												
27	Wood	EPS	Inside	normal												
28	Wood	EPS	Outside	normal	VR / Insul	VR / Insul		VR / Insul		VR / Insul				VR / Insul		
29	Wood	XPS	none	normal												
30	Wood	XPS	none	VR												
31	Wood	XPS	Inside	normal												
32	Wood	XPS	Outside	normal	VR / Insul	VR / Insul		VR / Insul		VR / Insul				VR / Insul		
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal												
36	Wood	none	Outside	normal	VR / PCC	VR / PCC				VR / PCC						
				Outdoor Temperature, °F	61.5	60.1	73.1	70.6	75.4	64.8	78.9	78.5	82.3	69	92.3	82.4
				Outdoor Temperature, °C	16.4	15.6	22.8	21.4	24.1	18.2	26.1	25.8	27.9	20.6	33.5	28.0
				Outdoor Relative Humidity, %	60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
				Indoor Temperature, °F	75	75	75	75	75	75	75	75	75	75	75	75
				Indoor Temperature, °C	24	24	24	24	24	24	24	24	24	24	24	24
				Indoor Relative Humidity, %	80	80	80	80	80	80	80	80	80	80	80	80

Table B12. Condensation Potential for the Outer Portion of Wet ICF Walls using ASHRAE 2.5% Summer Design Conditions with Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal									Insul / PCC			
2	EIFS	EPS	none	VR									Insul / PCC			
3	EIFS	EPS	Inside	normal									Insul / PCC			
4	EIFS	EPS	Outside	normal												
5	EIFS	XPS	none	normal									Insul / PCC			
6	EIFS	XPS	none	VR									Insul / PCC			
7	EIFS	XPS	Inside	normal									Insul / PCC			
8	EIFS	XPS	Outside	normal												
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal												
12	EIFS	none	Outside	normal												
13	Stucco	EPS	none	normal									Insul / PCC			
14	Stucco	EPS	none	VR									Insul / PCC			
15	Stucco	EPS	Inside	normal									Insul / PCC			
16	Stucco	EPS	Outside	normal												
17	Stucco	XPS	none	normal									Insul / PCC			
18	Stucco	XPS	none	VR									Insul / PCC			
19	Stucco	XPS	Inside	normal									Insul / PCC			
20	Stucco	XPS	Outside	normal												
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal												
24	Stucco	none	Outside	normal												
25	Wood	EPS	none	normal									Insul / PCC			
26	Wood	EPS	none	VR									Insul / PCC			
27	Wood	EPS	Inside	normal									Insul / PCC			
28	Wood	EPS	Outside	normal												
29	Wood	XPS	none	normal									Insul / PCC			
30	Wood	XPS	none	VR									Insul / PCC			
31	Wood	XPS	Inside	normal									Insul / PCC			
32	Wood	XPS	Outside	normal												
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal												
36	Wood	none	Outside	normal												
				Outdoor Temperature, °F	78	82	89	88	90	80	91	93	93	80	107	90
				Outdoor Temperature, °C	26	28	32	31	32	27	33	34	34	27	42	32
				Outdoor Relative Humidity, %	60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
				Indoor Temperature, °F	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5
				Indoor Temperature, °C	23	23	23	23	23	23	23	23	23	23	23	23
				Indoor Relative Humidity, %	65	65	65	65	65	65	65	65	65	65	65	65

Table B13. Condensation Potential for the Outer Portion of Wet ICF Walls using NOAA Average July Conditions with Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal												
2	EIFS	EPS	none	VR												
3	EIFS	EPS	Inside	normal												
4	EIFS	EPS	Outside	normal	VR / Insul	VR / Insul		VR / Insul		VR / Insul				VR / Insul		
5	EIFS	XPS	none	normal												
6	EIFS	XPS	none	VR												
7	EIFS	XPS	Inside	normal												
8	EIFS	XPS	Outside	normal	VR / Insul	VR / Insul				VR / Insul				VR / Insul		
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal												
12	EIFS	none	Outside	normal	VR / PCC	VR / PCC				VR / PCC						
13	Stucco	EPS	none	normal												
14	Stucco	EPS	none	VR												
15	Stucco	EPS	Inside	normal												
16	Stucco	EPS	Outside	normal	VR / Insul	VR / Insul		VR / Insul		VR / Insul				VR / Insul		
17	Stucco	XPS	none	normal												
18	Stucco	XPS	none	VR												
19	Stucco	XPS	Inside	normal												
20	Stucco	XPS	Outside	normal	VR / Insul	VR / Insul				VR / Insul				VR / Insul		
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal												
24	Stucco	none	Outside	normal	VR / PCC	VR / PCC				VR / PCC						
25	Wood	EPS	none	normal												
26	Wood	EPS	none	VR												
27	Wood	EPS	Inside	normal												
28	Wood	EPS	Outside	normal	VR / Insul	VR / Insul		VR / Insul		VR / Insul				VR / Insul		
29	Wood	XPS	none	normal												
30	Wood	XPS	none	VR												
31	Wood	XPS	Inside	normal												
32	Wood	XPS	Outside	normal	VR / Insul	VR / Insul				VR / Insul				VR / Insul		
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal												
36	Wood	none	Outside	normal	VR / PCC	VR / PCC										
Outdoor Temperature, °F					61.5	60.1	73.1	70.6	75.4	64.8	78.9	78.5	82.3	69	92.3	82.4
Outdoor Temperature, °C					16.4	15.6	22.8	21.4	24.1	18.2	26.1	25.8	27.9	20.6	33.5	28.0
Outdoor Relative Humidity, %					60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
Indoor Temperature, °F					73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5
Indoor Temperature, °C					23	23	23	23	23	23	23	23	23	23	23	23
Indoor Relative Humidity, %					65	65	65	65	65	65	65	65	65	65	65	65

Table B14. Condensation Potential for the Inner Portion of Wet ICF Walls using ASHRAE 97.5% Winter Design Conditions

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
2	EIFS	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
3	EIFS	EPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC		Insul / PCC					
4	EIFS	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
5	EIFS	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
6	EIFS	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
7	EIFS	XPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC		Insul / PCC	Insul / PCC				
8	EIFS	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
9	EIFS	none	none	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC		Dry / PCC	
10	EIFS	none	none	VR	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC		Dry / PCC	
11	EIFS	none	Inside	normal	Interior	Interior	Interior	Interior	Interior	Dry / VR	Interior	Interior	Dry / VR		Dry / VR	
12	EIFS	none	Outside	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC		Dry / PCC	
13	Stucco	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
14	Stucco	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
15	Stucco	EPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC		Insul / PCC					
16	Stucco	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
17	Stucco	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
18	Stucco	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
19	Stucco	XPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC		Insul / PCC	Insul / PCC				
20	Stucco	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
21	Stucco	none	none	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC		Dry / PCC	
22	Stucco	none	none	VR	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC		Dry / PCC	
23	Stucco	none	Inside	normal	Interior	Interior	Interior	Interior	Interior	Dry / VR	Interior	Interior	Dry / VR		Dry / VR	
24	Stucco	none	Outside	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Interior	Interior	Dry / PCC		Dry / PCC	
25	Wood	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
26	Wood	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
27	Wood	EPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC		Insul / PCC					
28	Wood	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
29	Wood	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
30	Wood	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
31	Wood	XPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC		Insul / PCC					
32	Wood	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC			
33	Wood	none	none	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC		Dry / PCC	
34	Wood	none	none	VR	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC				
35	Wood	none	Inside	normal	Interior	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR		Dry / VR	
36	Wood	none	Outside	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC		Dry / PCC	
				Outdoor Temperature, °F	-47	-25	-12	-7	6	26	17	22	31	43	34	47
				Outdoor Temperature, °C	-44	-32	-24	-22	-14	-3	-8	-6	-1	6	1	8
				Outdoor Relative Humidity, %	67	73	69	73.5	73	77	61	67	78	64.5	50	71.5
				Indoor Temperature, °F	72	72	72	72	72	72	72	72	72	72	72	72
				Indoor Temperature, °C	22	22	22	22	22	22	22	22	22	22	22	22
				Indoor Relative Humidity, %	50	50	50	50	50	50	50	50	50	50	50	50

Table B15. Condensation Potential for the Inner Portion of Wet ICF Walls using NOAA Average January Conditions

No.	Construction Materials				Location											
	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
2	EIFS	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
3	EIFS	EPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
4	EIFS	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
5	EIFS	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
6	EIFS	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
7	EIFS	XPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
8	EIFS	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
9	EIFS	none	none	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC				
10	EIFS	none	none	VR	Interior	Interior	Interior	Interior	Dry / PCC		Dry / PCC					
11	EIFS	none	Inside	normal	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR				
12	EIFS	none	Outside	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC				
13	Stucco	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
14	Stucco	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
15	Stucco	EPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
16	Stucco	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
17	Stucco	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
18	Stucco	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
19	Stucco	XPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
20	Stucco	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
21	Stucco	none	none	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC				
22	Stucco	none	none	VR	Interior	Interior	Interior	Interior	Dry / PCC		Dry / PCC					
23	Stucco	none	Inside	normal	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR				
24	Stucco	none	Outside	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC				
25	Wood	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
26	Wood	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
27	Wood	EPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
28	Wood	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
29	Wood	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
30	Wood	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
31	Wood	XPS	Inside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
32	Wood	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
33	Wood	none	none	normal	Interior	Interior	Interior	Dry / PCC	Dry / PCC		Dry / PCC					
34	Wood	none	none	VR	Interior	Interior	Interior	Dry / PCC	Dry / PCC							
35	Wood	none	Inside	normal	Interior	Interior	Interior	Dry / VR	Dry / VR		Dry / VR					
36	Wood	none	Outside	normal	Interior	Interior	Interior	Dry / PCC	Dry / PCC		Dry / PCC					
Outdoor Temperature, °F					-12.8	9.5	11.2	15.6	28.9	39.1	35.2	40.5	51.5	56	52.3	67.1
Outdoor Temperature, °C					-24.9	-12.5	-11.6	-9.1	-1.7	3.9	1.8	4.7	10.8	13.3	11.3	19.5
Outdoor Relative Humidity, %					67	73	69	73.5	73	77	61	67	78	64.5	50	71.5
Indoor Temperature, °F					72	72	72	72	72	72	72	72	72	72	72	72
Indoor Temperature, °C					22	22	22	22	22	22	22	22	22	22	22	22
Indoor Relative Humidity, %					50	50	50	50	50	50	50	50	50	50	50	50

Table B16. Condensation Potential for the Inner Portion of Wet ICF Walls using ASHRAE 2.5% Summer Design Conditions without Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal												
2	EIFS	EPS	none	VR											Dry / Insul	
3	EIFS	EPS	Inside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
4	EIFS	EPS	Outside	normal												
5	EIFS	XPS	none	normal												
6	EIFS	XPS	none	VR											Interior	
7	EIFS	XPS	Inside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
8	EIFS	XPS	Outside	normal												
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal		VR / PCC	VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC
12	EIFS	none	Outside	normal												
13	Stucco	EPS	none	normal												
14	Stucco	EPS	none	VR											Dry / Insul	
15	Stucco	EPS	Inside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
16	Stucco	EPS	Outside	normal												
17	Stucco	XPS	none	normal												
18	Stucco	XPS	none	VR											Interior	
19	Stucco	XPS	Inside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
20	Stucco	XPS	Outside	normal												
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal		VR / PCC	VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC
24	Stucco	none	Outside	normal												
25	Wood	EPS	none	normal												
26	Wood	EPS	none	VR											Dry / Insul	
27	Wood	EPS	Inside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
28	Wood	EPS	Outside	normal												
29	Wood	XPS	none	normal												
30	Wood	XPS	none	VR											Interior	
31	Wood	XPS	Inside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
32	Wood	XPS	Outside	normal												
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal			VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC
36	Wood	none	Outside	normal												
				Outdoor Temperature, °F	78	82	89	88	90	80	91	93	93	80	107	90
				Outdoor Temperature, °C	26	28	32	31	32	27	33	34	34	27	42	32
				Outdoor Relative Humidity, %	60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
				Indoor Temperature, °F	75	75	75	75	75	75	75	75	75	75	75	75
				Indoor Temperature, °C	24	24	24	24	24	24	24	24	24	24	24	24
				Indoor Relative Humidity, %	80	80	80	80	80	80	80	80	80	80	80	80

Table B17. Condensation Potential for the Inner Portion of Wet ICF Walls using NOAA Average July Conditions without Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal	Insul / PCC	Insul / PCC										
2	EIFS	EPS	none	VR	Insul / PCC	Insul / PCC										
3	EIFS	EPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
4	EIFS	EPS	Outside	normal	Insul / PCC	Insul / PCC										
5	EIFS	XPS	none	normal	Insul / PCC	Insul / PCC										
6	EIFS	XPS	none	VR		Insul / PCC										
7	EIFS	XPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
8	EIFS	XPS	Outside	normal	Insul / PCC	Insul / PCC										
9	EIFS	none	none	normal	Dry / PCC	Dry / PCC										
10	EIFS	none	none	VR	Dry / PCC	Dry / PCC										
11	EIFS	none	Inside	normal	Dry / VR	Dry / VR				Dry / VR			VR / PCC		VR / PCC	VR / PCC
12	EIFS	none	Outside	normal	Dry / PCC	Dry / PCC										
13	Stucco	EPS	none	normal	Insul / PCC	Insul / PCC										
14	Stucco	EPS	none	VR	Insul / PCC	Insul / PCC										
15	Stucco	EPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
16	Stucco	EPS	Outside	normal	Insul / PCC	Insul / PCC										
17	Stucco	XPS	none	normal	Insul / PCC	Insul / PCC										
18	Stucco	XPS	none	VR		Insul / PCC										
19	Stucco	XPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
20	Stucco	XPS	Outside	normal	Insul / PCC	Insul / PCC										
21	Stucco	none	none	normal	Dry / PCC	Dry / PCC										
22	Stucco	none	none	VR	Dry / PCC	Dry / PCC										
23	Stucco	none	Inside	normal	Dry / VR	Dry / VR				Dry / VR			VR / PCC		VR / PCC	VR / PCC
24	Stucco	none	Outside	normal	Dry / PCC	Dry / PCC										
25	Wood	EPS	none	normal	Insul / PCC	Insul / PCC										
26	Wood	EPS	none	VR		Insul / PCC										
27	Wood	EPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
28	Wood	EPS	Outside	normal	Insul / PCC	Insul / PCC										
29	Wood	XPS	none	normal		Insul / PCC										
30	Wood	XPS	none	VR		Insul / PCC										
31	Wood	XPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
32	Wood	XPS	Outside	normal		Insul / PCC										
33	Wood	none	none	normal	Dry / PCC	Dry / PCC										
34	Wood	none	none	VR		Dry / PCC										
35	Wood	none	Inside	normal	Dry / VR	Dry / VR							VR / PCC		VR / PCC	VR / PCC
36	Wood	none	Outside	normal	Dry / PCC	Dry / PCC										
Outdoor Temperature, °F					61.5	60.1	73.1	70.6	75.4	64.8	78.9	78.5	82.3	69	92.3	82.4
Outdoor Temperature, °C					16.4	15.6	22.8	21.4	24.1	18.2	26.1	25.8	27.9	20.6	33.5	28.0
Outdoor Relative Humidity, %					60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
Indoor Temperature, °F					75	75	75	75	75	75	75	75	75	75	75	75
Indoor Temperature, °C					24	24	24	24	24	24	24	24	24	24	24	24
Indoor Relative Humidity, %					80	80	80	80	80	80	80	80	80	80	80	80

Table B18. Condensation Potential for Inner Portion of Wet ICF Walls using ASHRAE 2.5% Summer Design Conditions with Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal												
2	EIFS	EPS	none	VR												
3	EIFS	EPS	Inside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
4	EIFS	EPS	Outside	normal												
5	EIFS	XPS	none	normal												
6	EIFS	XPS	none	VR												
7	EIFS	XPS	Inside	normal		VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
8	EIFS	XPS	Outside	normal												
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal			VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC
12	EIFS	none	Outside	normal												
13	Stucco	EPS	none	normal												
14	Stucco	EPS	none	VR												
15	Stucco	EPS	Inside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
16	Stucco	EPS	Outside	normal												
17	Stucco	XPS	none	normal												
18	Stucco	XPS	none	VR												
19	Stucco	XPS	Inside	normal		VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
20	Stucco	XPS	Outside	normal												
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal			VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC
24	Stucco	none	Outside	normal												
25	Wood	EPS	none	normal												
26	Wood	EPS	none	VR												
27	Wood	EPS	Inside	normal	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
28	Wood	EPS	Outside	normal												
29	Wood	XPS	none	normal												
30	Wood	XPS	none	VR												
31	Wood	XPS	Inside	normal		VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul	VR / Insul
32	Wood	XPS	Outside	normal												
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal			VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC	VR / PCC		VR / PCC	VR / PCC
36	Wood	none	Outside	normal												
Outdoor Temperature, °F					78	82	89	88	90	80	91	93	93	80	107	90
Outdoor Temperature, °C					26	28	32	31	32	27	33	34	34	27	42	32
Outdoor Relative Humidity, %					60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
Indoor Temperature, °F					73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5
Indoor Temperature, °C					23	23	23	23	23	23	23	23	23	23	23	23
Indoor Relative Humidity, %					65	65	65	65	65	65	65	65	65	65	65	65

Table B19. Condensation Potential for Inner Portion of Wet ICF Walls using NOAA Average July Conditions with Air Conditioning

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal												
2	EIFS	EPS	none	VR												
3	EIFS	EPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
4	EIFS	EPS	Outside	normal												
5	EIFS	XPS	none	normal												
6	EIFS	XPS	none	VR												
7	EIFS	XPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
8	EIFS	XPS	Outside	normal												
9	EIFS	none	none	normal												
10	EIFS	none	none	VR												
11	EIFS	none	Inside	normal											VR / PCC	
12	EIFS	none	Outside	normal												
13	Stucco	EPS	none	normal												
14	Stucco	EPS	none	VR												
15	Stucco	EPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
16	Stucco	EPS	Outside	normal												
17	Stucco	XPS	none	normal												
18	Stucco	XPS	none	VR												
19	Stucco	XPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
20	Stucco	XPS	Outside	normal												
21	Stucco	none	none	normal												
22	Stucco	none	none	VR												
23	Stucco	none	Inside	normal											VR / PCC	
24	Stucco	none	Outside	normal												
25	Wood	EPS	none	normal												
26	Wood	EPS	none	VR												
27	Wood	EPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
28	Wood	EPS	Outside	normal												
29	Wood	XPS	none	normal												
30	Wood	XPS	none	VR												
31	Wood	XPS	Inside	normal							VR / Insul	VR / Insul	VR / Insul		VR / Insul	VR / Insul
32	Wood	XPS	Outside	normal												
33	Wood	none	none	normal												
34	Wood	none	none	VR												
35	Wood	none	Inside	normal											VR / PCC	
36	Wood	none	Outside	normal												
Outdoor Temperature, °F					61.5	60.1	73.1	70.6	75.4	64.8	78.9	78.5	82.3	69	92.3	82.4
Outdoor Temperature, °C					16.4	15.6	22.8	21.4	24.1	18.2	26.1	25.8	27.9	20.6	33.5	28.0
Outdoor Relative Humidity, %					60.5	66	67	71	71	65	64.5	73	78.5	76.5	32.5	74
Indoor Temperature, °F					73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5
Indoor Temperature, °C					23	23	23	23	23	23	23	23	23	23	23	23
Indoor Relative Humidity, %					65	65	65	65	65	65	65	65	65	65	65	65

Table B20. Maximum Indoor Relative Humidity for no Condensation during Winter Design Conditions when Vapor Retarding Paint is Used as the Primary Vapor Retarder

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	-	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
2	EIFS	EPS	-	VR	Insul / PCC	Insul / PCC										
3	EIFS	EPS	Inside	normal	Insul / Ext											
4	EIFS	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
5	EIFS	XPS	-	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
6	EIFS	XPS	-	VR	Insul / PCC	Insul / PCC										
7	EIFS	XPS	Inside	normal	Insul / Ext											
8	EIFS	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
9	EIFS	none	-	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC				
10	EIFS	none	-	VR	Interior	Interior	Interior	Interior	Dry / PCC							
11	EIFS	none	Inside	normal	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR	Dry / VR			
12	EIFS	none	Outside	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC		PCC / VR	
13	Stucco	EPS	-	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
14	Stucco	EPS	-	VR	Insul / PCC	Insul / PCC										
15	Stucco	EPS	Inside	normal	Insul / Ext											
16	Stucco	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
17	Stucco	XPS	-	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
18	Stucco	XPS	-	VR	Insul / PCC	Insul / PCC										
19	Stucco	XPS	Inside	normal	Insul / Ext											
20	Stucco	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
21	Stucco	none	-	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC				
22	Stucco	none	-	VR	Interior	Interior	Interior	Interior								
23	Stucco	none	Inside	normal	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR				
24	Stucco	none	Outside	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC	PCC / VR		PCC / VR	
25	Wood	EPS	-	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
26	Wood	EPS	-	VR	Insul / PCC	Insul / PCC										
27	Wood	EPS	Inside	normal	Insul / Sid											
28	Wood	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
29	Wood	XPS	-	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
30	Wood	XPS	-	VR	Insul / PCC	Insul / PCC										
31	Wood	XPS	Inside	normal	Insul / Sid											
32	Wood	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
33	Wood	none	-	normal	Interior	Interior	Interior	Dry / PCC	Dry / PCC		Dry / PCC					
34	Wood	none	-	VR	Interior	Interior	Interior									
35	Wood	none	Inside	normal	Interior	Interior	Interior	Dry / VR	Dry / VR		Dry / VR	Dry / VR				
36	Wood	none	Outside	normal	Interior	Interior	Interior	Dry / PCC	Dry / PCC	PCC / VR	Dry / PCC	Dry / PCC	PCC / VR			
Outdoor Temperature, °F					-47	-25	-12	-7	6	26	17	22	31	43	34	47
Outdoor Temperature, °C					-44	-32	-24	-22	-14	-3	-8	-6	-1	6	1	8
Outdoor Relative Humidity, %					67	73	69	73.5	73	77	61	67	78	64.5	50	71.5
Indoor Temperature, °F					72	72	72	72	72	72	72	72	72	72	72	72
Indoor Temperature, °C					22	22	22	22	22	22	22	22	22	22	22	22
Indoor Relative Humidity, %					38	38	38	38	38	38	38	38	38	38	38	38

NOTE: Gray indicates area of interest.

Table B21. Maximum Indoor Relative Humidity for no Condensation during Winter Design Conditions for a Recommended ICF Wall Configuration in Edmonton, Alberta

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
2	EIFS	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC									
3	EIFS	EPS	Inside	normal	Insul / Ext											
4	EIFS	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR	
5	EIFS	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
6	EIFS	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC									
7	EIFS	XPS	Inside	normal	Insul / PCC											
8	EIFS	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR	
9	EIFS	none	none	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC			
10	EIFS	none	none	VR	Interior	Interior	Interior	Interior	Interior							
11	EIFS	none	Inside	normal	Interior	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR		Dry / VR	
12	EIFS	none	Outside	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC		Dry / PCC	
13	Stucco	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
14	Stucco	EPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC									
15	Stucco	EPS	Inside	normal	Insul / Ext											
16	Stucco	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR	
17	Stucco	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
18	Stucco	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC									
19	Stucco	XPS	Inside	normal	Insul / PCC											
20	Stucco	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR	
21	Stucco	none	none	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC			
22	Stucco	none	none	VR	Interior	Interior	Interior	Interior	Interior							
23	Stucco	none	Inside	normal	Interior	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR		Dry / VR	
24	Stucco	none	Outside	normal	Interior	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC		Dry / PCC	
25	Wood	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC							
26	Wood	EPS	none	VR	Insul / PCC	Insul / PCC										
27	Wood	EPS	Inside	normal	Insul / Sid											
28	Wood	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR	
29	Wood	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
30	Wood	XPS	none	VR	Insul / PCC	Insul / PCC	Insul / PCC									
31	Wood	XPS	Inside	normal	Insul / PCC											
32	Wood	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / PCC	Insul / VR	Insul / VR		Insul / VR	
33	Wood	none	none	normal	Interior	Interior	Interior	Interior	Dry / PCC		Dry / PCC	Dry / PCC				
34	Wood	none	none	VR	Interior	Interior	Interior	Interior								
35	Wood	none	Inside	normal	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR				
36	Wood	none	Outside	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC	PCC / VR		PCC / VR	
				Outdoor Temperature, °F	-47	-25	-12	-7	6	26	17	22	31	43	34	47
				Outdoor Temperature, °C	-44	-32	-24	-22	-14	-3	-8	-6	-1	6	1	8
				Outdoor Relative Humidity, %	67	73	69	73.5	73	77	61	67	78	64.5	50	71.5
				Indoor Temperature, °F	72	72	72	72	72	72	72	72	72	72	72	72
				Indoor Temperature, °C	22	22	22	22	22	22	22	22	22	22	22	22
				Indoor Relative Humidity, %	42	42	42	42	42	42	42	42	42	42	42	42

NOTE: Gray indicates area of interest.

Table B22. Maximum Indoor Relative Humidity for no Condensation during Winter Design Conditions for an ICF Wall with Exterior Hardboard Lap Siding in Fairbanks, Alaska

No.	Construction Materials				Location											
	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal	Insul / PCC	Insul / PCC										
2	EIFS	EPS	none	VR	Insul / PCC	Insul / Ext										
3	EIFS	EPS	Inside	normal	Insul / Ext											
4	EIFS	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR				
5	EIFS	XPS	none	normal	Insul / PCC	Insul / Ext										
6	EIFS	XPS	none	VR	Insul / PCC											
7	EIFS	XPS	Inside	normal	Insul / Ext											
8	EIFS	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR				
9	EIFS	none	none	normal	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC							
10	EIFS	none	none	VR	Interior	Dry / PCC										
11	EIFS	none	Inside	normal	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR							
12	EIFS	none	Outside	normal	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC		PCC / VR	PCC / VR				
13	Stucco	EPS	none	normal	Insul / PCC	Insul / PCC										
14	Stucco	EPS	none	VR	Insul / PCC	Insul / Ext										
15	Stucco	EPS	Inside	normal	Insul / Ext											
16	Stucco	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR				
17	Stucco	XPS	none	normal	Insul / PCC	Insul / Ext										
18	Stucco	XPS	none	VR	Insul / PCC	Insul / Ext										
19	Stucco	XPS	Inside	normal	Insul / Ext											
20	Stucco	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR				
21	Stucco	none	none	normal	Interior	Dry / PCC	Dry / PCC	Dry / PCC								
22	Stucco	none	none	VR	Interior	Dry / PCC										
23	Stucco	none	Inside	normal	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR							
24	Stucco	none	Outside	normal	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC		PCC / VR	PCC / VR				
25	Wood	EPS	none	normal	Insul / PCC	Insul / PCC										
26	Wood	EPS	none	VR	Insul / PCC											
27	Wood	EPS	Inside	normal												
28	Wood	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR				
29	Wood	XPS	none	normal	Insul / PCC											
30	Wood	XPS	none	VR	Insul / PCC											
31	Wood	XPS	Inside	normal												
32	Wood	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR	Insul / VR				
33	Wood	none	none	normal	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC								
34	Wood	none	none	VR	Dry / PCC											
35	Wood	none	Inside	normal	Dry / VR	Dry / VR	Dry / VR	Dry / VR								
36	Wood	none	Outside	normal	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC	PCC / VR							
Outdoor Temperature, °F					-47	-25	-12	-7	6	26	17	22	31	43	34	47
Outdoor Temperature, °C					-44	-32	-24	-22	-14	-3	-8	-6	-1	6	1	8
Outdoor Relative Humidity, %					67	73	69	73.5	73	77	61	67	78	64.5	50	71.5
Indoor Temperature, °F					72	72	72	72	72	72	72	72	72	72	72	72
Indoor Temperature, °C					22	22	22	22	22	22	22	22	22	22	22	22
Indoor Relative Humidity, %					21	21	21	21	21	21	21	21	21	21	21	21

NOTE: Gray indicates area of interest.

Table B23. Maximum Indoor Relative Humidity during Winter Design Conditions so that a Vapor Retarder is Not Required in Cincinnati, Ohio

	Construction Materials				Location											
No.	Exterior Surface	Insulation Type	Vapor Retarder	Paint Type	Fairbanks AL	Edmonton AB	Minneapolis MN	Madison WI	Cincinnati OH	Seattle WA	Washington DC	Charlotte NC	Lake Charles LA	Los Angeles CA	Phoenix AZ	Miami FL
1	EIFS	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
2	EIFS	EPS	none	VR	Insul / PCC	Insul / PCC										
3	EIFS	EPS	Inside	normal	Insul / Ext											
4	EIFS	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
5	EIFS	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
6	EIFS	XPS	none	VR	Insul / PCC	Insul / PCC										
7	EIFS	XPS	Inside	normal	Insul / Ext											
8	EIFS	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
9	EIFS	none	none	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC				
10	EIFS	none	none	VR	Interior	Interior	Interior	Interior	Dry / PCC							
11	EIFS	none	Inside	normal	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR	Dry / VR			
12	EIFS	none	Outside	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC		PCC / VR	
13	Stucco	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
14	Stucco	EPS	none	VR	Insul / PCC	Insul / PCC										
15	Stucco	EPS	Inside	normal	Insul / Ext											
16	Stucco	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
17	Stucco	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
18	Stucco	XPS	none	VR	Insul / PCC	Insul / PCC										
19	Stucco	XPS	Inside	normal	Insul / Ext											
20	Stucco	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
21	Stucco	none	none	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC				
22	Stucco	none	none	VR	Interior	Interior	Interior	Interior								
23	Stucco	none	Inside	normal	Interior	Interior	Interior	Interior	Dry / VR	Dry / VR	Dry / VR	Dry / VR				
24	Stucco	none	Outside	normal	Interior	Interior	Interior	Interior	Dry / PCC	Dry / PCC	Dry / PCC	Dry / PCC	PCC / VR		PCC / VR	
25	Wood	EPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
26	Wood	EPS	none	VR	Insul / PCC	Insul / PCC										
27	Wood	EPS	Inside	normal	Insul / Sid											
28	Wood	EPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
29	Wood	XPS	none	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC								
30	Wood	XPS	none	VR	Insul / PCC	Insul / PCC										
31	Wood	XPS	Inside	normal	Insul / Sid											
32	Wood	XPS	Outside	normal	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / PCC	Insul / VR	Insul / VR	Insul / VR	Insul / VR		Insul / VR	
33	Wood	none	none	normal	Interior	Interior	Interior	Dry / PCC	Dry / PCC		Dry / PCC					
34	Wood	none	none	VR	Interior	Interior	Interior									
35	Wood	none	Inside	normal	Interior	Interior	Interior	Dry / VR	Dry / VR		Dry / VR	Dry / VR				
36	Wood	none	Outside	normal	Interior	Interior	Interior	Dry / PCC	Dry / PCC	PCC / VR	Dry / PCC	Dry / PCC	PCC / VR			
Outdoor Temperature, °F					-47	-25	-12	-7	6	26	17	22	31	43	34	47
Outdoor Temperature, °C					-44	-32	-24	-22	-14	-3	-8	-6	-1	6	1	8
Outdoor Relative Humidity, %					67	73	69	73.5	73	77	61	67	78	64.5	50	71.5
Indoor Temperature, °F					72	72	72	72	72	72	72	72	72	72	72	72
Indoor Temperature, °C					22	22	22	22	22	22	22	22	22	22	22	22
Indoor Relative Humidity, %					38	38	38	38	38	38	38	38	38	38	38	38

NOTE: Gray indicates area of interest.

APPENDIX C. CLIMATE DATA

This appendix contains climate data regarding the heating degree-days, base 65, for a large number of locations throughout the U.S. and Canada. Heating degree data is presented in a Table C1 and summarized in Figure C1.

Figure C1 should be used as a quick reference as to whether a vapor retarder is required in the reader's area. Table C1 should be used as a confirmation of the figure. Table C1 also indicates locations where ICF walls may be subject to freeze-thaw damage if air entrained concrete is not utilized.

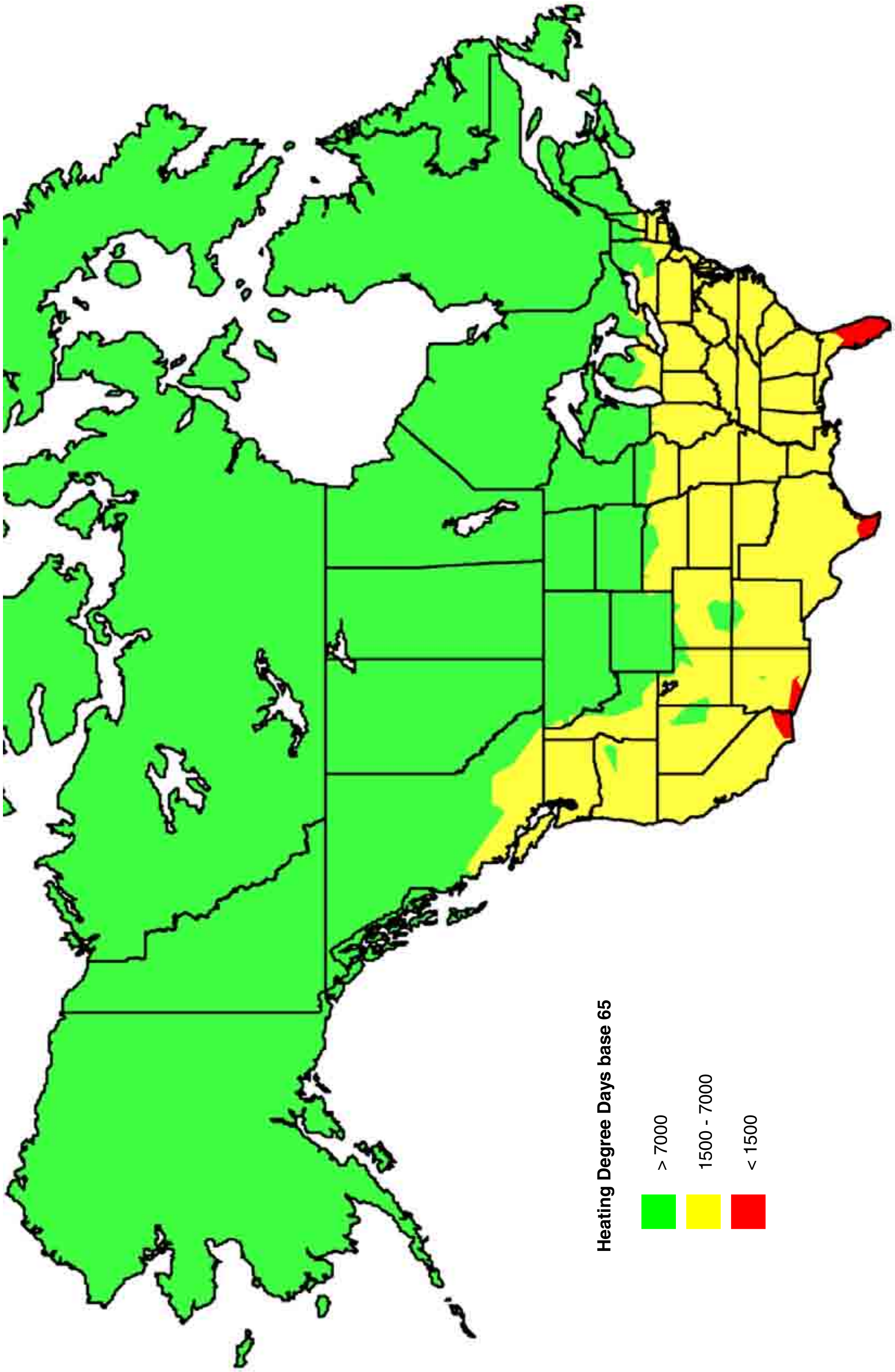


Figure C1. Heating degree day map of the U.S. and Canada

Table C1. Climate Data for the United States and Canada[9]

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	Required	Air Entrained
	Barrow	20,226	Required	Air Entrained
	Fairbanks	13,940	Required	Air Entrained
	Juneau	8,897	Required	
	Kodiak	8,817	Required	
	Nome	14,129	Required	Air Entrained
Arizona	Douglas	2,767		
	Flagstaff	7,131	Required	
	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 Hollywood	1,204		
	Crescent City	4,397		
	El Centro	1,156		

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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	Required	Air Entrained
	Boulder	5,554		

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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		

* "Required" indicates that a polyethylene vapor retarder is required between the drywall and the ICF.

** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table C1 (cont.). Climate Data for the United States and Canada[9]

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	Required	
	Lewiston	5,270		
	Moscow	6,782		
	Mountain Home	6,176		
	Pocatello	7,180	Required	
	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	Required	
	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	

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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	Required	
	Ft Dodge	7,261	Required	
	Iowa City	6,227		
	Keokuk	5,969		
	Marshalltown	7,170	Required	
	Mason City	7,837	Required	
	Newton	6,783		
	Ottumwa	6,269		
	Sioux City	6,893		
	Waterloo	7,406	Required	
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		

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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	Required	
	Bangor	7,930	Required	
	Caribou	9,651	Required	
	Lewiston	7,244	Required	
	Millinocket	8,902	Required	
	Portland	7,378	Required	
	Waterville	7,382	Required	
Maryland	Baltimore	4,707		
	Cumberland	5,036		
	Hagerstown	5,293		
	Salisbury	4,027		
Massachusetts	Boston	5,641		
	Clinton	6,698		

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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	Required	
	Battle Creek	6,416		
	Benton Harbor	6,303		
	Detroit	6,167		
	Escanaba	8,593	Required	
	Flint	6,979		
	Grand Rapids	6,973		
	Holland	6,747		
	Jackson	6,791		
	Kalamazoo	6,230		
	Lansing	7,101	Required	
	Marquette	8,356	Required	
	Muskegon	6,924		
	Pontiac	6,653		
	Port Huron	6,898		
	Saginaw	7,139	Required	
	Sault Saint Marie	9,316	Required	
	Traverse City	7,749	Required	
	Ypsilanti	6,466		
Minnesota	Albert Lea	8,146	Required	Air Entrained
	Alexandria	8,999	Required	Air Entrained
	Bemidji	10,200	Required	Air Entrained
	Brainerd	9,437	Required	Air Entrained
	Duluth	9,818	Required	Air Entrained
	Faribault	8,279	Required	
	International Falls	10,487	Required	Air Entrained
	Mankato	8,005	Required	Air Entrained
	Minneapolis-St Paul	7,981	Required	Air Entrained
	Rochester	8,250	Required	Air Entrained
	St Cloud	8,928	Required	
	Virginia	10,024	Required	Air Entrained
	Willmar	8,637	Required	
	Winona	7,694	Required	

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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	Required	
	Bozeman	9,908	Required	Air Entrained
	Butte	9,517	Required	Air Entrained
	Cut Bank	8,904	Required	Air Entrained
	Glasgow	8,745	Required	Air Entrained
	Glendive	8,178	Required	Air Entrained
	Great Falls	7,741	Required	Air Entrained
	Havre	8,447	Required	Air Entrained
	Helena	8,031	Required	Air Entrained
	Kalispell	8,378	Required	
	Lewistown	8,479	Required	Air Entrained
	Livingston	7,220	Required	Air Entrained
	Miles City	7,796	Required	Air Entrained
	Missoula	7,792	Required	

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Nebraska	Chadron	7,020	Required	
	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	Required	
	Ely	7,621	Required	
	Las Vegas	2,407		
	Lovelock	5,869		
	Reno	5,674		
	Tonopah	5,733		
	Winnemucca	6,315		
New Hampshire	Berlin	8,645	Required	
	Concord	7,554	Required	
	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		

* "Required" indicates that a polyethylene vapor retarder is required between the drywall and the ICF.

** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table C1 (cont.). Climate Data for the United States and Canada[9]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
New York	Albany	6,894		
	Auburn	6,782		
	Batavia	6,657		
	Binghamton	7,273	Required	
	Buffalo	6,747		
	Cortland	7,168	Required	
	Elmira	6,845		
	Geneva	6,939		
	Glens Falls	7,635	Required	
	Gloversville	7,664	Required	
	Ithaca	7,207	Required	
	Lockport	6,703		
	Massena	8,255	Required	
	New York City	4,805		
	Oswego	6,733		
	Plattsburgh	7,837	Required	
	Poughkeepsie	6,391		
	Rochester	6,734		
	Rome	7,244	Required	
	Schenectady	6,881		
	Syracuse	6,834		
	Utica	7,066	Required	
	Watertown	7,540	Required	
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	Required	Air Entrained
	Devils Lake	9,950	Required	Air Entrained
	Dickinson	8,657	Required	Air Entrained

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
N. Dakota (cont.)	Fargo	9,254	Required	Air Entrained
	Grand Forks	9,733	Required	Air Entrained
	Jamestown	9,168	Required	Air Entrained
	Minot	9,193	Required	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		

* "Required" indicates that a polyethylene vapor retarder is required between the drywall and the ICF.

** "Air Entrained" indicates that air entrained concrete is recommended to avoid potential freeze-thaw damage.

Table C1 (cont.). Climate Data for the United States and Canada [9)]

State/Province	City	HDD65	Vapor Retarder*	Concrete Type**
Oklahoma (cont.)	Tulsa	3,691		
	Woodward	3,900		
Oregon	Astoria	5,158		
	Baker	7,155	Required	
	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		

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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	Required	Air Entrained
	Brookings	8,653	Required	Air Entrained
	Huron	7,923	Required	Air Entrained
	Mitchell	7,558	Required	
	Pierre	7,411	Required	
	Rapid City	7,301	Required	
	Sioux Falls	7,809	Required	
	Watertown	8,375	Required	Air Entrained
	Yankton	7,304	Required	
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		

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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	Required	
Vermont	Burlington	7,771	Required	
	Rutland	7,066	Required	

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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	Required	
	Ashland	8,960	Required	Air Entrained
	Beloit	7,161	Required	
	Eau Claire	8,330	Required	
	Fond du Lac	7,541	Required	
	Green Bay	8,089	Required	
	La Crosse	7,491	Required	

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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

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

Table C1 (cont.). Climate Data for the United States and Canada[9]

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

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

APPENDIX D. ICF WINDOW DETAILS

This appendix contains six window details developed from limited available details and 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.

Figure D1 contains general notes applicable to all figures in appendices D, E, and F. Figure D2 presents typical head flashing end dam and sealant details common to Figures D3 though D8. Figure D3 presents an ICF wall with a flush-mount (surface mount) vinyl window and lap siding. Figure D4 presents an ICF wall with a flush-mount window with EIFS. Figure D5 presents an ICF wall with a flush-mount wood window and a portland cement stucco exterior finish. Figure D6 presents a recessed vinyl clad window with portland cement stucco. Figure D7 presents an ICF wall with a flush-mount vinyl window and vinyl siding. Figure D8 presents a recessed vinyl-clad window and vinyl siding. Details presented in Figures D7 and D8 are anticipated to be the most common details for use in residential tract housing.

GENERAL NOTES

Windows

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

Foundations and Below-Grade Walls

- Materials for subterranean insect control not shown.
- 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 D1. General notes for all ICF window and wall details.

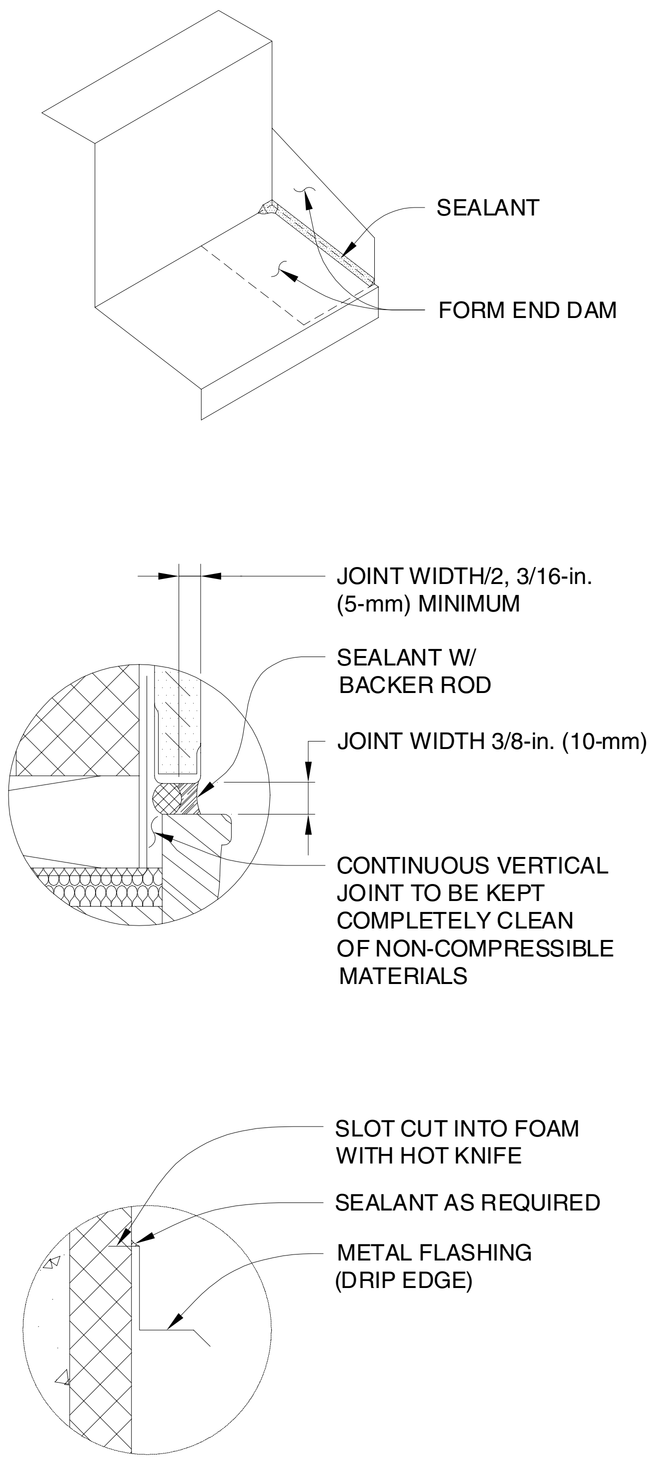


Figure D2. Typical head flashing end dam and sealant details.

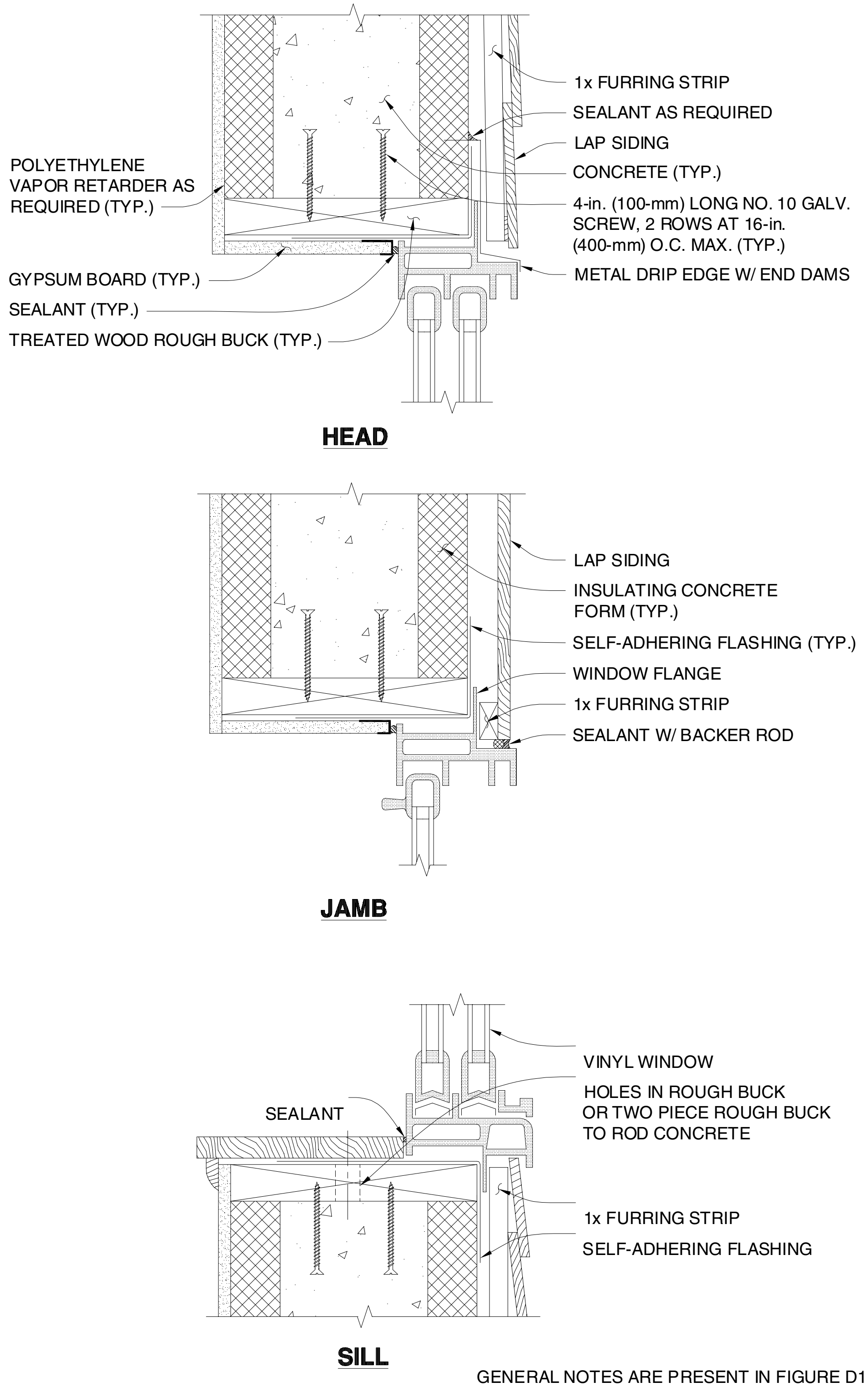
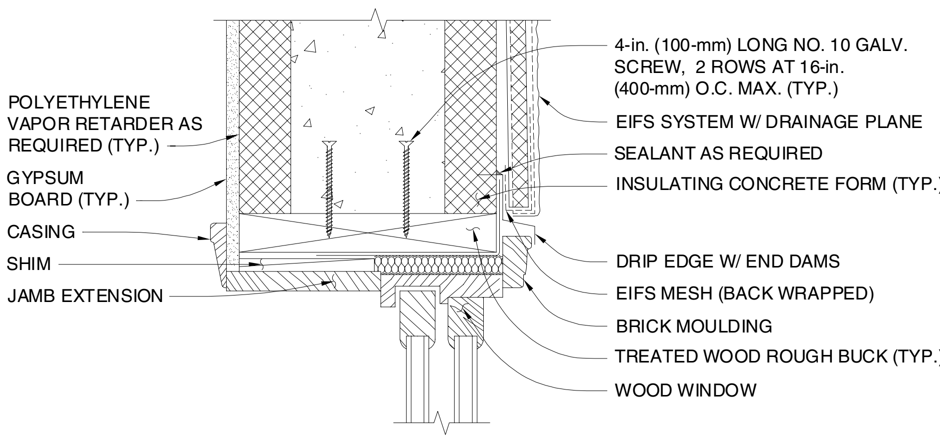
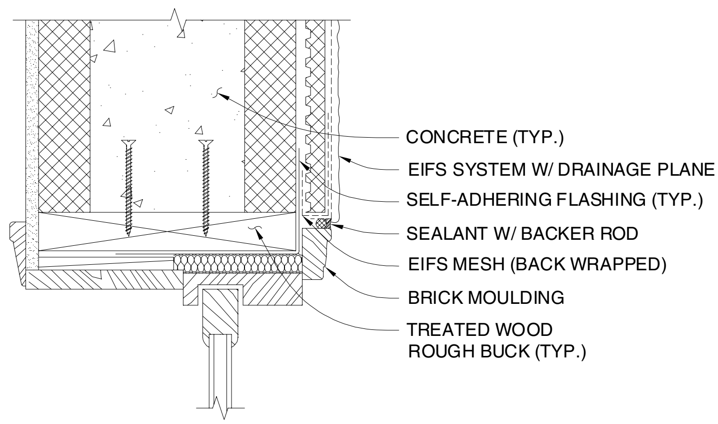


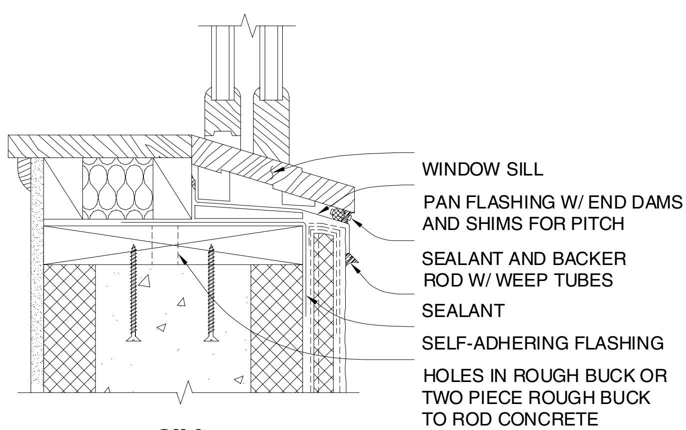
Figure D3. ICF wall with flush-mount vinyl window and lap siding.



HEAD



JAMB



SILL

GENERAL NOTES ARE PRESENT IN FIGURE D1.

Figure D4. ICF wall with flush-mount wood window and EIFS.

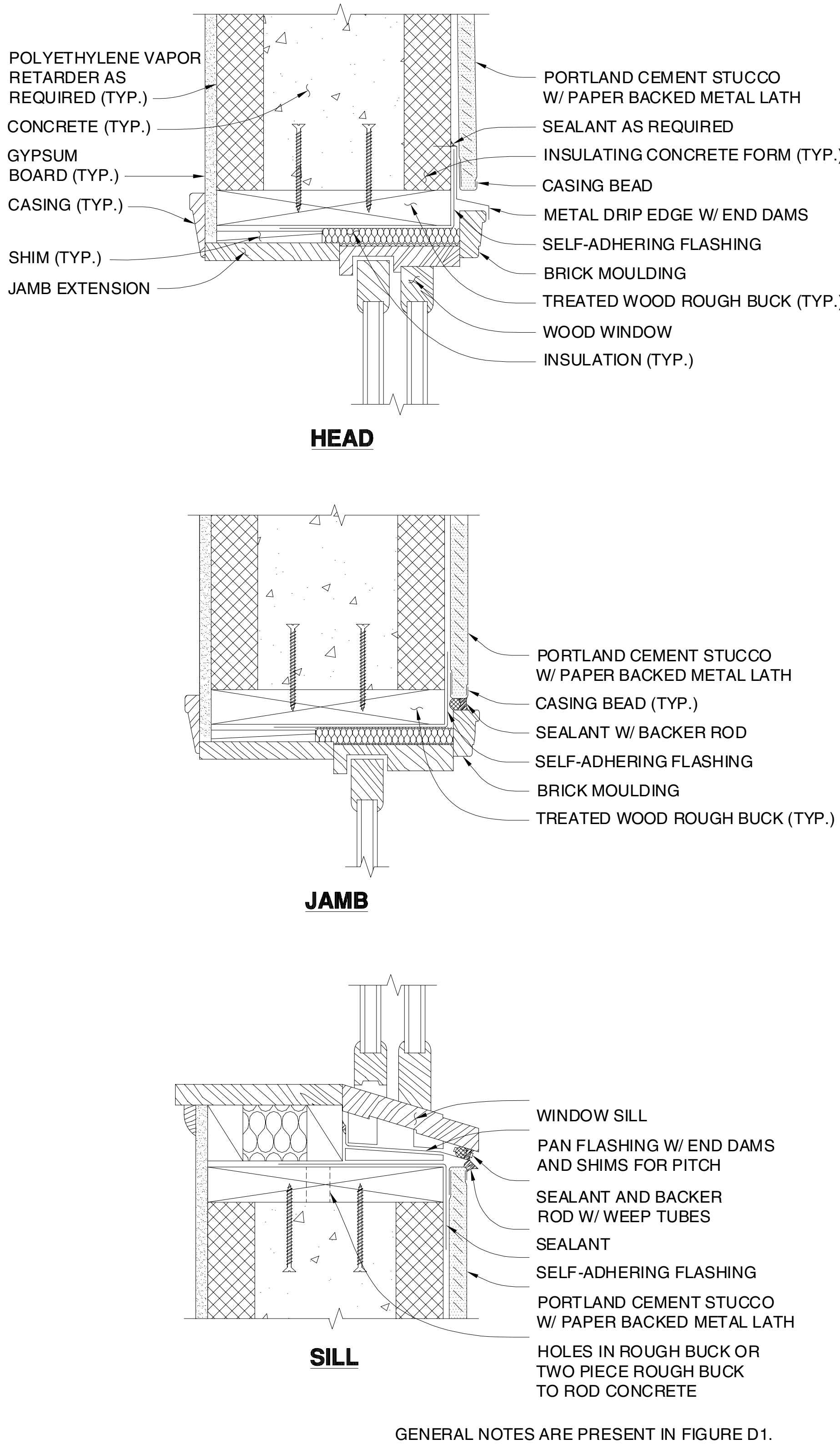


Figure D5. ICF wall with flush-mount wood window and portland cement stucco.

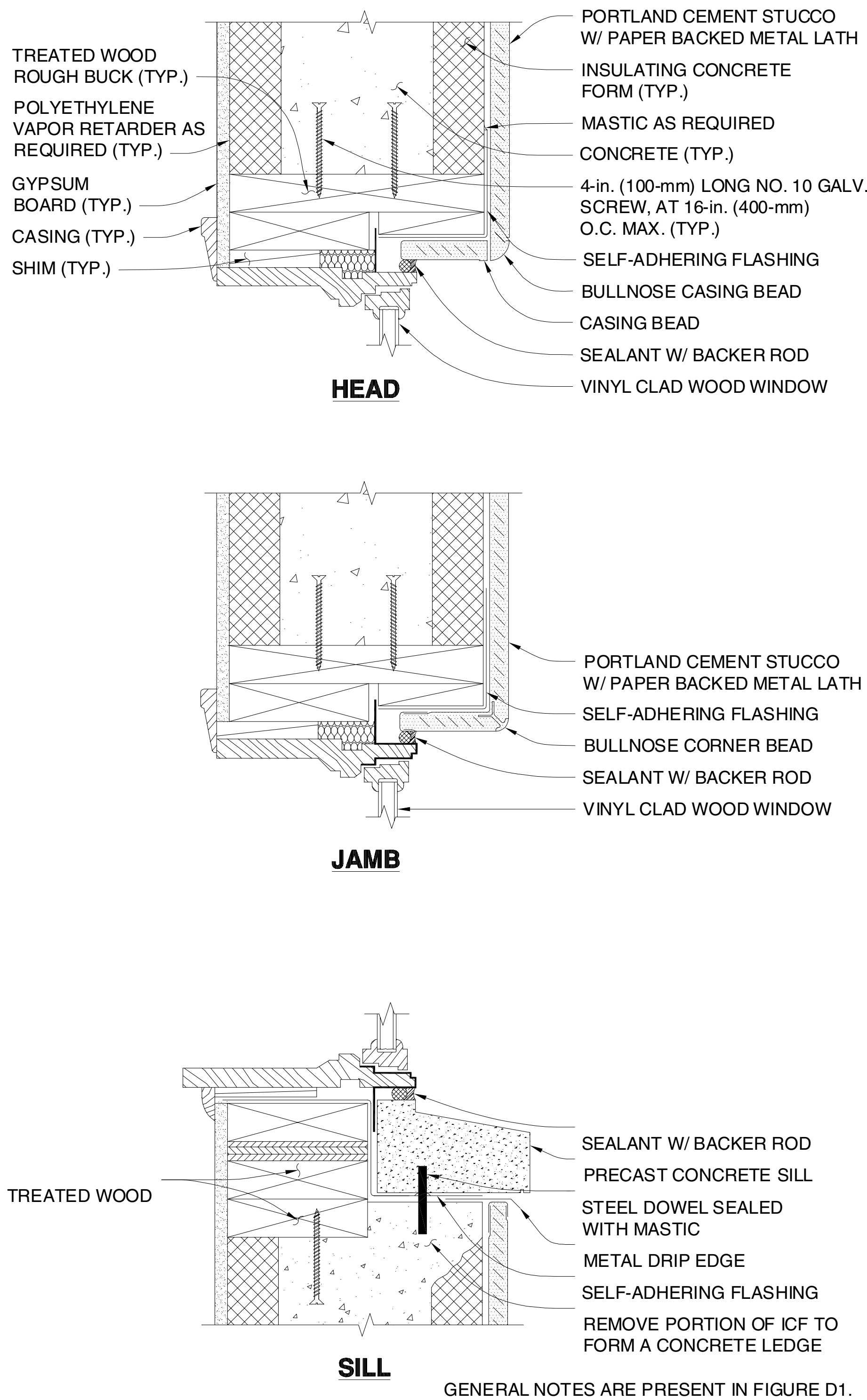


Figure D6. ICF wall with recessed vinyl-clad wood window and portland cement stucco.

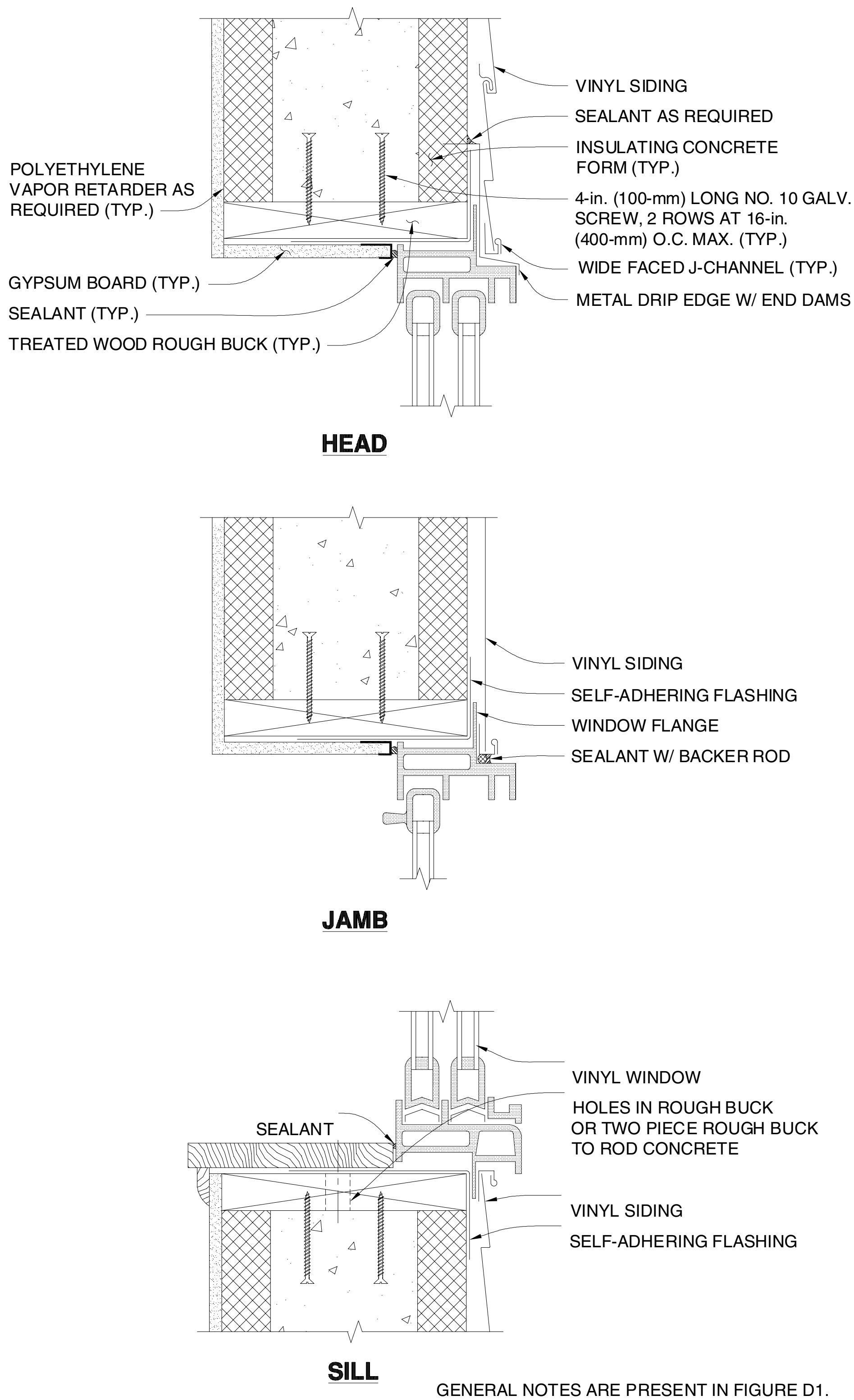


Figure D7. ICF wall with flush-mount vinyl window and vinyl siding.

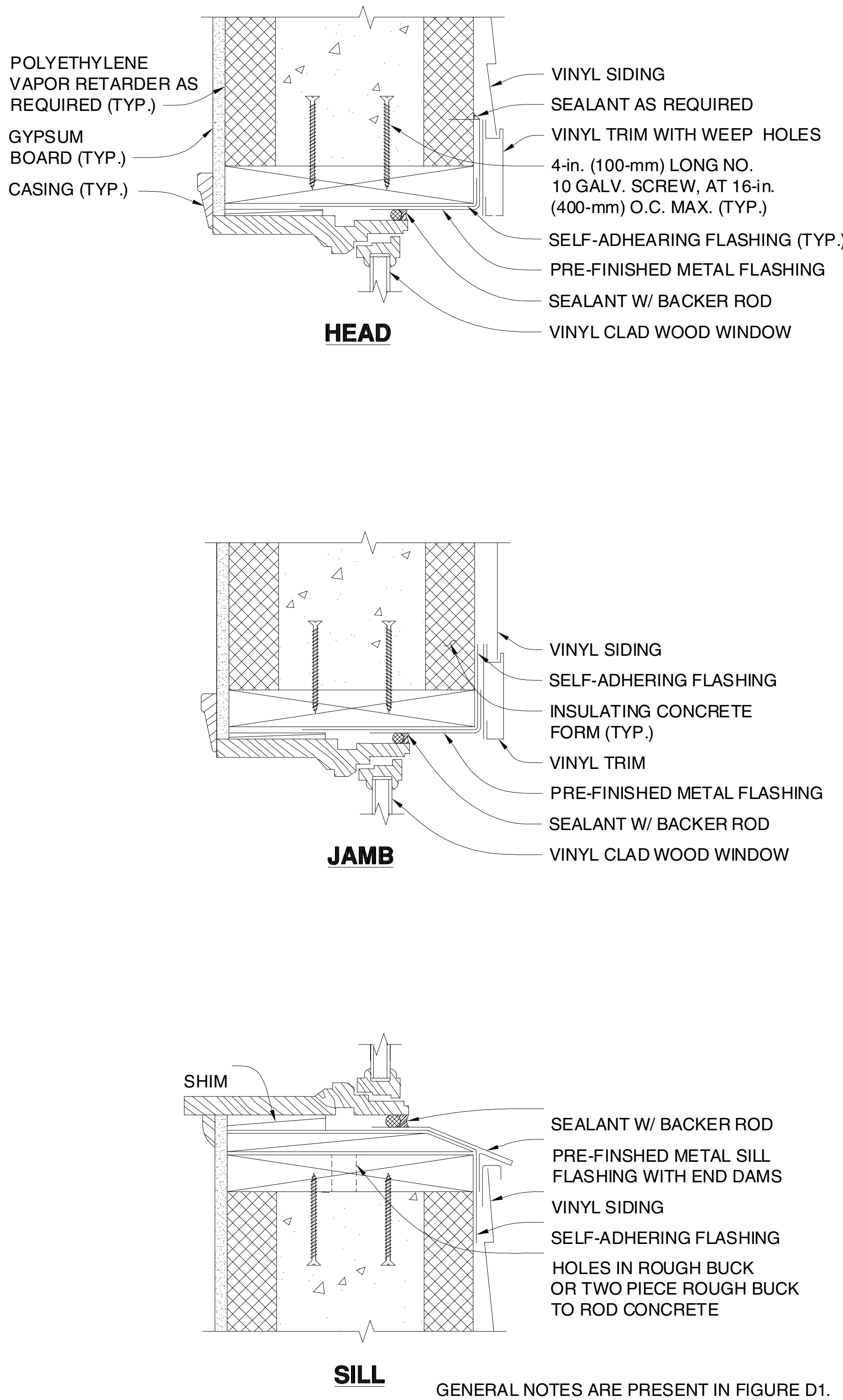


Figure D8. ICF wall with recessed vinyl-clad wood window and vinyl siding.

APPENDIX E. CONSTRUCTION SEQUENCING OF WINDOWS

This appendix contains a series of three-dimensional sequenced drawings showing the construction of ICF walls with a recessed window and a flush-mount window. These drawings provide the reader with step-by-step directions for installing windows in ICF walls. In all of the figures, items shaded in gray are the specific items being installed or discussed.

Figures E1 through E10 present construction sequencing for a recessed vinyl-clad wood window with portland cement stucco. Figures E11 through E16 present construction sequencing for a flush-mount vinyl window with vinyl siding. Many of the steps shown in these details are common for other the other combinations of windows and exterior cladding in ICF walls.

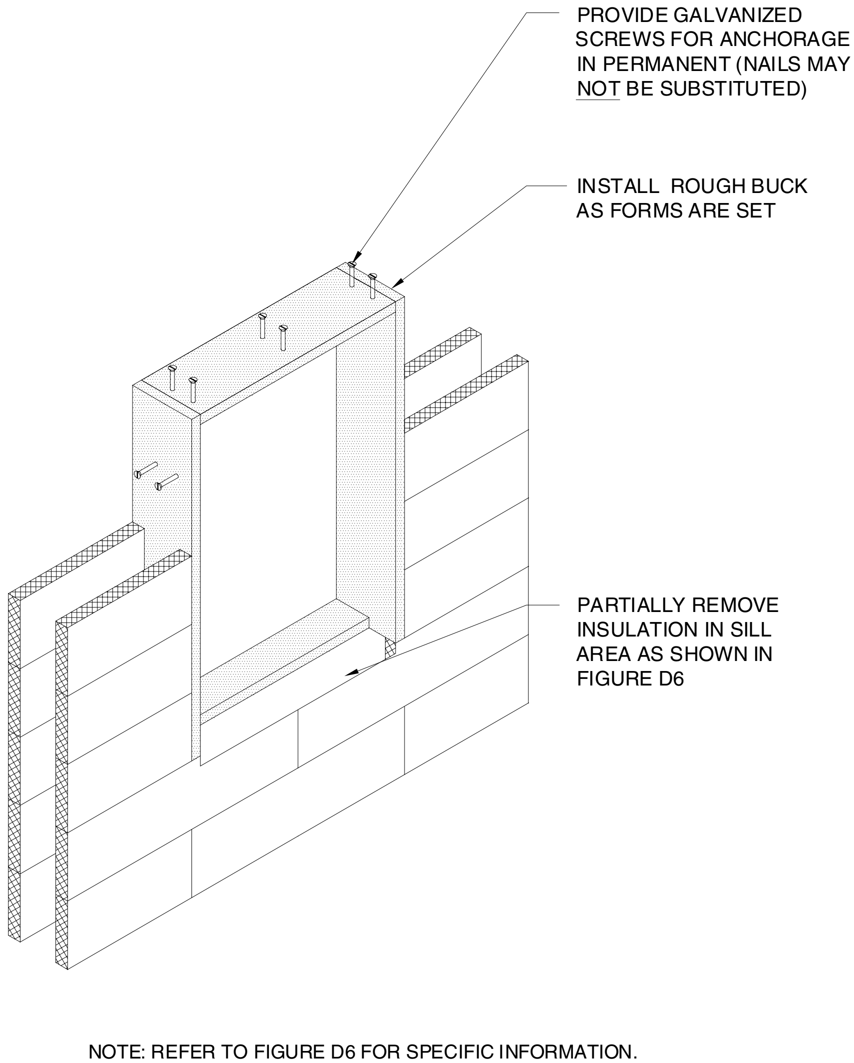


Figure E1. Partial installation of the wood buck in ICFs.

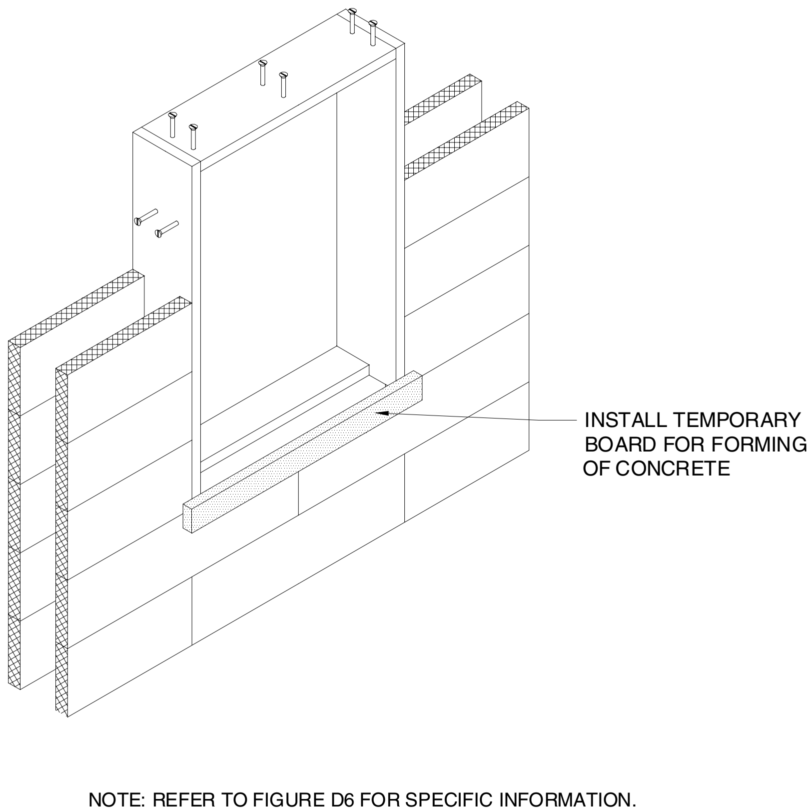
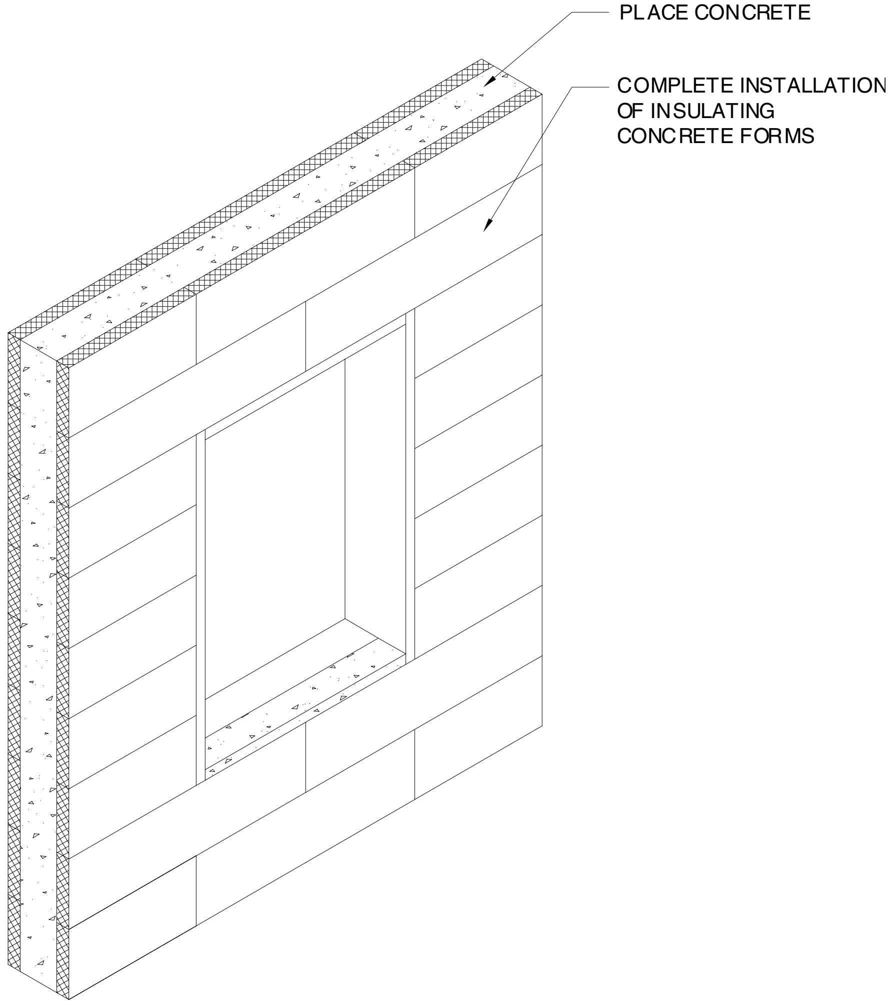
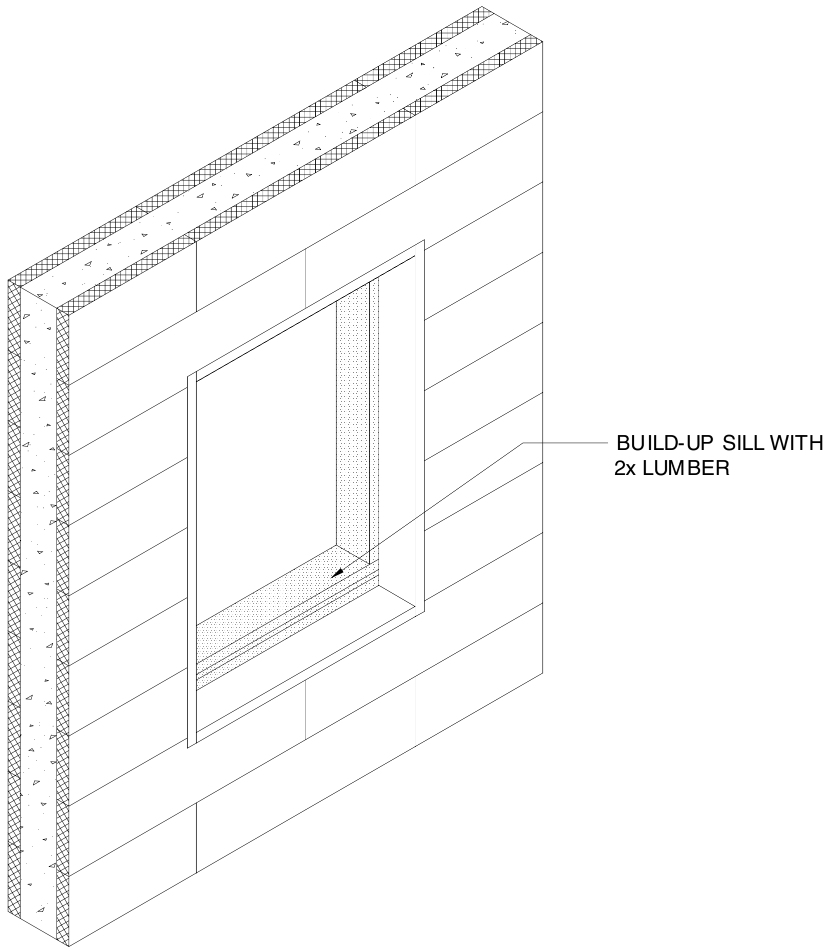


Figure E2. Completion of wood buck with temporary forming.



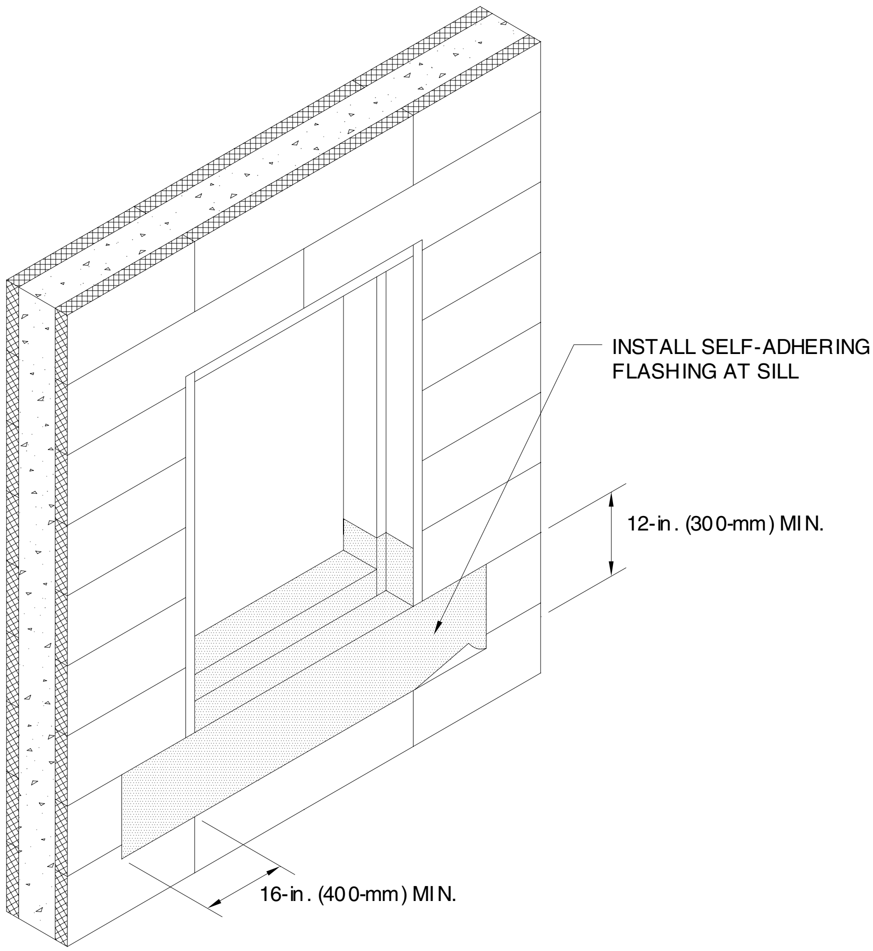
NOTE: REFER TO FIGURE D6 FOR SPECIFIC INFORMATION.

Figure E3. Completion of ICFs and placement of concrete.



NOTE: REFER TO FIGURE D6 FOR SPECIFIC INFORMATION.

Figure E4. Build-up of window sill.



NOTE: REFER TO FIGURE D6 FOR SPECIFIC INFORMATION.

Figure E5. Installation of self-adhering flashing at the sill.

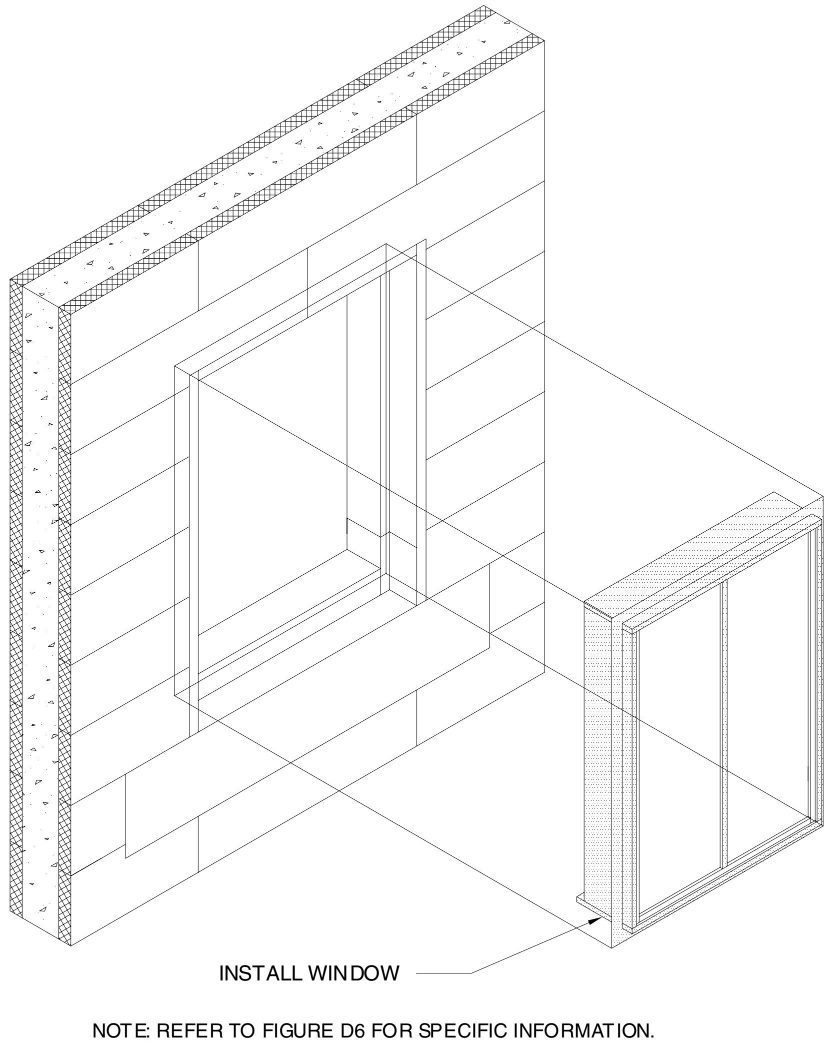
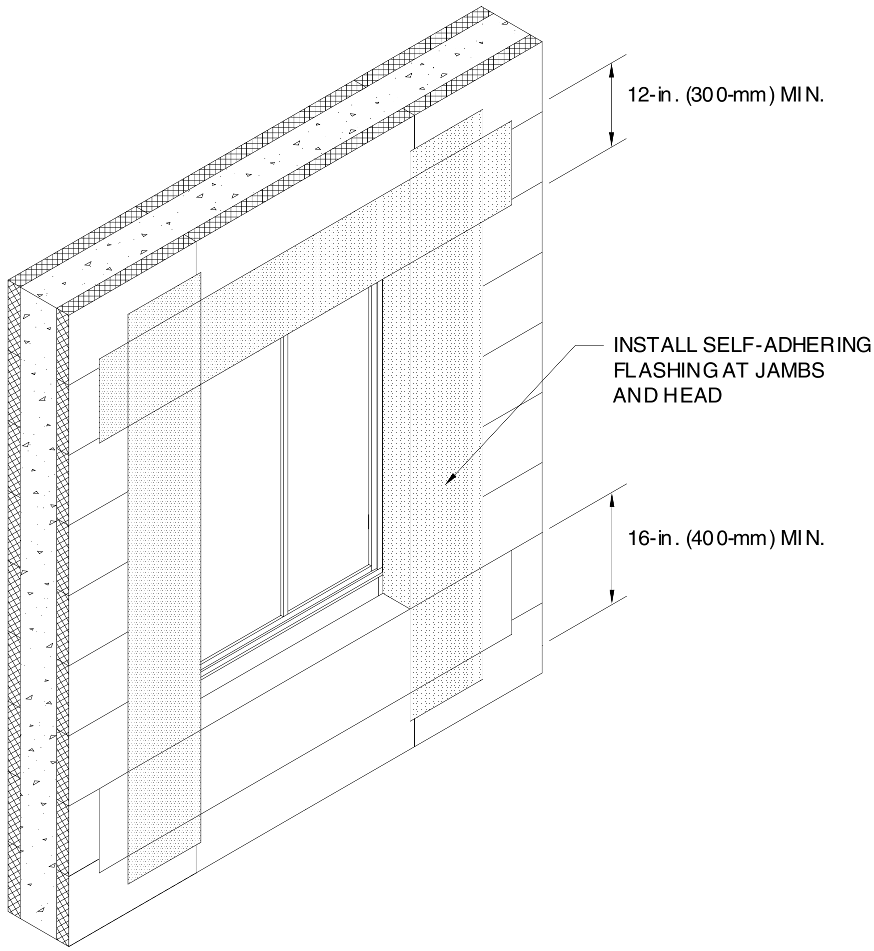


Figure E6. Installation of recessed window.



NOTE: REFER TO FIGURE D6 FOR SPECIFIC INFORMATION.

Figure E7. Installation of self-adhering flashing at jambs and head.

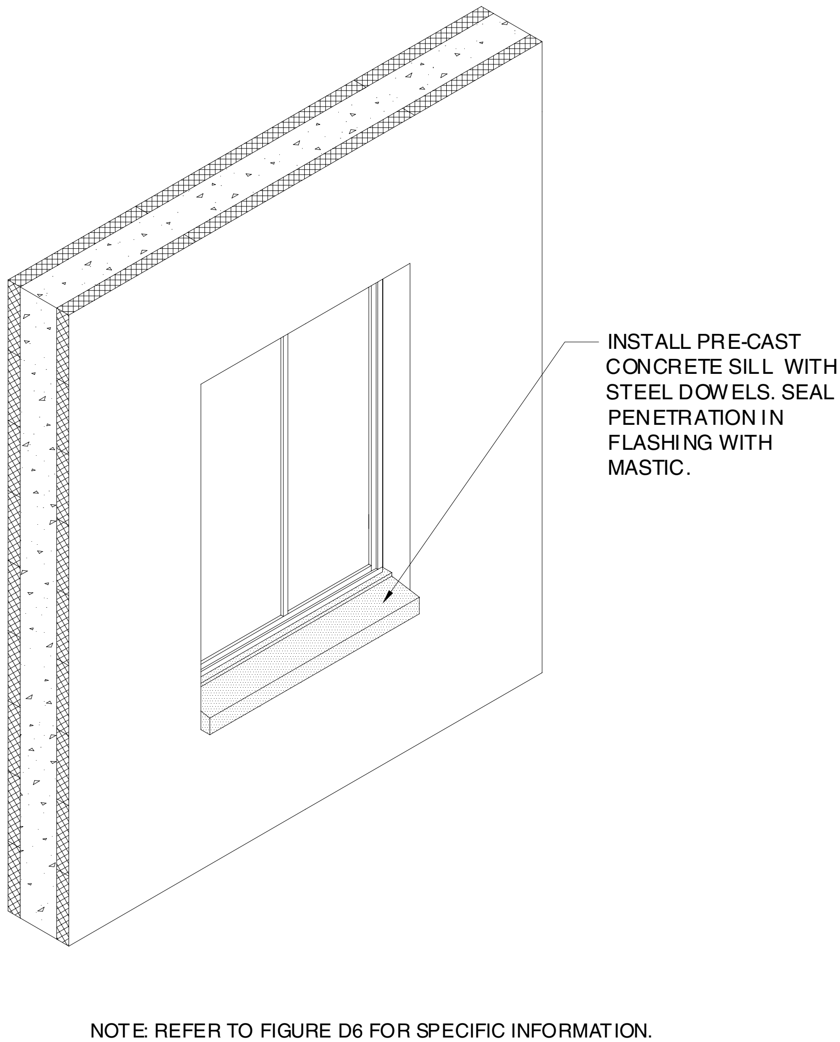
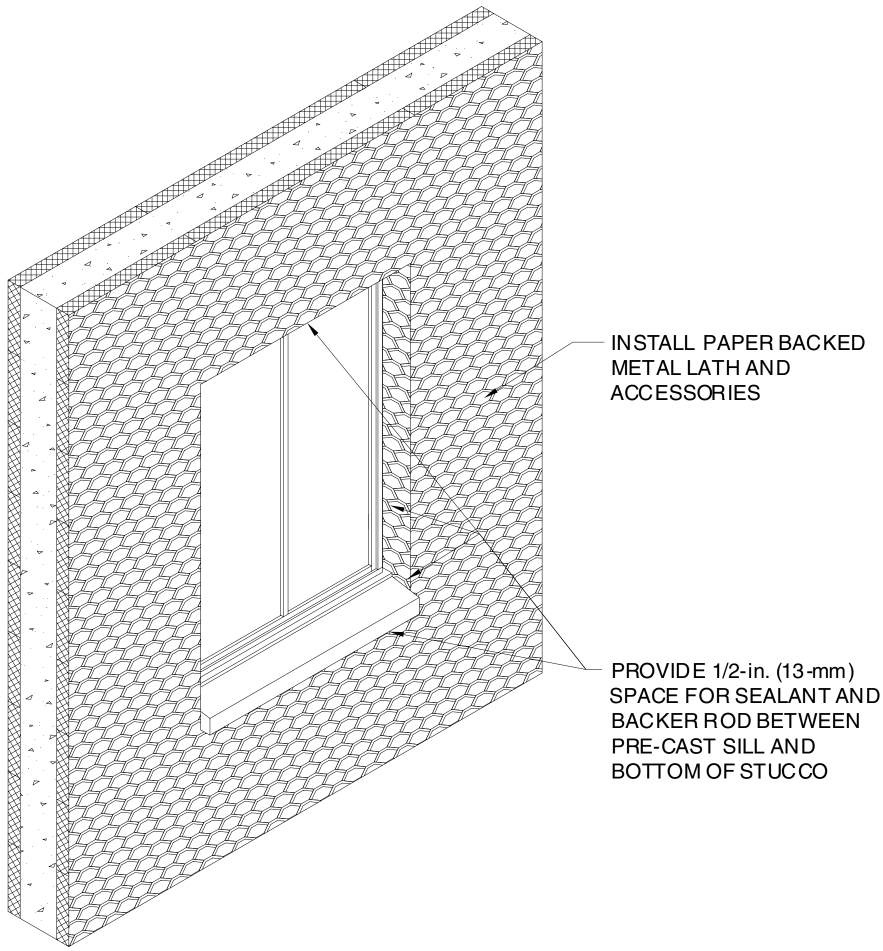
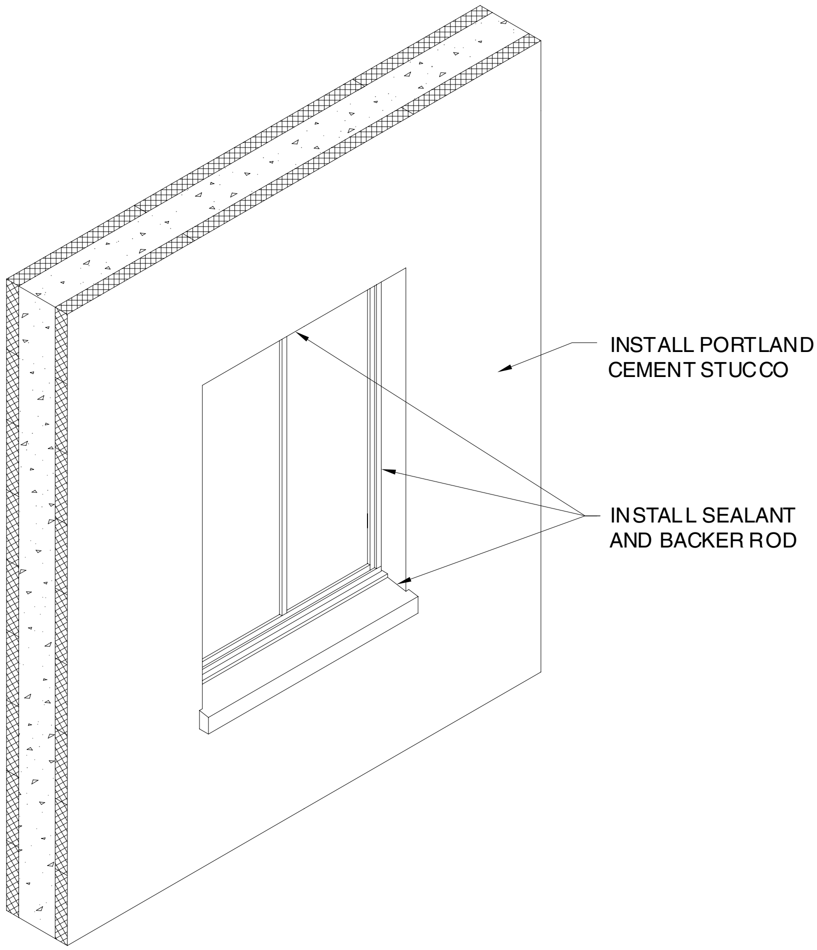


Figure E8. Installation of the pre-cast concrete sill.



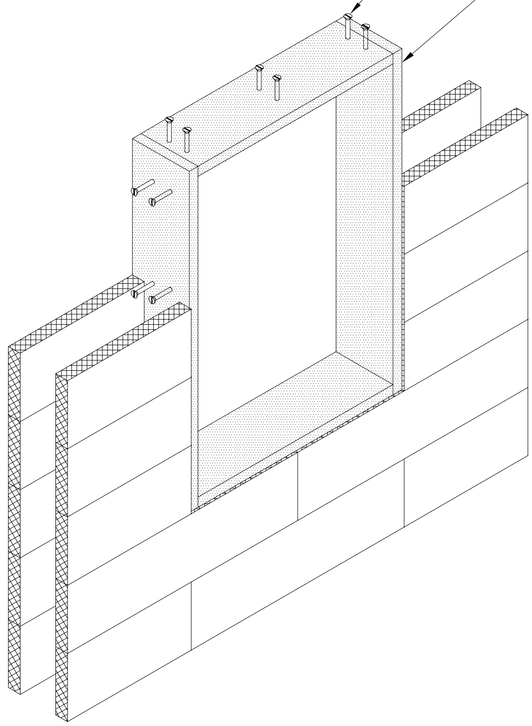
NOTE: REFER TO FIGURE D6 FOR SPECIFIC INFORMATION.

Figure E9. Installation of metal lathe and accessories for portland cement stucco.



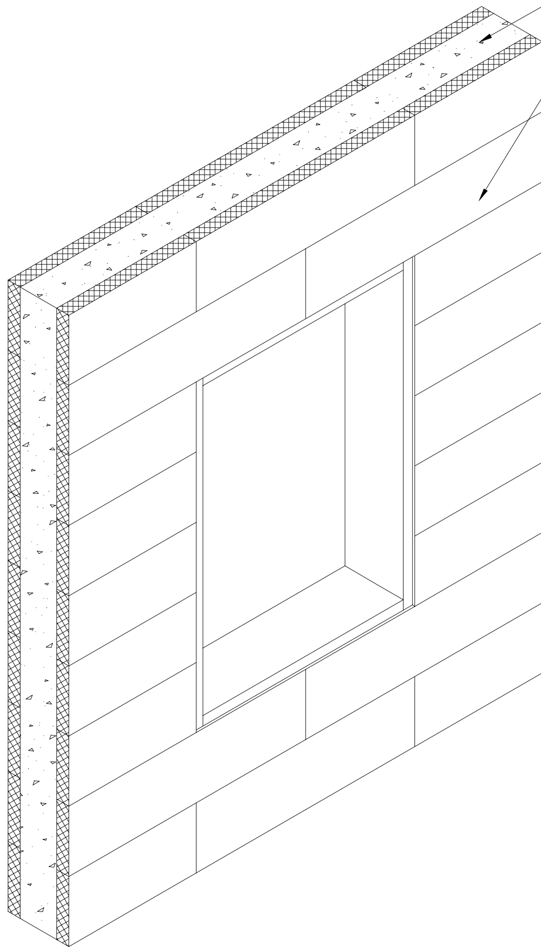
NOTE: REFER TO FIGURE D6 FOR SPECIFIC INFORMATION.

Figure E10. Installation of portland cement stucco.



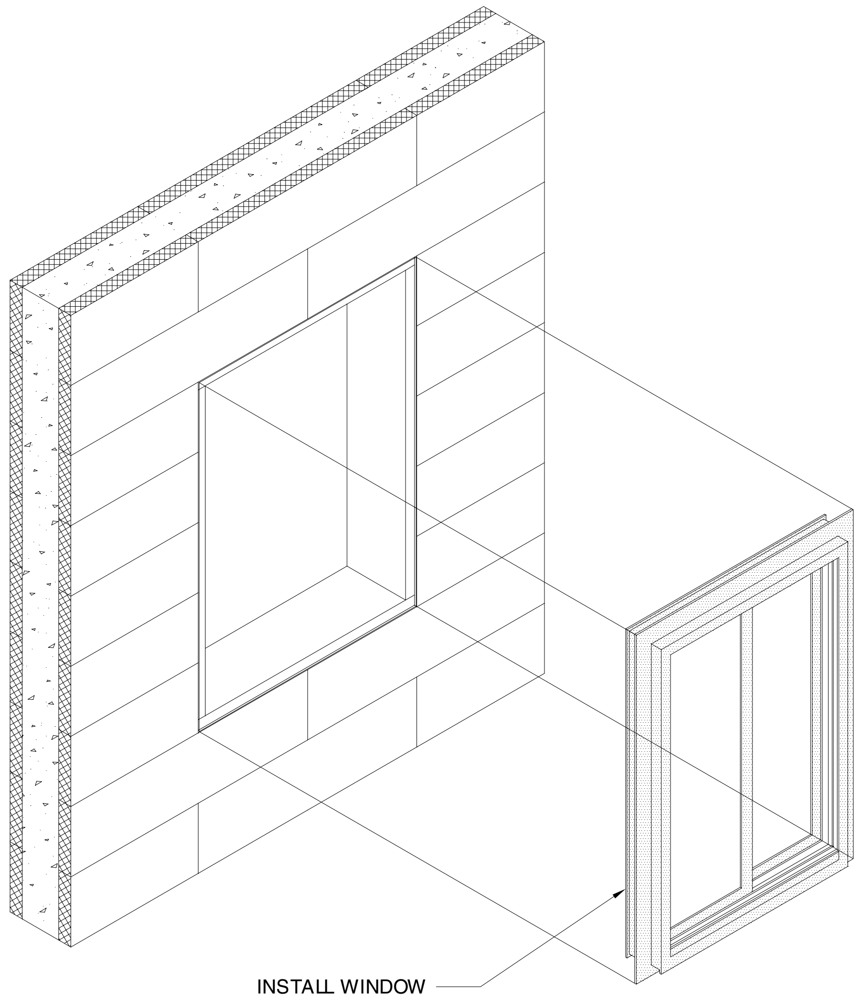
NOTE: REFER TO FIGURE D7 FOR SPECIFIC INFORMATION.

Figure E11. Installation of the wood buck in ICFs.



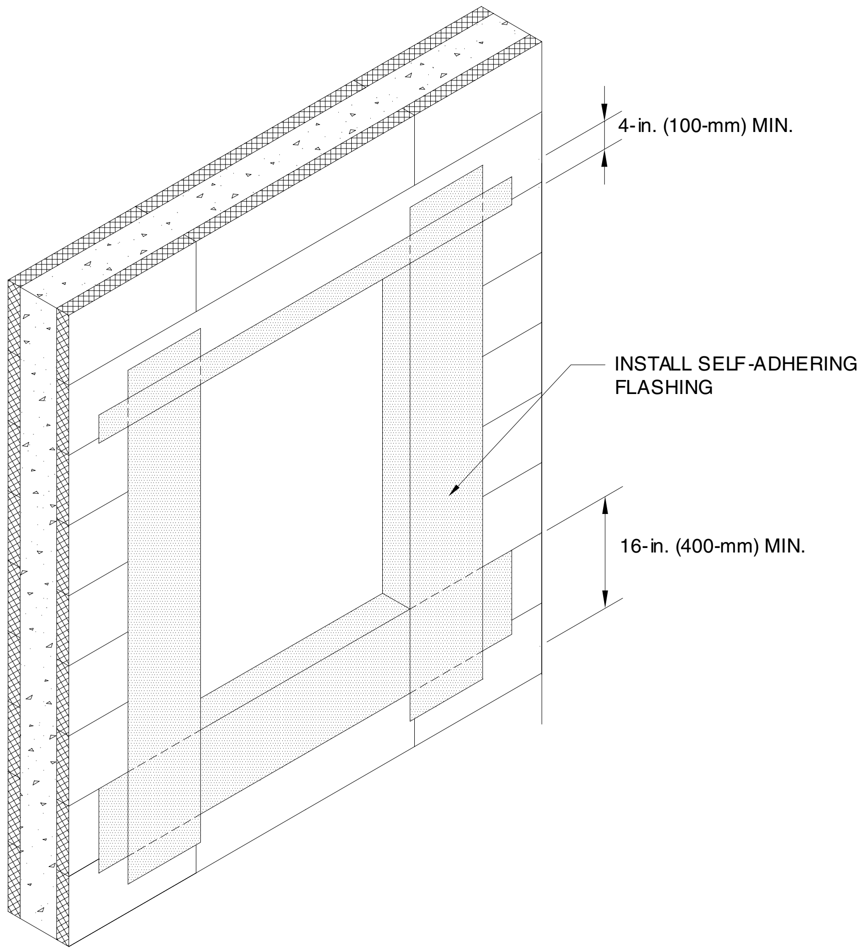
NOTE: REFER TO FIGURE D7 FOR SPECIFIC INFORMATION.

Figure E12. Completion of ICFs and placement of concrete.



NOTE: REFER TO FIGURE D7 FOR SPECIFIC INFORMATION.

Figure E13. Installation of flush-mount window.



NOTE: REFER TO FIGURE D7 FOR SPECIFIC INFORMATION.

Figure E14. Installation of self-adhering flashing.

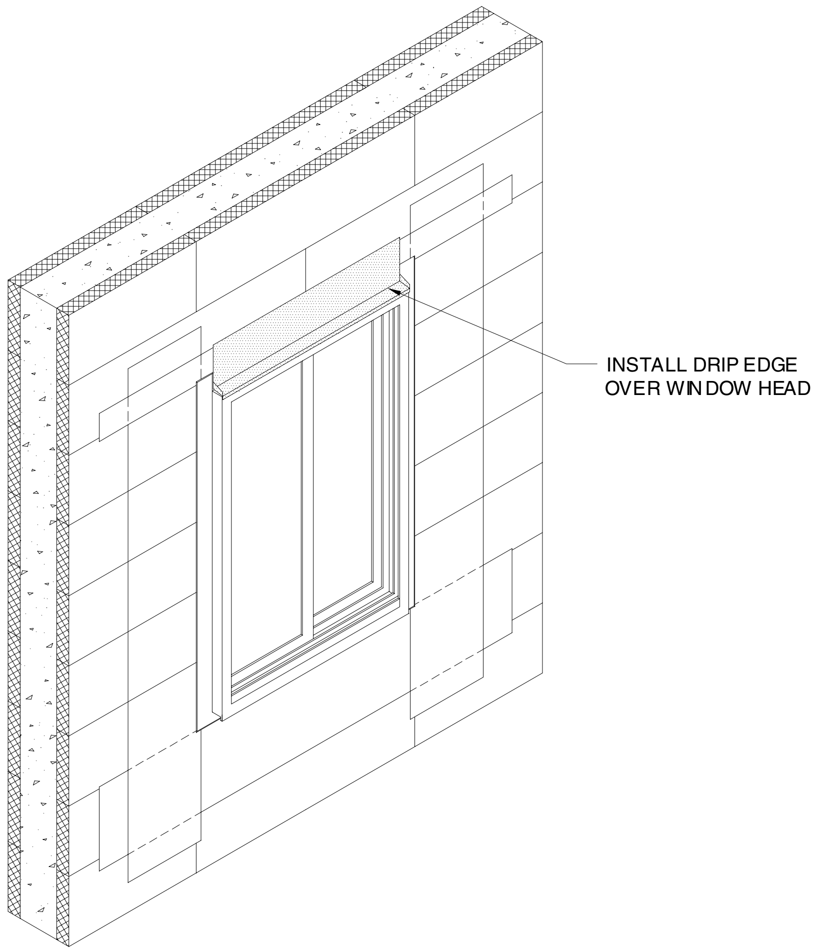
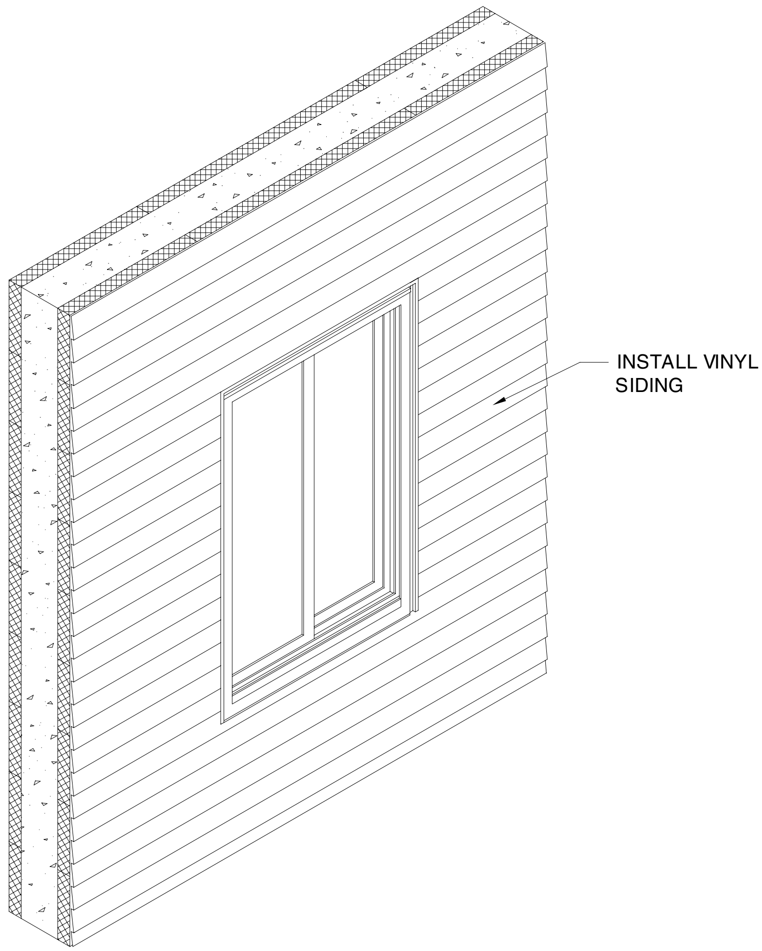


Figure E15. Installation of metal drip edge with end dams at head.



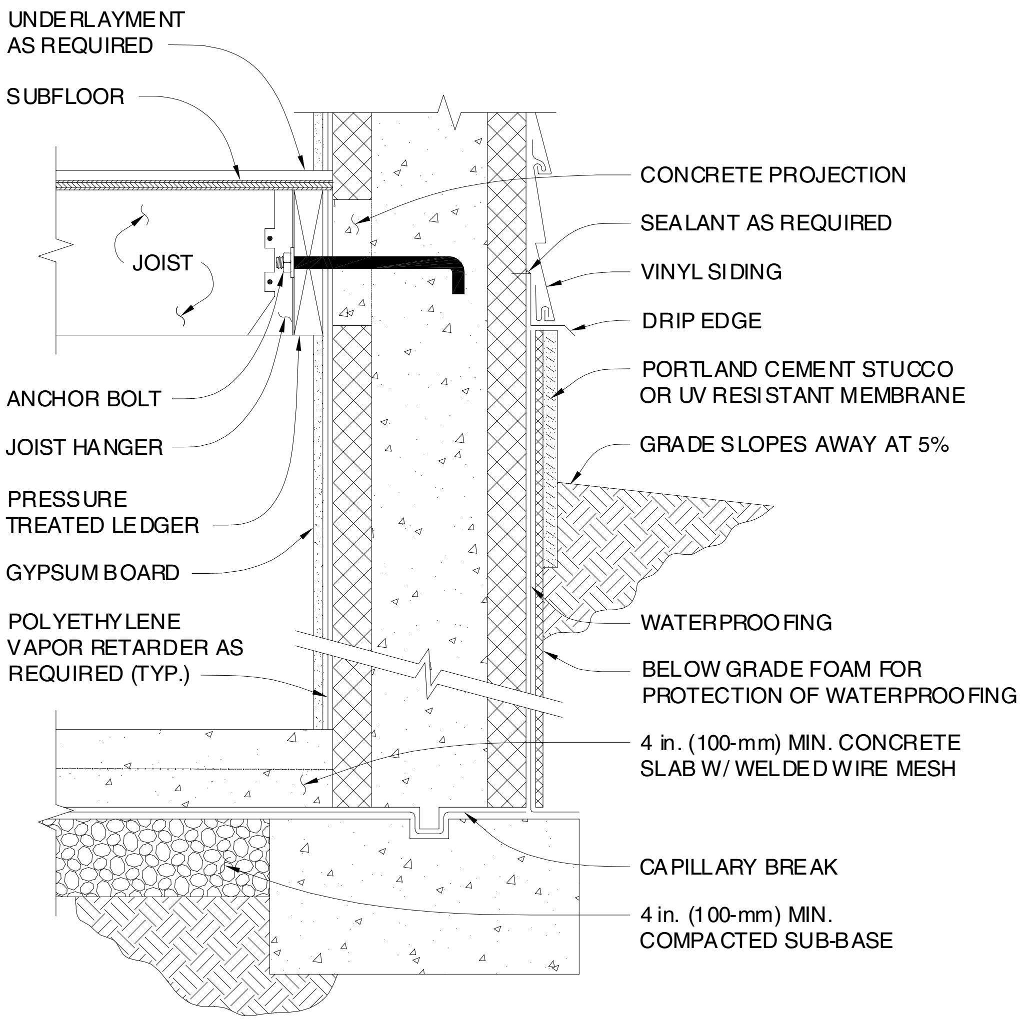
NOTE: REFER TO FIGURE D7 FOR SPECIFIC INFORMATION.

Figure E16. Installation of vinyl siding.

APPENDIX F. WHOLE WALL DETAILS

This appendix contains sixteen 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 slab-on-grade, exterior insulated concrete basement or crawlspace walls, and ICF basement or crawlspace walls.

Figures F1 through F4 present above-grade ICF walls constructed on below-grade ICF walls. Figures F5 through F8 present above-grade ICF walls constructed on concrete slabs-on-grade, with an exterior perimeter beams. Figures F9 through F12 present above-grade ICF walls constructed on below-grade insulated concrete walls. Figures F13 through F16 present the termination of the ICF walls at the roofline.



GENERAL NOTES ARE PRESENT IN FIGURE D1.

Figure F1. Above- and below-grade ICF walls with vinyl siding.

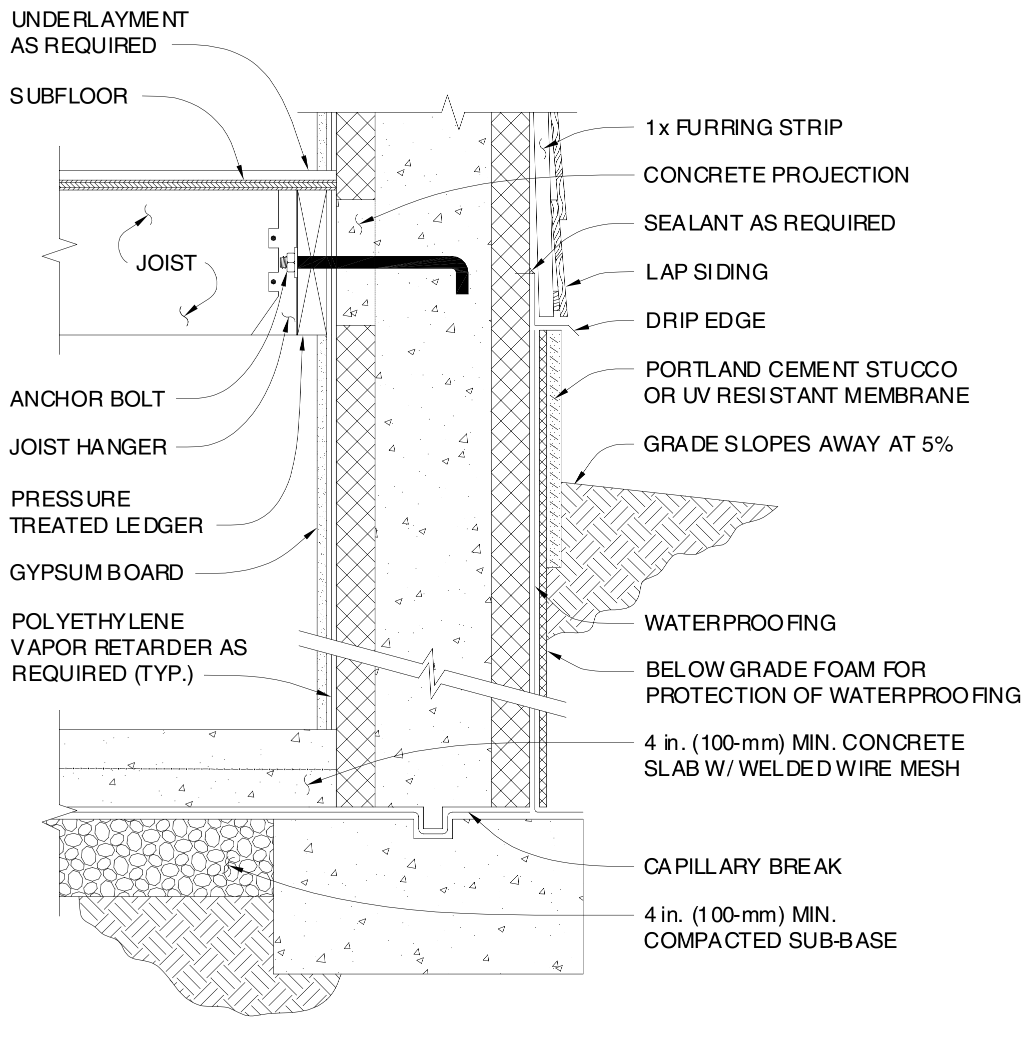


Figure F2. Above- and below-grade ICF walls with lap siding.

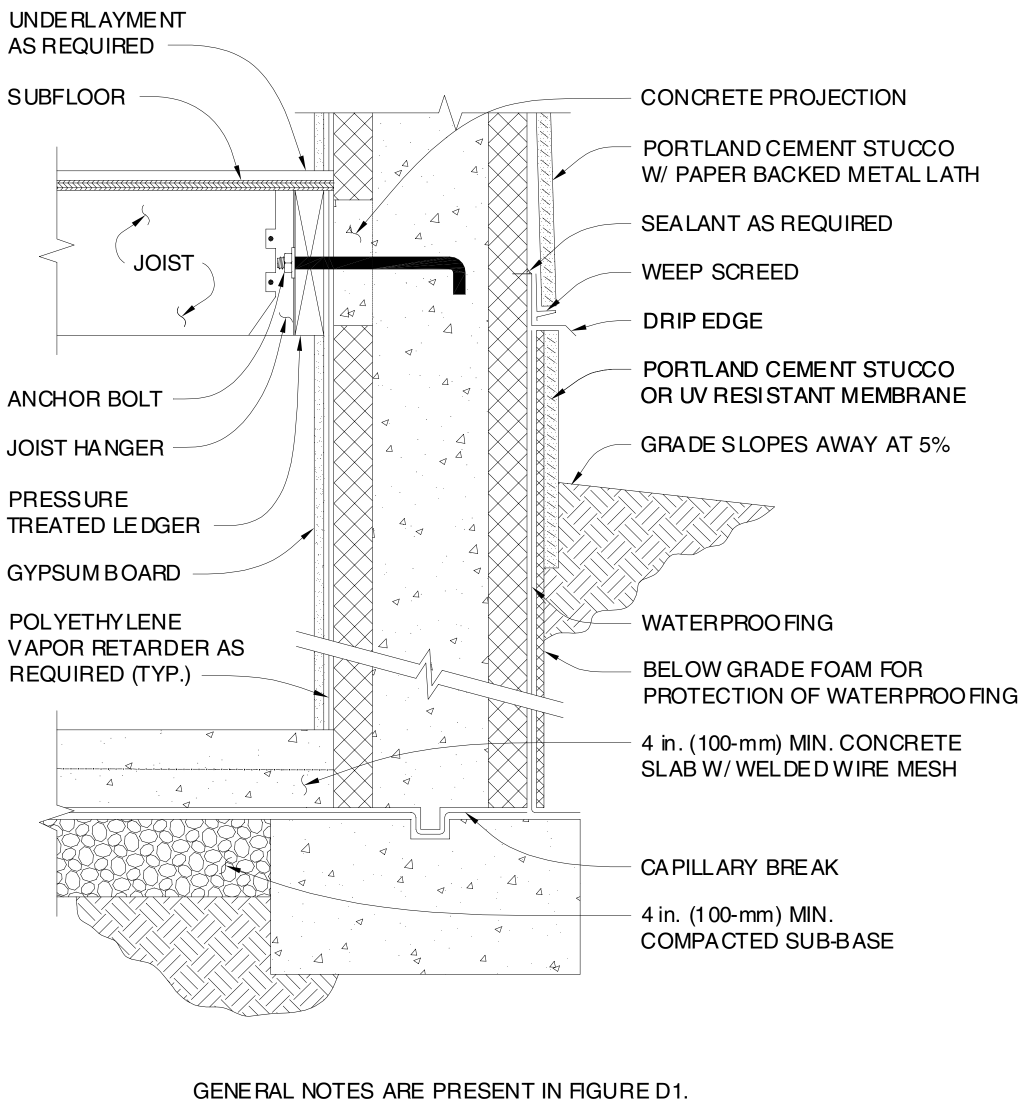
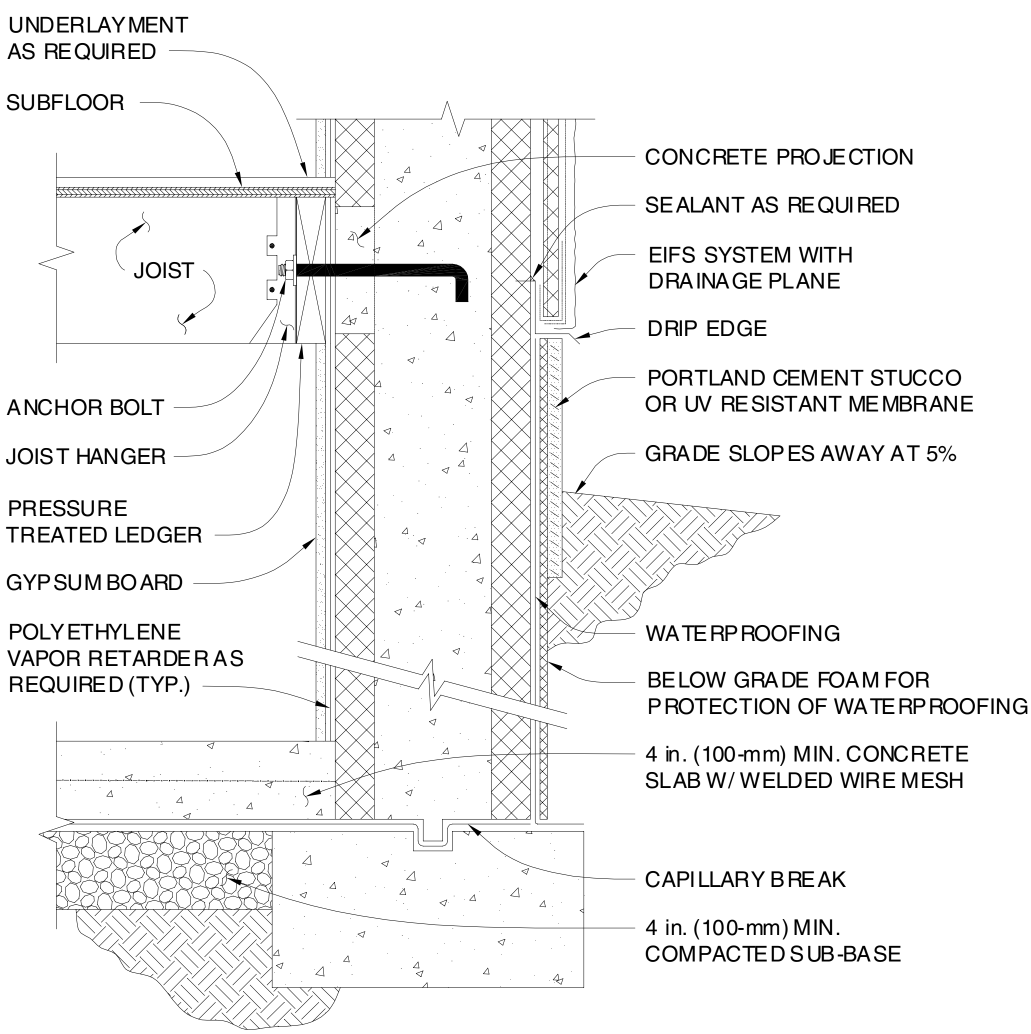


Figure F3. Above- and below-grade ICF walls with portland cement stucco.



GENERAL NOTES ARE PRESENT IN FIGURE D1.

Figure F4. Above- and below-grade ICF walls with EIFS.

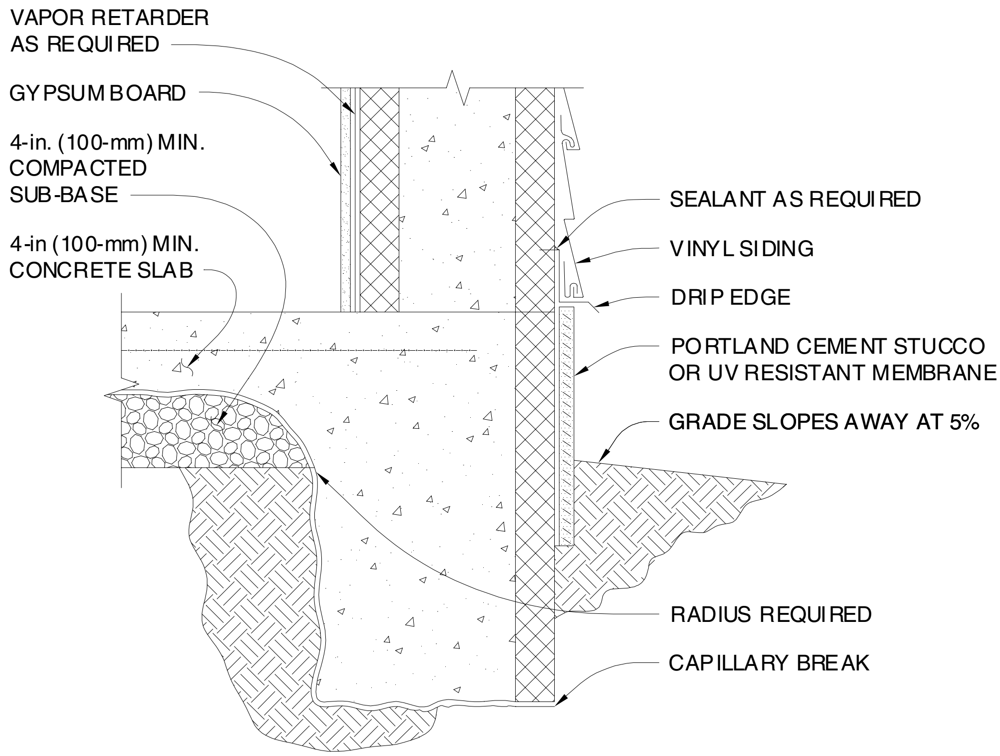


Figure F5. Above-grade ICF wall with vinyl siding on a slab-on-grade foundation.

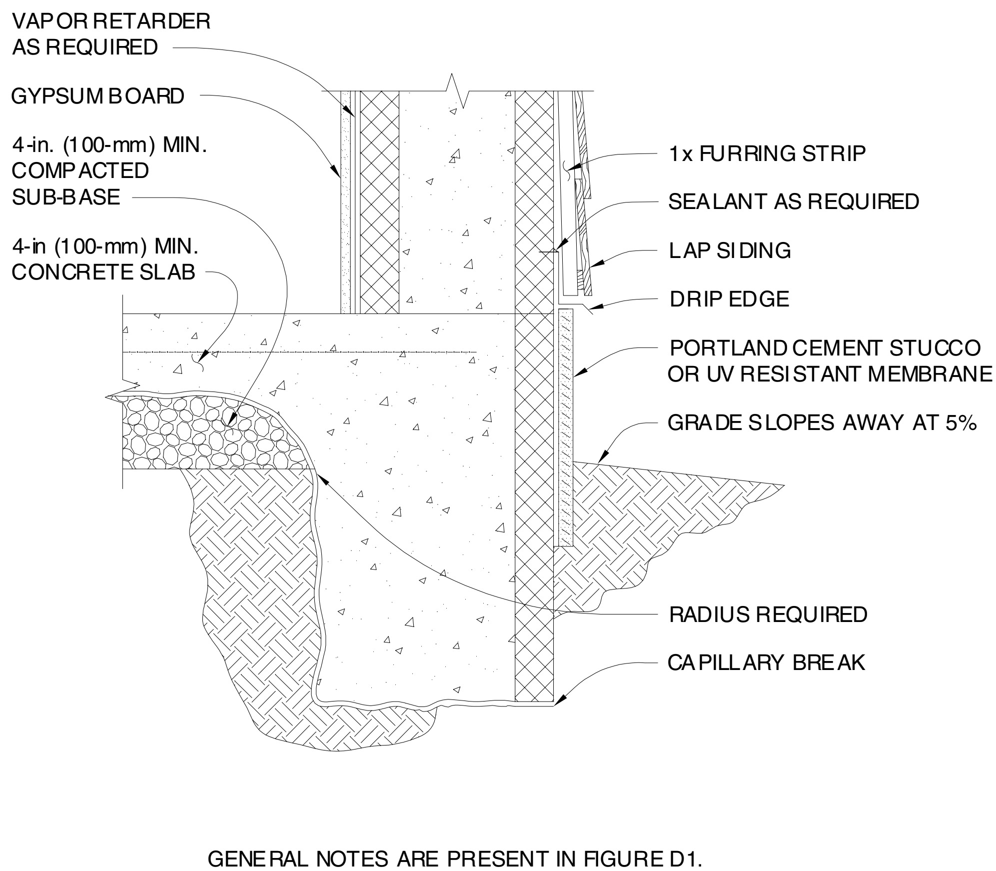


Figure F6. Above-grade ICF wall with lap siding on a slab-on-grade foundation.

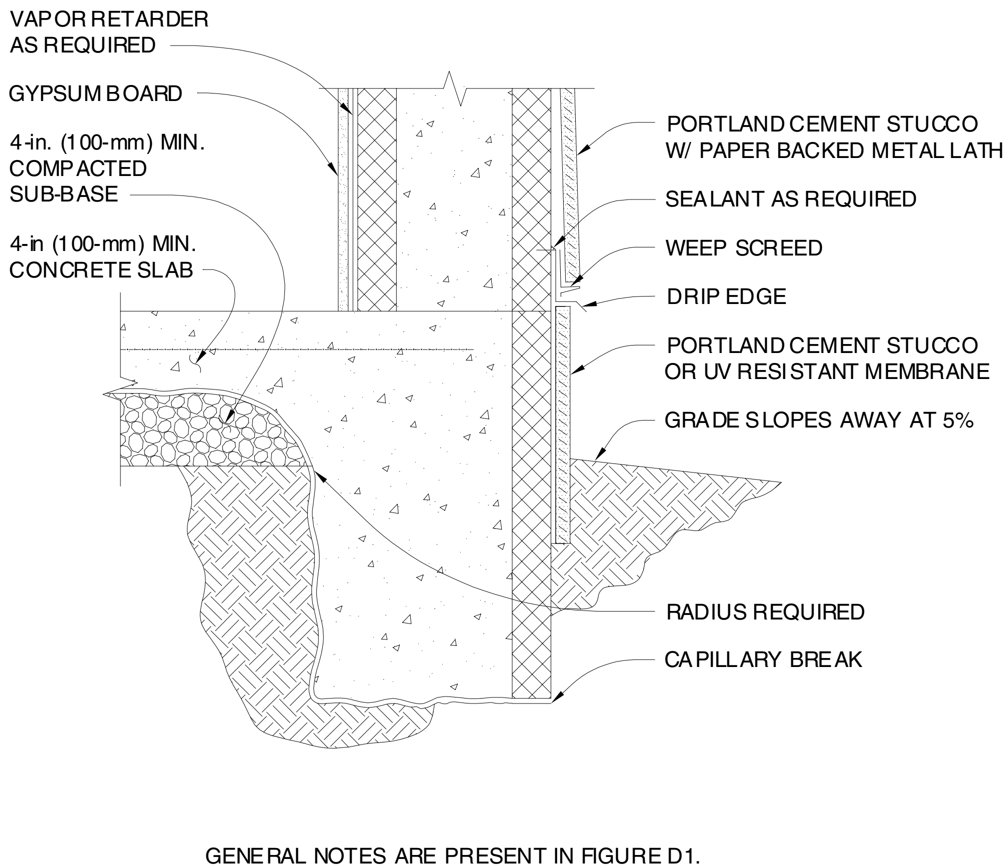
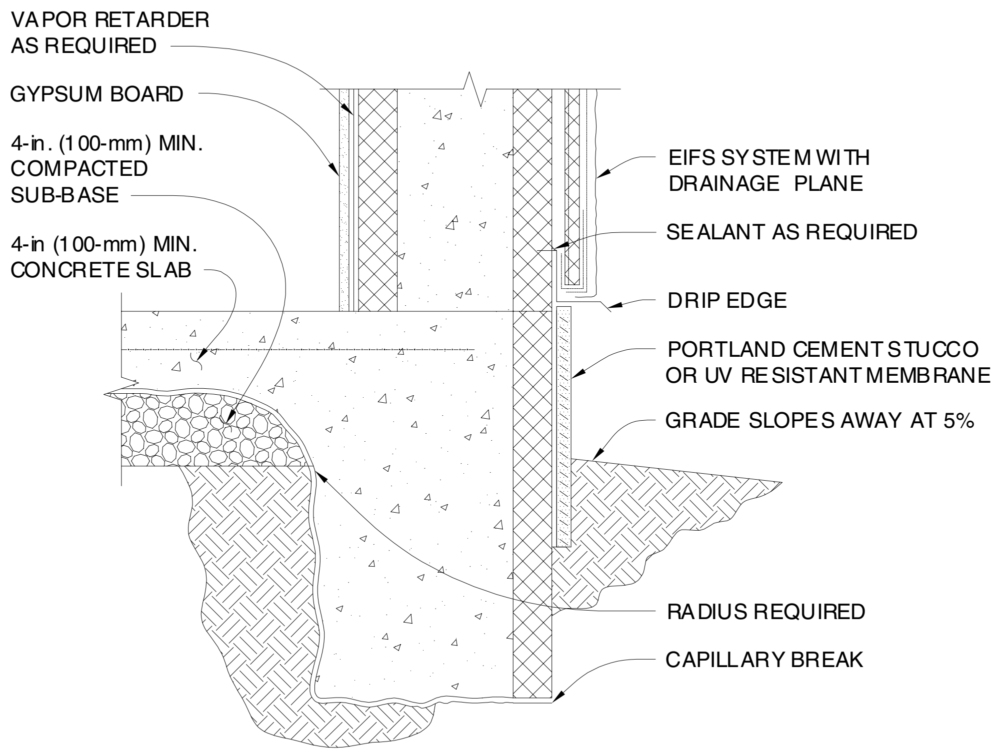


Figure F7. Above-grade ICF wall with portland cement stucco on a slab-on-grade foundation.



GENERAL NOTES ARE PRESENT IN FIGURE D1.

Figure F8. Above-grade ICF wall with EIFS on a slab-on-grade foundation.

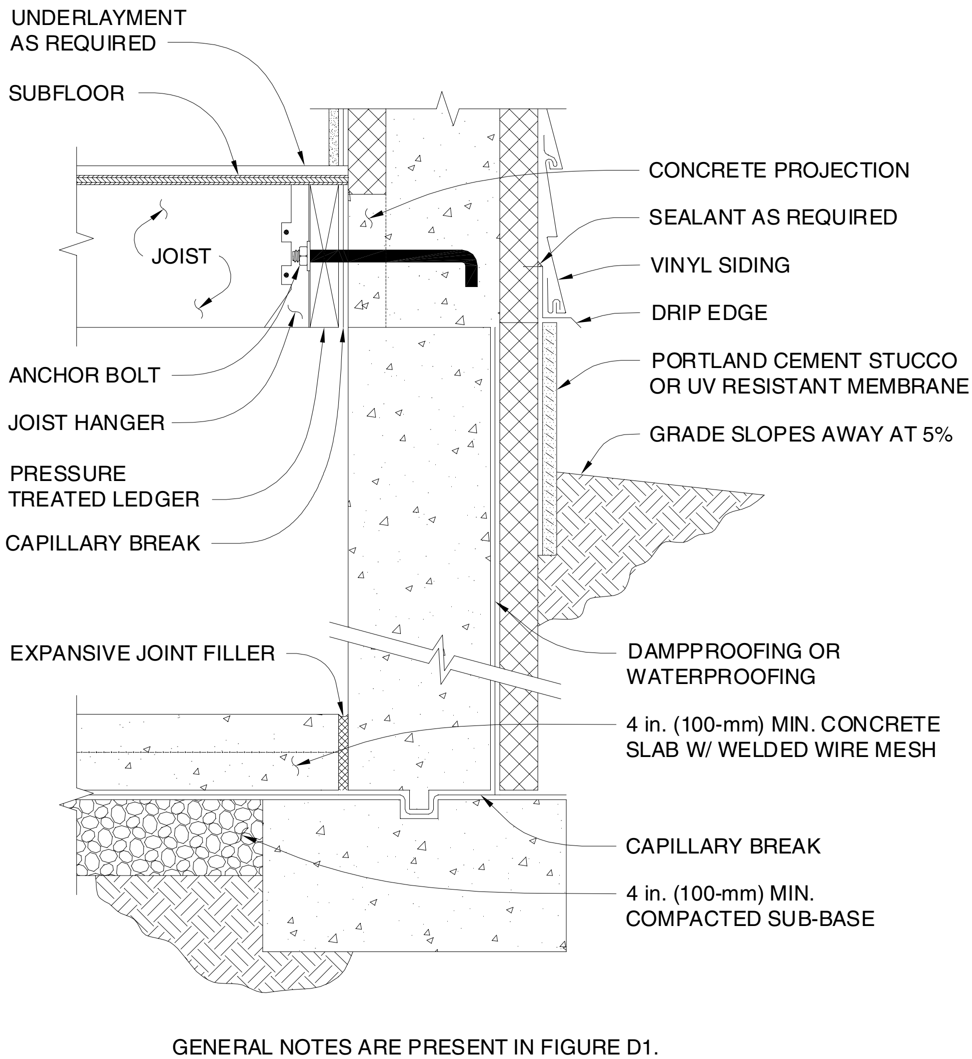


Figure F9. Above-grade ICF wall with vinyl siding on a below-grade insulated concrete wall.

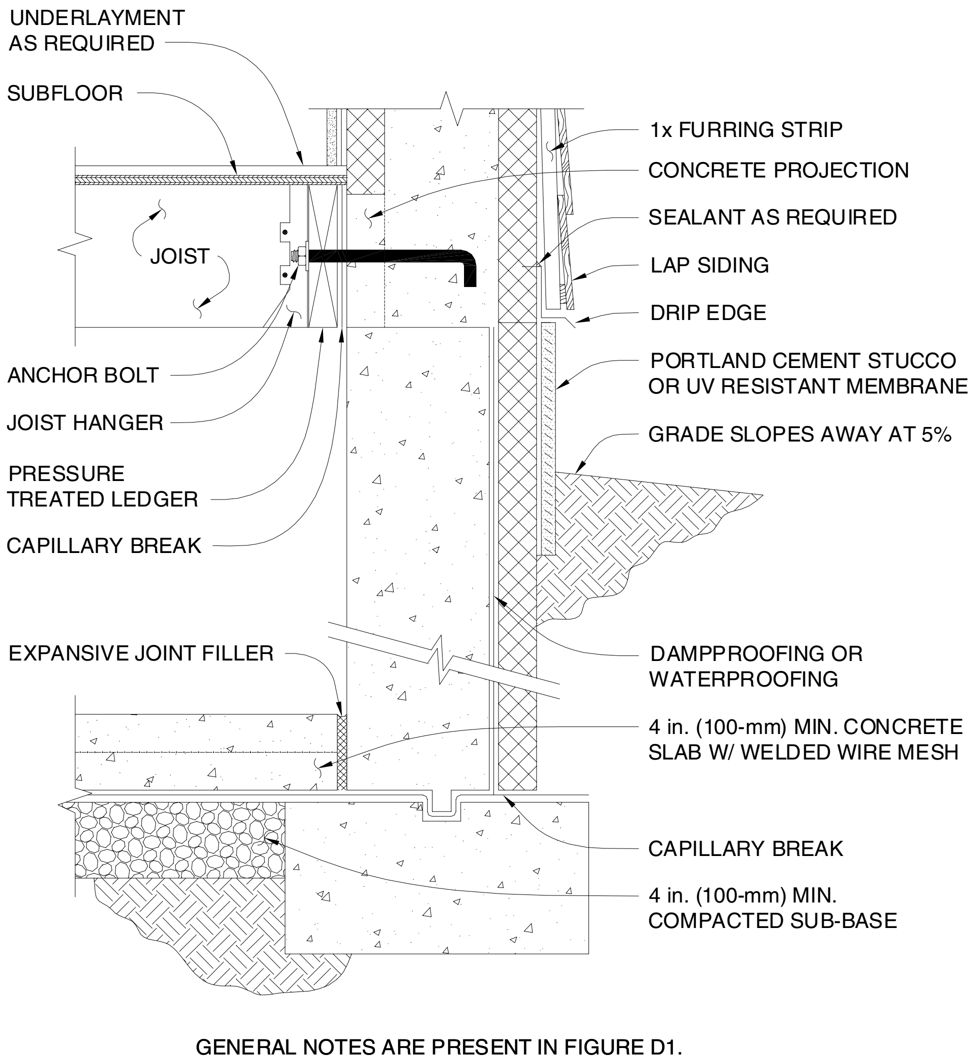
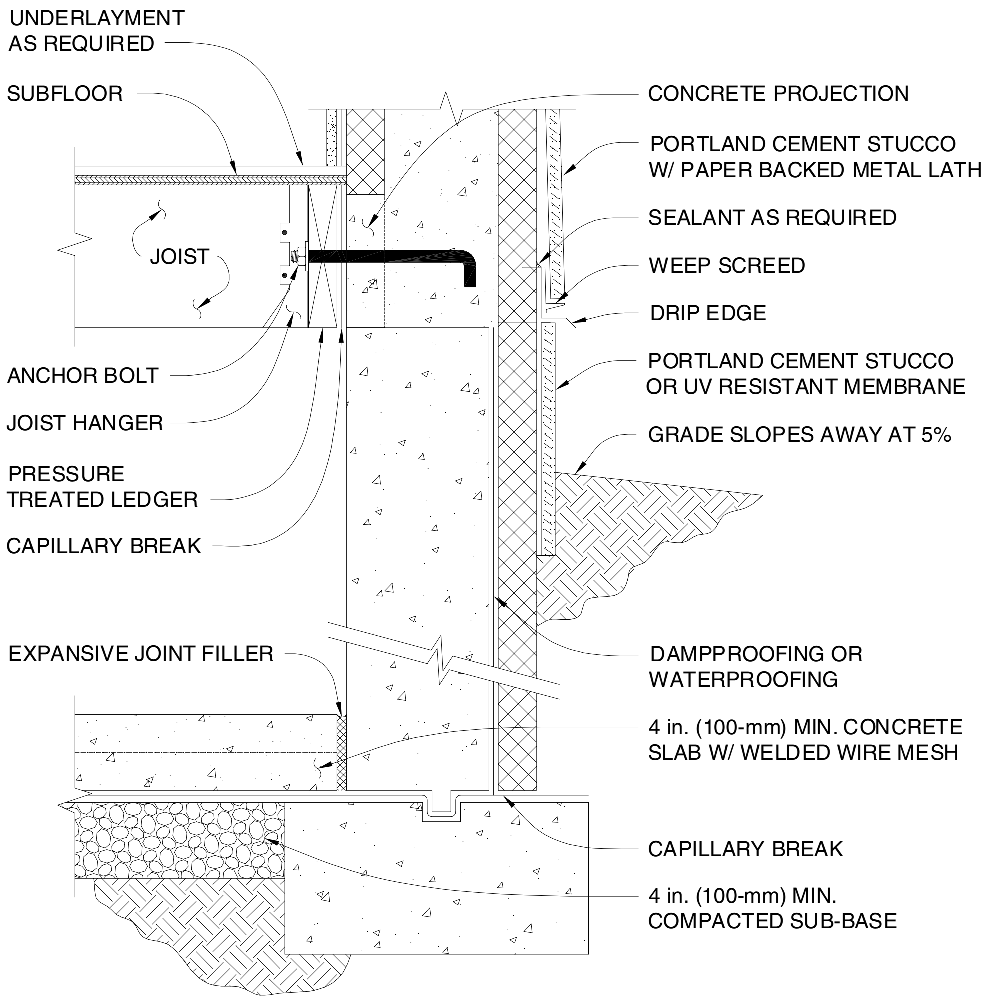
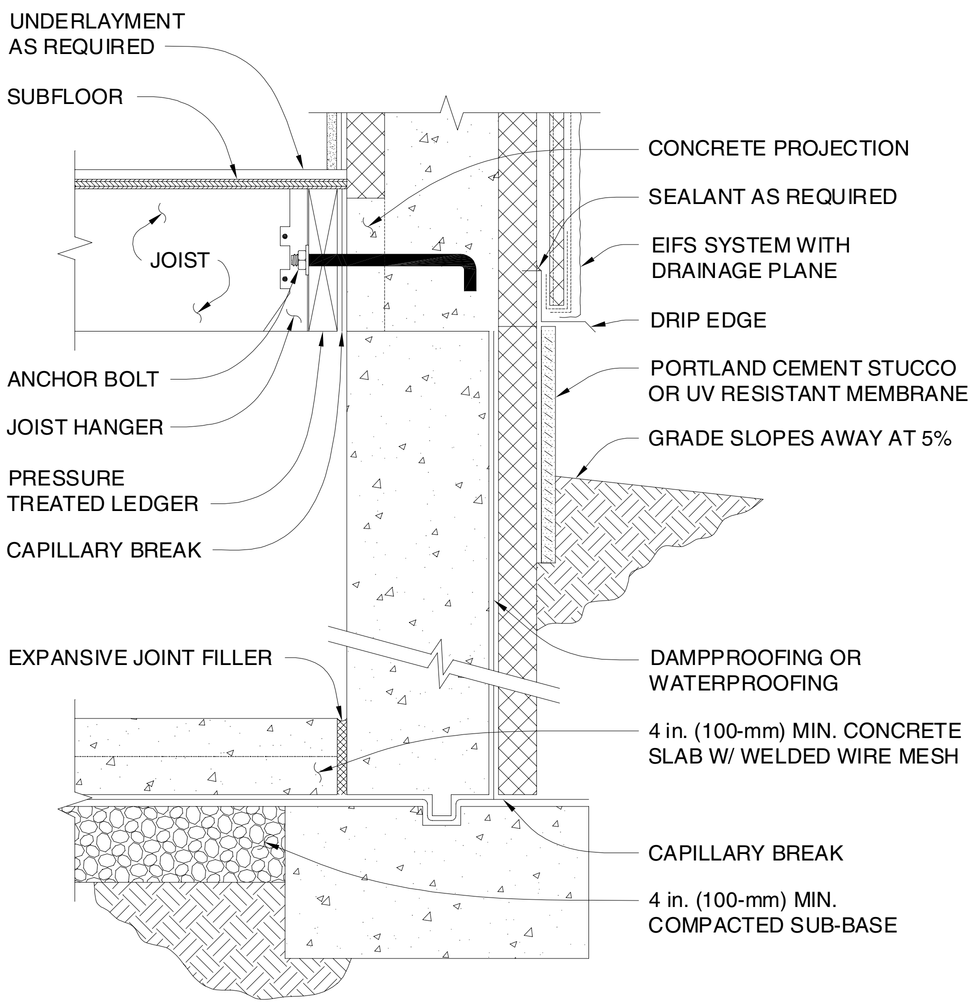


Figure F10. Above-grade ICF wall with lap siding on a below-grade insulated concrete wall.



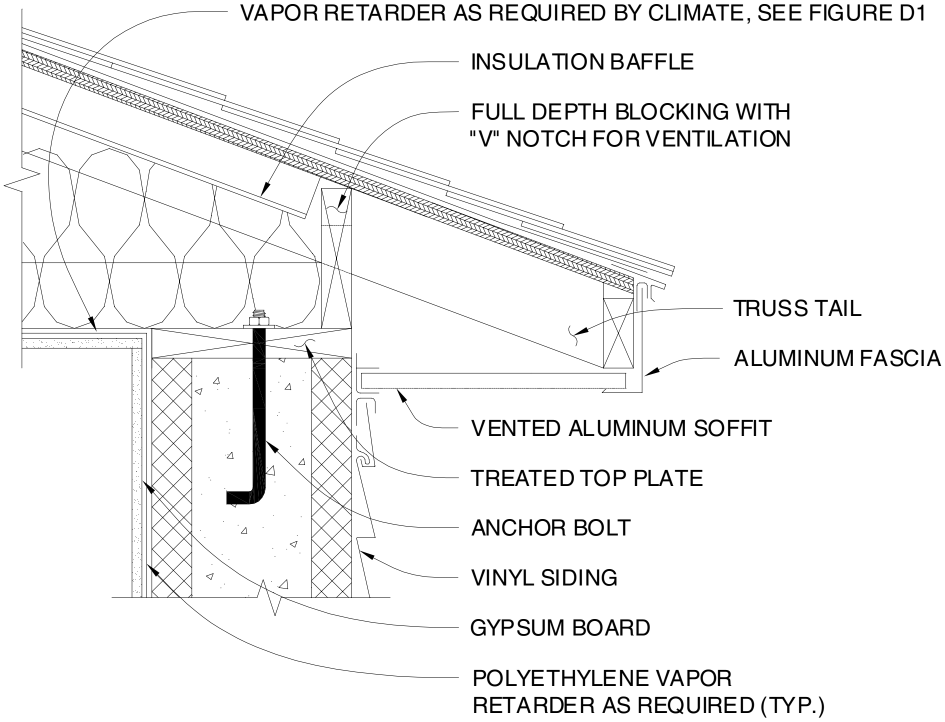
GENERAL NOTES ARE PRESENT IN FIGURE D1.

Figure F11. Above-grade ICF wall with portland cement stucco on a below-grade insulated concrete wall.



GENERAL NOTES ARE PRESENT IN FIGURE D1.

Figure F12. Above-grade ICF wall with EIFS on a below-grade insulated concrete wall.



GENERAL NOTES ARE PRESENT IN FIGURE D1.

Figure F13. Above-grade ICF wall with vinyl siding at the roofline.

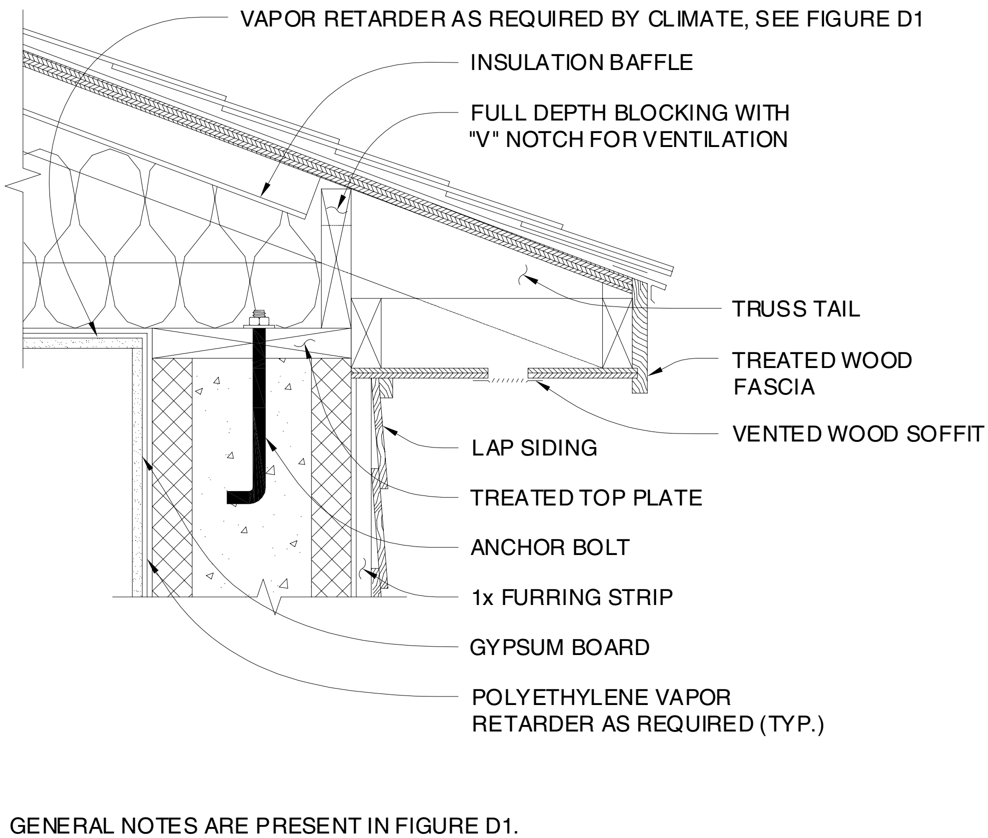
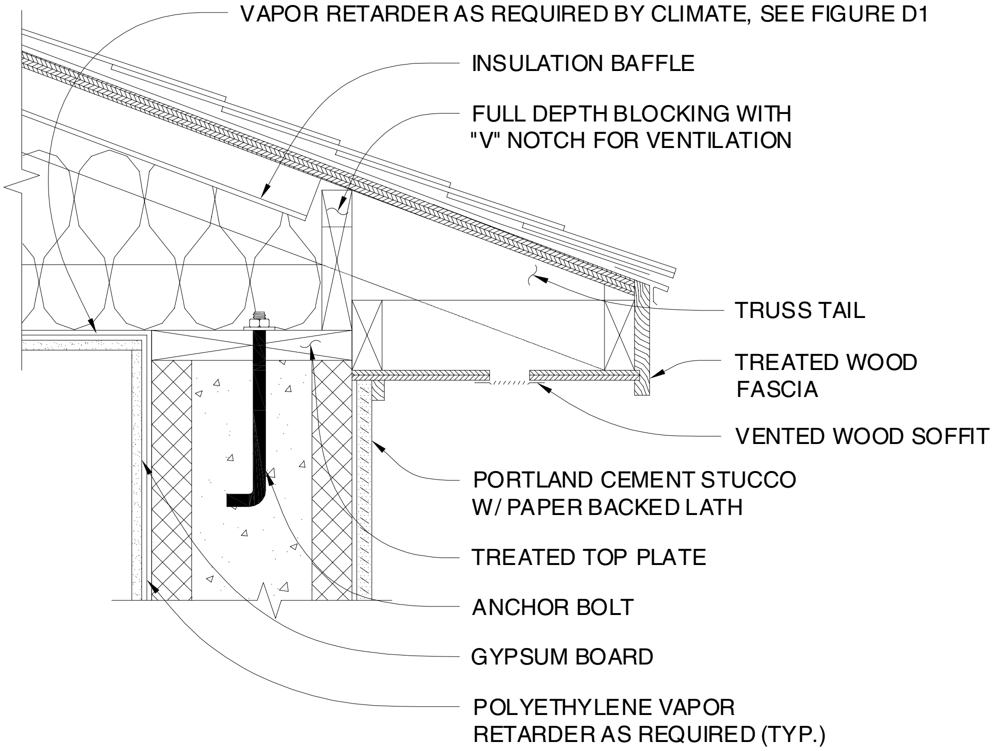
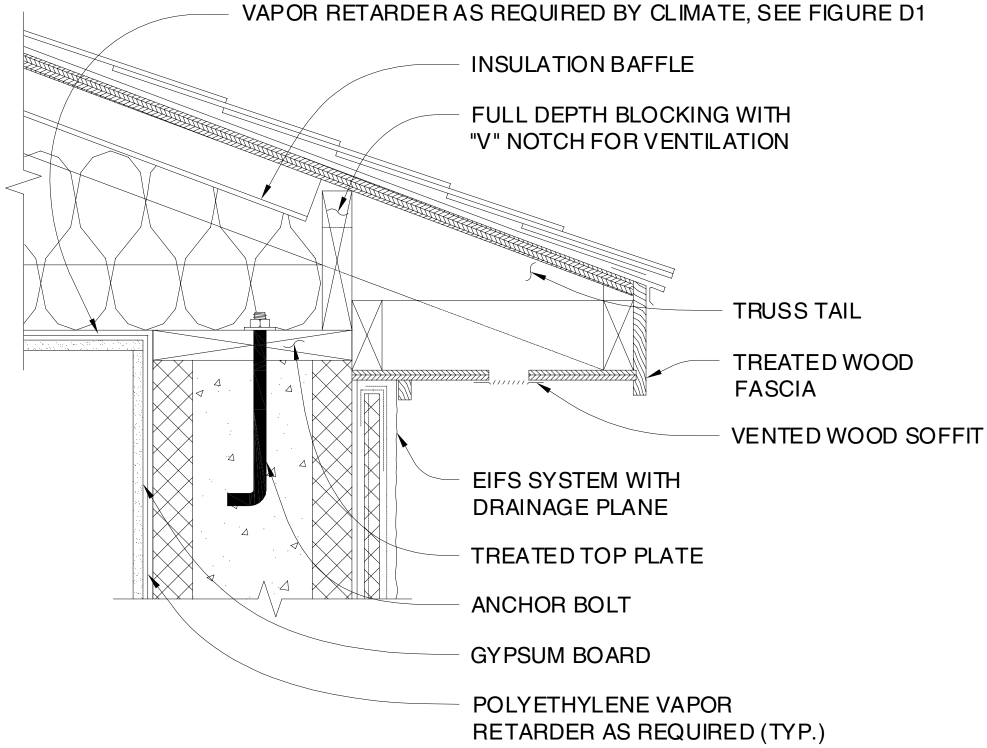


Figure F14. Above-grade ICF wall with lap siding at the roofline.



GENERAL NOTES ARE PRESENT IN FIGURE D1.

Figure F15. Above-grade ICF wall with portland cement stucco at the roofline.



GENERAL NOTES ARE PRESENT IN FIGURE D1.

Figure F16. Above-grade ICF wall with EIFS at the roofline.