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Cold-Weather Construction of ICF Walls

by John Gajda

KEYWORDS

Cold weather, concrete, construction, freezing, housing, ICF, insulating concrete form, residential, thermal mass, walls, winter conditions

ABSTRACT

Concrete construction during cold-weather conditions requires special considerations to ensure that concrete achieves a critical strength prior to freezing. Insulating concrete forms (ICFs) offer the ability to construct concrete walls at temperatures below that of concrete cast in reusable forms.

To determine the lowest temperature at which ICF walls can be constructed, five ICF walls were constructed and monitored during sub-freezing conditions. Walls were constructed to simulate conditions at various locations in a typical residential wall, such as at the center of a wall, at a window or door penetration, and on a frozen footing.

Data collected from the monitoring of walls were used to verify computer models, which were then used to extrapolate results to a wide variety of conditions and concrete mix designs.

Results indicate that ICF walls can be safely constructed at temperatures below that of walls cast in reusable forms. In very cold weather conditions, minimal precautions may be required, especially at wall penetrations and edges. As with concrete walls cast in reusable forms, ICF walls should not be constructed on frozen footings.

REFERENCE

Gajda, John, *Cold-Weather Construction of ICF Walls*, R&D Serial No. 2615, Portland Cement Association, 2002, 36 pages.

COLD-WEATHER CONSTRUCTION OF ICF WALLS

by John Gajda *

INTRODUCTION

Concrete construction during cold-weather conditions requires special considerations to ensure that concrete is not damaged by prematurely freezing. Compressive strength gain of concrete is considerably slower at low temperatures and significant reductions in ultimate strength of up to 50% can occur if the fresh concrete freezes before adequate strength is developed (McNeese, 1952). However, studies have shown that if the concrete compressive strength reaches a minimum of 3.5 MPa (500 psi) before it freezes, the ultimate compressive strength will not be affected (Powers, 1962). In addition, provided that the concrete achieves this critical strength prior to freezing, the length of time the concrete is frozen or the temperature to which the concrete drops has no effect on the compressive strength after it thaws.

Concrete walls can be constructed in all seasons using reusable formwork, however, during cold weather conditions, the use of windbreaks, insulated formwork, heaters, and other required measures can greatly increase the cost and time of construction. This places practical limits on the length of the residential construction season, especially in northern climates.

Due to their inherent insulating capacity, insulating concrete forms (ICFs) offer the ability to safely construct concrete walls at temperatures below that of concrete walls cast in reusable forms. This ability extends the construction season, potentially extending it into the coldest periods of winter.

Because of a lack of available information specific to cold-weather practices for ICFs, building code officials and others many times require that ICF walls be constructed utilizing typical cold-weather concrete practices for concrete walls cast in reusable forms (ACI, 2002). This results in potentially unnecessary cost increases and construction delays.

To determine the lowest air temperatures that ICF walls can be safely constructed without fear of freezing damage to the fresh concrete, five ICF walls were constructed and monitored during sub-freezing conditions. Results were used to verify computer models, which were used to extrapolate results for a variety of different temperature conditions and concrete mix designs.

WALL CONSTRUCTION AND MONITORING

The five ICF walls were constructed and monitored during sub-freezing conditions. The walls were configured and constructed to simulate conditions at (i) the center of a wall, (ii) adjacent to a wood buck, and (iii) on a frozen footing. These areas are shown in Figure 1. The two "center of

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wall" configurations were tested first. The two "adjacent to a wood buck" configurations were tested next. The "on a frozen footing" configuration was tested last.

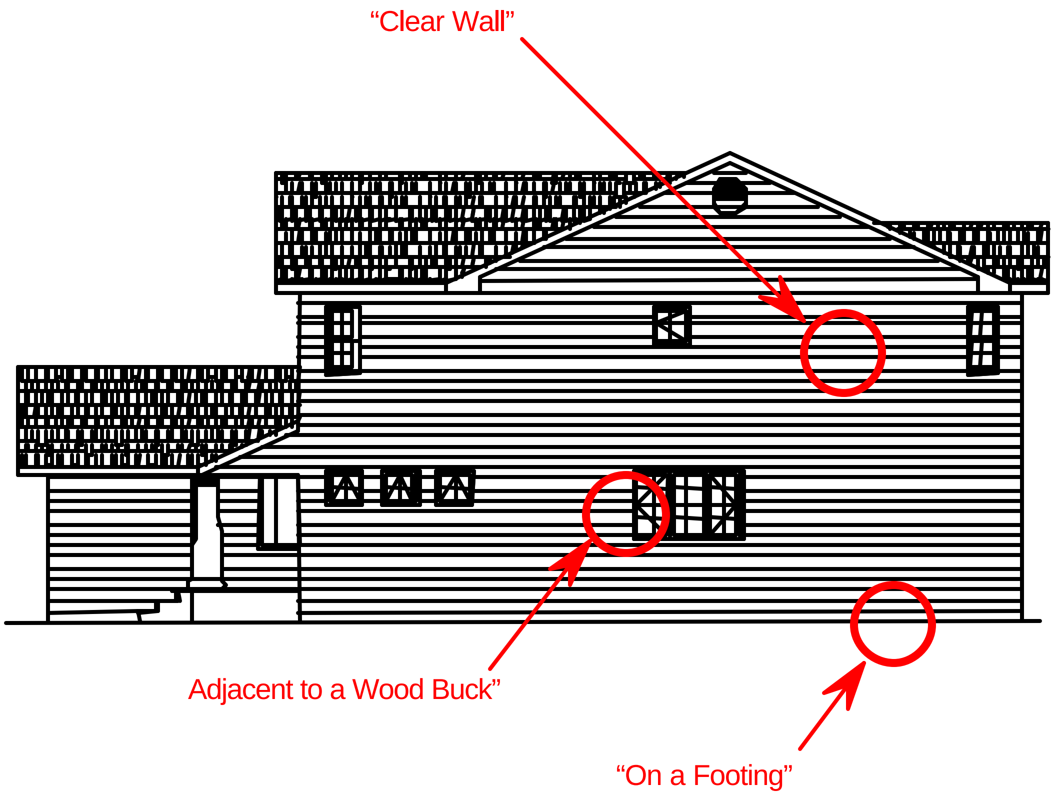

Figure 1. Typical areas in an ICF wall.

General Description

The walls utilized flat panel ICFs with expanded polystyrene insulation and integral plastic ties. Three of the walls utilized 6-in. ICFs*, while the remaining walls utilized 4-in. ICFs†. In all cases, wall sections were 1200 mm (48 in.) wide by 1200 mm (48 in.) high. The appropriate perimeter surfaces were highly insulated to simulate larger wall sections. Wall sections were constructed on movable carts, as shown in Figure 2. This allowed for the walls to be partially constructed, instrumented with thermocouples, and preconditioned at a nominal temperature of -18°C (0°F) prior to placement of the concrete. Due to logistical constraints, the walls were moved out of the -18°C (0°F) environment during placement of the concrete. The walls were returned to the -18°C (0°F) environment as soon as possible, typically in less than 30 minutes after they were removed. Figure 3 shows the placement of concrete in a wall.

* A 6-in. flat panel ICF has a 150-mm (6-in.) concrete core with 50 mm (2 in.) of polystyrene insulation on either side. The total wall thickness is 250 mm (10 in.) All dimensions are nominal.

† A 4-in. flat panel ICF consists of a 100-mm (4-in.) concrete core with 2 in. of polystyrene insulation on either side. The total wall thickness is 200 mm (8 in.) All dimensions are nominal.

Figure 2. ICF wall section were constructed on a movable carts.

Concrete was provided by a local ready-mix supplier. For all walls, the same concrete mix was ordered. The concrete was to be air entrained, contain 9.5-mm ($^3/_8$-in.) pea gravel, and have a nominal compressive strength of 20 MPa (3000 psi) at 28 days. Because pea gravel was not conveniently available to the ready-mix supplier, 9.5-mm ($^3/_8$-in.) crushed limestone was substituted. The ready-mix supplier reported that the concrete mix was air-entrained and contained 335 kg/m^3 (564 pcy) of Type I/II cement.

In all walls, 100×200-mm (4×8-in.) standard cylindrical test specimens for measuring compressive strength were integrally cast into the wall. This provided a convenient method of determining the compressive strength of the concrete at the time of freezing. After each wall section froze, these specimens were removed from the walls, allowed to warm to room temperature over a 12-hour period, and measured for compressive strength. During the required warming period, it is estimated that the increase in compressive strength was less than 5% from the frozen state. Companion 7- and 28-day compressive strength specimens were cured at laboratory conditions. The three wall configurations, recorded temperatures, and measured compressive strengths are described below.

Configuration 1 – Center of Wall (Clear Wall)

This configuration was designed to represent conditions at the center of an ICF wall, away from edges, corners, and penetrations. Testing was performed using the 4- and 6-in. flat-panel ICFs.

Figure 3. Concrete was placed directly from ready-mix truck into wall sections.

To simulate the "clear wall" condition it was necessary to prevent heat flow through the edges of the polystyrene of the ICFs. Therefore, the perimeter surfaces of the ICF walls were super-insulated with 150 mm (6 in.) of extruded polystyrene board insulation. The thermal resistance*, commonly called R-value, of the perimeter insulation was approximately 5 $K \cdot m^2/W$ (30 $ft^2 \cdot °F \cdot hr/Btu$). This is more than three times greater than the R-value of each of the polystyrene layers of the ICFs.

In each of the walls, three thermocouples were located at the center of the wall. Within a wall, the first thermocouple was located at the interface between the concrete and the polystyrene of the ICF, the second was located at the mid-thickness of the wall, and the third was located midway between the first two thermocouples.

Temperatures were measured in the wall sections until the concrete temperature at the center of the wall was less than -7°C (20°F). Figure 4 presents the recorded temperatures at the center of the 4- and 6-in. walls. Temperatures at various locations in each wall, especially across the thickness, were virtually identical and therefore are not presented. The average air temperature over the 7-day period was approximately -20°C (-4°F). It is interesting to note that the slope of the time-temperature curve for both walls changes at a temperature of -3°C (27°F)

*Thermal resistance depends on many factors, such as the type of material, its density, its temperature, and the presence of thermal bridges. For example, dry expanded polystyrene board with a density of 20.0 kg/m^3 and no thermal bridges has an R_{SI}-value of 0.28 $K \cdot m^2/W$ per centimeter thickness when its mean temperature is 24°C (similarly, when the density is 1.25 lb/ft^3, it has an R-value of 4.0 $ft^2 \cdot °F \cdot hr/Btu$ per inch when its mean temperature is 75°F). Refer to product manufacturer's literature to get actual R-values.

for the 4-in. wall and at -4°C (25°F) for the 6-in. wall. This is the approximate temperature where freezing of the concrete begins. Utilizing this criterion, the 4-in. wall started to freeze at a time of 3.0 days after placement, while the 6-in. wall started to freeze at 5.5 days after placement.

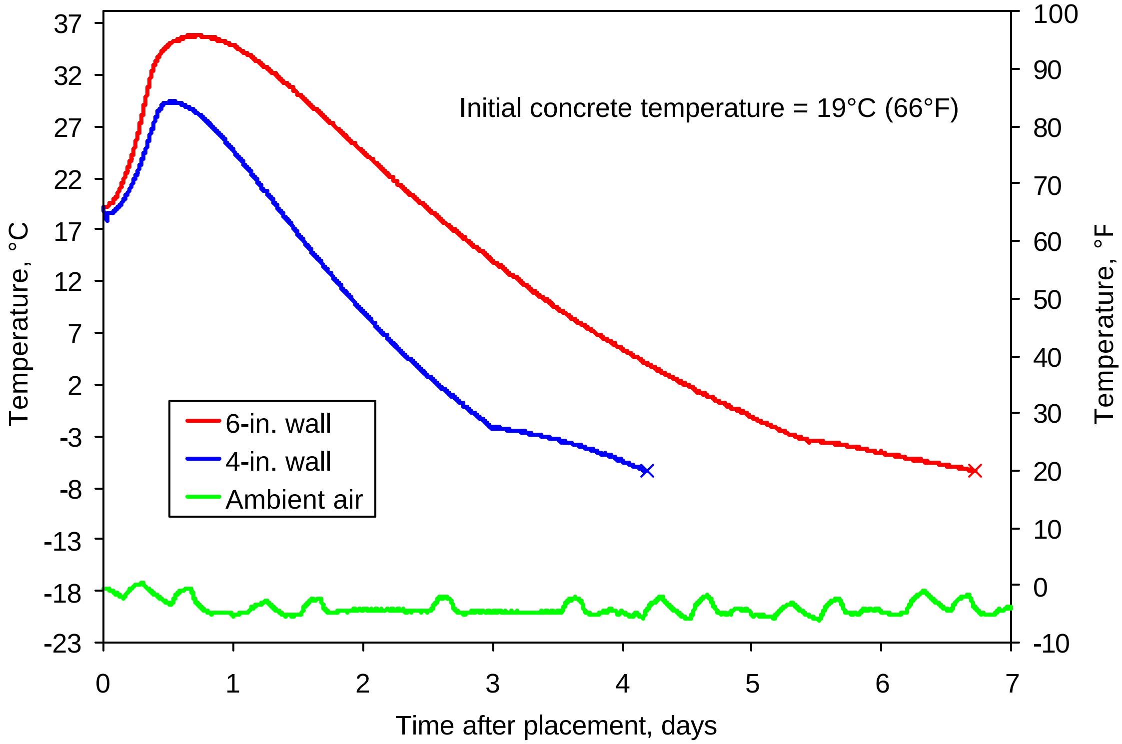

Figure 4. Recorded temperatures for the "center of wall" configuration.

Compressive strengths were measured as previously described, and are presented in Table 1. As can be seen, both the 7- and 28-day compressive strengths were significantly greater than the requested compressive strength. At the time of freezing, compressive strength of the 4-in. wall was approximately 58% that of the 28-day compressive strength. Similarly, the compressive strength of the 6-in. wall was approximately 66% that of the 28-day compressive strength. Because the compressive strength was greater than 3.5 MPa (500 psi) at the time of freezing, no adverse effects of this freezing are anticipated.

Table 1. Compressive Strength of Concrete Utilized in the "Center of Wall" Configuration

Wall	Average compressive strength, MPa (psi)		
	At freezing[1]	7-day[2]	28-day[2]
4-in.	19.5 (2830)	25.2 (3660)	33.6 (4870)
6-in.	22.1 (3200)		

1. Cylinders were cast inside walls and were removed and tested after the concrete in the walls began to freeze.
2. The 7- and 28-day compressive strengths are based on companion cylinders that were continuously cured at 100% relative humidity and 23±2°C (73±3°F).

Configuration 2 – Adjacent to a Wood Buck

This configuration was designed to represent conditions at a typical window or door penetration with a 38-mm (2-in.) thick wood buck anchored with 13-mm (½-in.) diameter steel bolts. Again, testing was performed using both the 4- and 6-in. flat-panel ICFs. The perimeter top and bottom surfaces of the walls were super-insulated as described above.

To determine the effect of the steel anchor bolts, thermocouples were placed directly behind the bolts in both the 4- and 6-in. walls. This is the worst-case condition. Because the steel is an efficient conductor of heat, thermocouples were also placed on an anchor bolt that was insulated with extruded polystyrene insulation. Because of a small gap between the wood buck and the insulation, the effective R-value of the insulation placed over the anchor bolt was estimated to be approximately 0.5 $K{\cdot}m^2/W$ (3 $ft^2{\cdot}°F{\cdot}hr/Btu$). This is less than half the R-value of each of the polystyrene layers of the ICFs. Figure 5 shows the general layout of the walls and thermocouple locations.

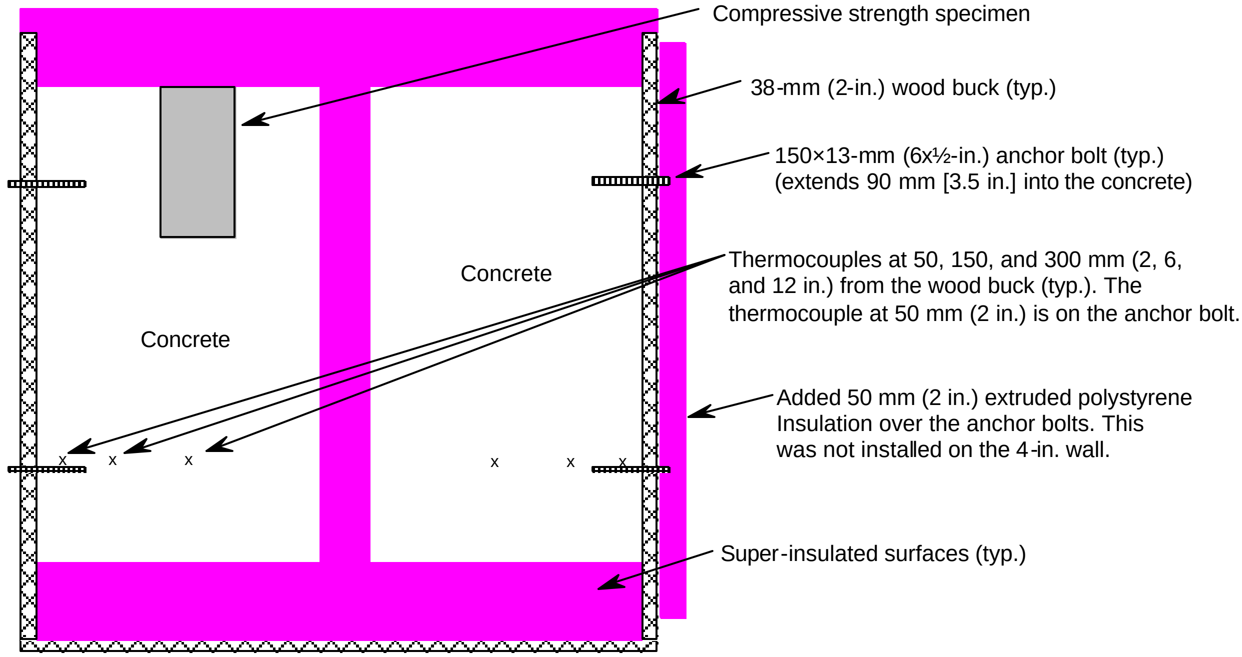

Figure 5. Layout of the "adjacent to wood buck" configuration.

Temperatures were measured in the walls until the measured concrete temperatures were less than -7°C (20°F). Figures 6 through 8 present the recorded temperatures in the 4-in. wall with exposed steel anchor bolts, the 6-in. walls with exposed steel anchor bolts, and 6-in. walls with insulated steel anchor bolts, respectively. The average air temperature over the period shown in the figures was approximately -20°C (-4°F).

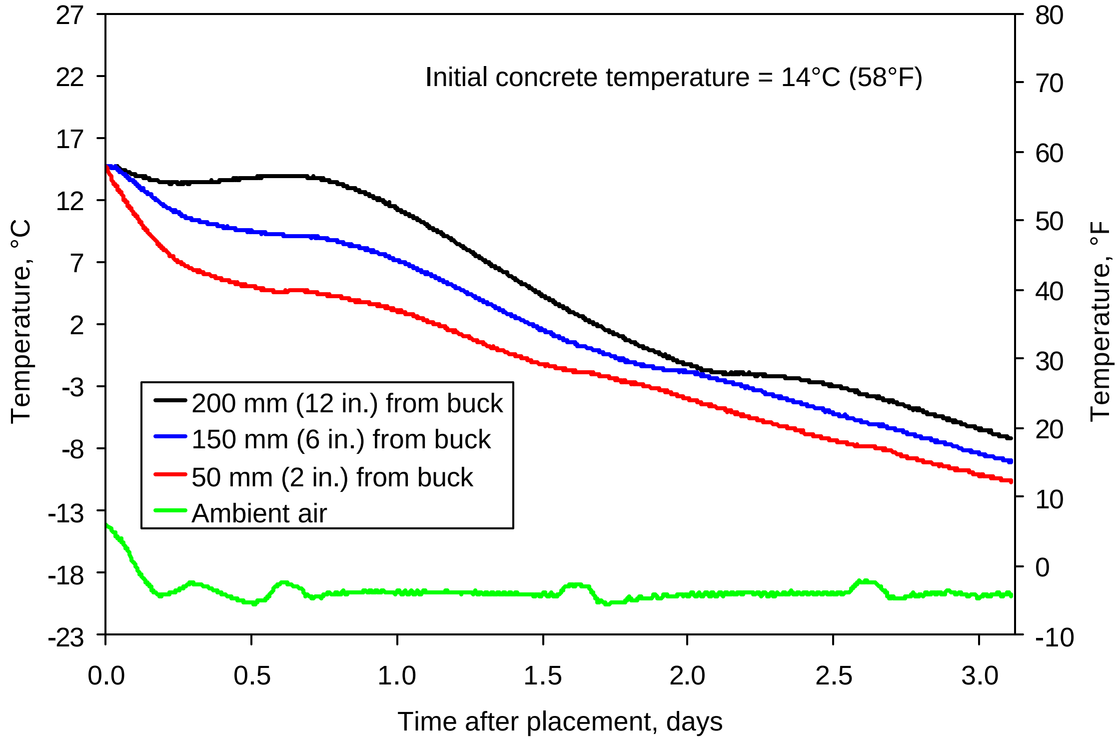

Figure 6. Recorded temperatures for the "adjacent to a wood buck" configuration for a 4-in. ICF wall with uninsulated anchor bolts.

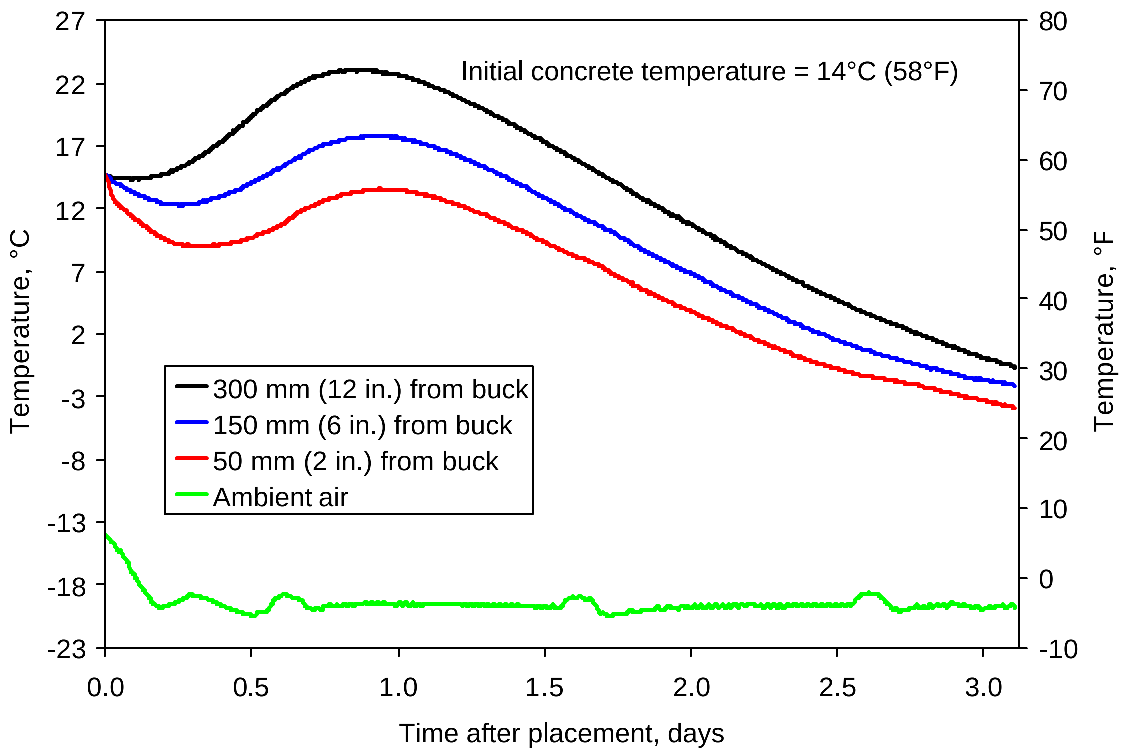

Figure 7. Recorded temperatures for the "adjacent to a wood buck" configuration for a 6-in. ICF wall with uninsulated anchor bolts.

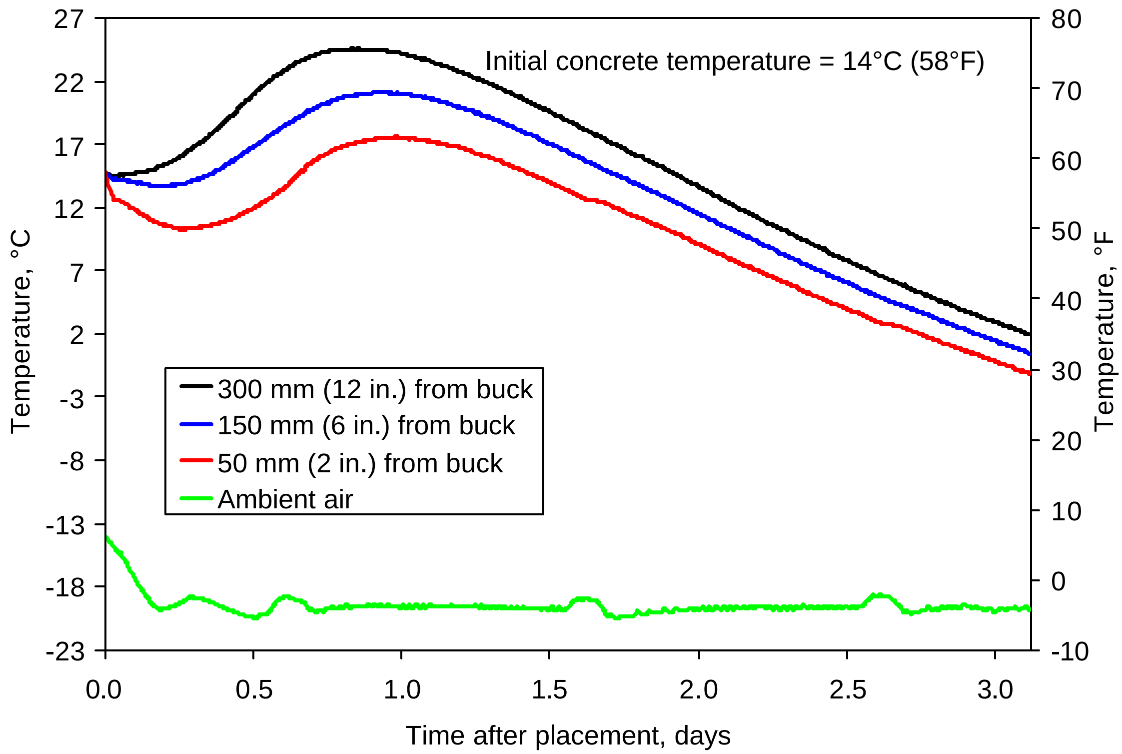

Figure 8. Recorded temperatures for the "adjacent to a wood buck" configuration for a 6-in. ICF wall with insulated anchor bolts.

Similar to that of the "center of wall", the initial freezing temperature of the concrete is approximately -2.2°C (28°F) for the 4-in. wall and -1.7°C (29°F) for the 6-in. wall. Based on this, the area behind the anchor bolt froze in the 4-in. wall at a time of 1.5 days, while the same area in the 6-in. wall froze at a time of 2.6 days. With the insulation over the anchor bolt in the 6-in. wall, the time of freezing was delayed to a time of 3.3 days.

Compressive strengths were measured as previously described, and are presented in Table 2. As can be seen, the concrete had 7- and 28-day laboratory-cured compressive strengths that were significantly lower than ordered. This is because of the excessive entrained air content. Although the concrete mix design was virtually identical to that of the first set of walls, the high air content significantly reduced the concrete unit weight and the compressive strength.

The concrete compressive strength specimens were located at the 300-mm (12-in.) thermocouple locations, and therefore are higher than the compressive strengths at the anchor bolts. Compressive strengths at the anchor bolts were estimated based on a maturity method (PCA, 2002) and are also presented in Table 2.

At the time of freezing, estimated compressive strength of the concrete at the uninsulated anchor bolt in the 4-in. wall was approximately 7% that of the 28-day compressive strength. Likewise, the estimated compressive strength of the concrete at the uninsulated anchor bolt in the 6-in. wall was approximately 27% that of the 28-day compressive strength. Adding the insulation over the anchor bolt in the 6-in. wall increased the estimated compressive strength at the time of freezing to approximately 35% that of the 28-day compressive strength.

Table 2. Compressive Strength of Concrete Utilized in the "Adjacent to a Wood Buck" Configuration

Wall	Average compressive strength, MPa (psi)			
	At freezing		Laboratory cured[3]	
	Measured[1]	Estimated[2]	7 Day	28 Day
4-in. with uninsulated anchor bolts	10.8 (1570)	1.0 (150)	12.4 (1800)	14.8 (2150)
6-in. with uninsulated anchor bolts	10.3 (1500)	4.0 (580)		
6-in. with insulated anchor bolts	Not measured	5.2 (750)		

1. Cylinders were cast inside walls, at a distance of 300 mm (12 in.) from the anchor bolts.
2. Estimated based on a maturity calculation (PCA, 2002) for the concrete at the anchor bolts.
3. The 7- and 28-day compressive strengths are based on companion cylinders that were continuously cured at 100% relative humidity and 23±2°C (73±3°F).

Because the compressive strength of the concrete was low, the concrete surrounding the uninsulated anchor bolts in the 4- and 6-in. walls would likely have sustained permanent compressive strength reductions due to premature freezing. This is because the concrete did not achieve a compressive strength of at least 3.5 MPa (500 psi) before it began to freeze. Insulating the anchor bolt in the 6-in. wall is anticipated to sufficiently prevent permanent damage to the concrete. Even if the concrete compressive strength was as ordered, the concrete at the uninsulated anchor bolts in the 4-in. wall would not have had sufficient compressive strength prior to freezing.

Configuration 3 – On a Frozen Footing

This configuration was designed to represent a 6-in. ICF wall being placed on a frozen footing. The perimeter side and top surfaces of the wall that were not in contact with the footing were super-insulated, as described above. The footing was 460 mm (18 in.) wide by 150 mm (6 in.) deep. Both the concrete footing and the ICF forms were preconditioned for approximately 18 hours at a nominal temperature of -18°C (0°F) prior to placement of the ICF concrete. At the time of placement, the average temperature in the footing was approximately -4°C (25°F).

Thermocouples were located in the footing, at the interface between the footing and ICF concrete, and at 150 mm, 300 mm, 460 mm, and 610 mm (6, 12, 18, and 24 in., respectively) above the top of the footing. Several of the thermocouples, including those in the footing and at the interface between the footing and ICF concrete were damaged during or after the concrete placement.

Figure 9 presents the measured concrete temperatures. The average air temperature for the period shown in the figure was approximately -19°C (-2°F). The damaged thermocouple at the interface between the footing and ICF concrete of the footing indicated a temperature of 0°C (32°F) before failing. This suggests that the footing immediately froze the liquid water in the fresh concrete at the interface between the ICF and the footing. This will result in a layer of frozen concrete at the base of the wall that will compromises its structural integrity.

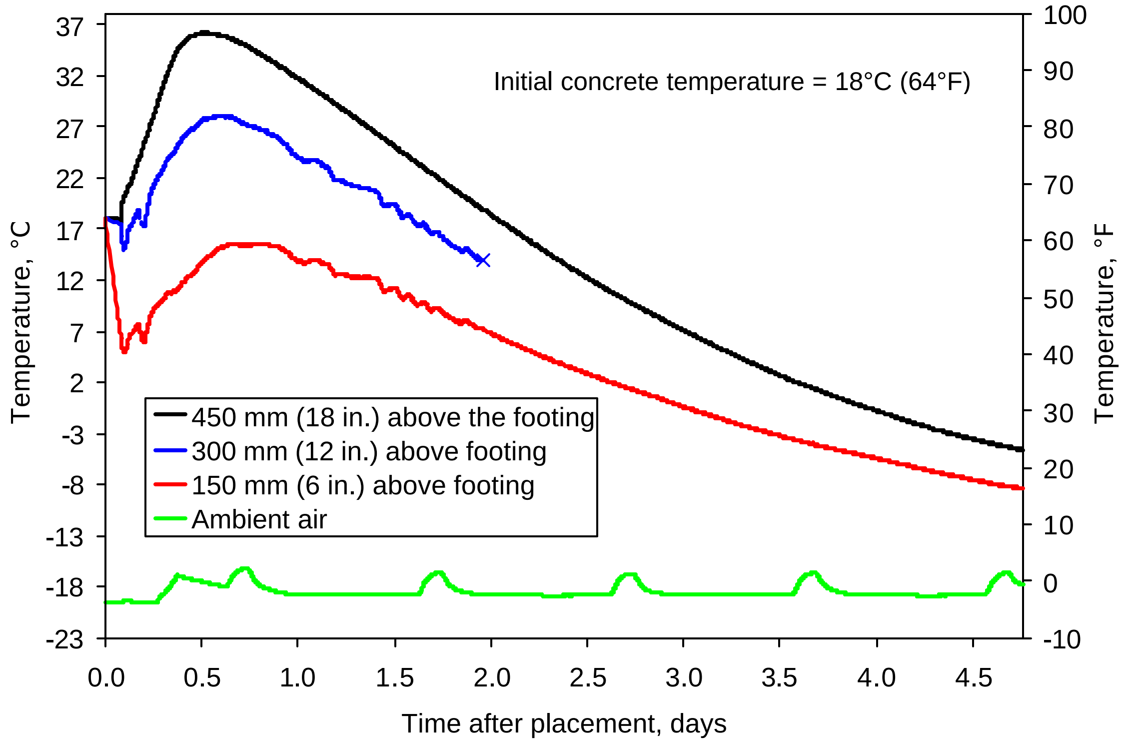

Figure 9. Recorded temperatures for the "on a frozen footing" configuration.

Compressive strengths were measured as previously described, and are presented in Table 3. As can be seen, the concrete had 7- and 28-day laboratory-cured compressive strengths that were significantly higher than ordered. The compressive strength specimens in the wall were located at the bottom of the wall, in contact with the footing. At the time of freezing, the concrete compressive strength was approximately 69% that of the 28-day compressive strength.

Based on the recorded temperatures at 150 mm (6 in.) above the top of the footing, the compressive strength at this location was estimated using the maturity method to be approximately half that of the measured compressive strength. The estimated compressive strength is also presented in Table 3.

Table 3. Compressive Strength of Concrete Utilized in the "On a Frozen Footing" Configuration

Wall	**Average compressive strength, MPa (psi)**			
	At freezing		**7-day**[3]	**28-day**[3]
	Measured[1]	Estimated[2]		
6-in.	34.7 (5030)	16.8 (2430)	43.3 (6280)	50.3 (7290)

1. Cylinders were cast inside walls and were removed and tested after the concrete in the walls started to freeze.
2. Estimated based on temperature data recorded at the location of the cylinders cast into the wall.
3. The 7- and 28-day compressive strengths are based on companion cylinders that were continuously cured at 100% relative humidity and 23±2°C (73±3°F).

RESULTS FOR OTHER CONDITIONS

Thermal modeling was performed to extrapolate results to a variety of placement conditions and to determine cases where freezing of concrete is predicted to occur. The modeling utilized proprietary multidimensional finite-difference software to determine concrete temperatures and estimated compressive strength based on maturity at various times after placement.

For the modeling, a 28-day concrete compressive strength of 25 MPa (3500 psi) was assumed. This is approximately 16% higher than the required compressive strength referenced by most ICF manufacturers, but is somewhat representative of the average compressive strength that is supplied when a 20 MPa (3000 psi) concrete is required.

A maturity function was developed for this compressive strength based on typical concrete compressive strength development at various temperatures (PCA, 2002). The maturity function is used to estimate the concrete compressive strength from the concrete temperature.

The thermal model was compared to results of the "center of wall" configuration for validation purposes. The predicted temperatures were within a few degrees of the measured temperatures, and estimated compressive strengths were slightly lower than measured.

The potential to reach a critical compressive strength of 3.5 MPa (500 psi) before freezing was modeled for a variety of concrete mix designs, average air temperatures, initial concrete temperatures, ICF form R-values, two ICF wall thicknesses, at a variety of critical locations in a typical structure with ICF walls.

Concrete mixes were assumed to contain either 230, 280, 330, or 390 kg/m^3 (380, 470, 560, or 660 pcy, respectively) of a typical Type I/II cement. Average outdoor air temperatures were assumed to range from 4 to -30°C (40 to -20°F). Initial concrete temperatures were assumed to range from 21 to 4°C (70 to 40°F). ICF R-values (each layer of polystyrene) were assumed to range from 0.7 to 1.8 $K{\cdot}m^2/W$ (4 to 10 $ft^2{\cdot}°F{\cdot}hr/Btu$). Analyses were performed for 4- and 6-in. flat panel ICFs.

Table 4 summarizes the information presented in Tables 5 through 13. Each of these tables are presented in pairs: one in SI units (identified by the suffix "A" after the table number) and one in U.S. customary units (identified by the suffix "B" after the table number). The SI-unit tables are presented first. In the tables, "OK" indicates conditions where the concrete is predicted to achieve sufficient strength, that is a compressive strength of 3.5 MPa (500 psi), before freezing. The symbol "Fr" means that the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed in these conditions, because the ultimate compressive strength will likely be seriously affected. The summary information in Table 4 is specific to flat panel ICFs with a minimum of 50 mm (2 in.) expanded polystyrene on each side of the concrete core and exposed perimeter surfaces covered with R_{SI}-0.4 (R-2) insulation. However, since these two tables represent a worse-case scenario, meeting the requirements of these tables will result in meeting the requirements of the other tables. See Tables 5 through 13 for additional information or for other placement situations

Tables 5 and 6 present the freezing potential for the 4- and 6-in. flat panel ICF walls, respectively, at locations away from corners, edges, and penetrations. The portion of the walls represented by these tables are identical to the “clear wall” configuration described above.

Table 7 presents the freezing potential for the 4- and 6-in. flat panel ICF walls at a 38-mm (2-in.) thick wood buck with uninsulated steel anchor bolts. If anchor bolts are not present, or bolts are insulated, Tables 8 and 9 should be utilized. These calculations are specific to ICFs with a minimum of 38 mm (2 in.) of expanded polystyrene—equivalent to an R-value of 1.4 $K \cdot m^2/W$ (8 $ft^2 \cdot °F \cdot hr/Btu$)—on each side of the concrete core. The “edge insulation” in Tables 8 and 9 refers to the R-value of the added insulation temporarily installed over the anchor bolt and wood buck that isolates it from the air. See the footnote on page 4 for typical materials that can be used.

Tables 10 and 11 present results for 90-degree corners in the ICF walls. As can be seen, results are similar to those of the “clear wall” areas, as presented in Tables 5 and 6.

Tables 12 and 13 present results for a lintel above a door or window buck. The lintel was 300 mm (12 in.) high, and had wood or insulation over the exposed concrete surfaces. Lintels typically have a greater volume ratio of reinforcing steel than in other areas of the wall.

Results can be interpolated within and between the tables. The most common interpolation is anticipated to be related to the concrete mix design. Concrete mixes with fly ash and slag will likely have lower early age concrete strengths and may be more susceptible to freezing damage. If these materials are present in a concrete mix, it is conservative to consider only the quantity of Type I/II cement when using these tables.

Table 4A. Summary Freezing Potential of Flat Panel ICFs for all Locations (SI Units)*

Temperature, °C		230 kg/m³†		280 kg/m³†		330 kg/m³†		390 kg/m³†	
Air, average	Concrete, initial‡	ICF wall size		ICF wall size		ICF wall size		ICF wall size	
		"4-in."	"6-in."	"4-in."	"6-in."	"4-in."	"6-in."	"4-in."	"6-in."
4	21	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK
-1	21	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK
-7	21	Fr	OK	OK	OK	OK	OK	OK	OK
	16	Fr	Fr	Fr	OK	OK	OK	OK	OK
	10	Fr	Fr	Fr	OK	Fr	OK	OK	OK
	4	Fr	Fr	Fr	Fr	Fr	OK	OK	OK
-12	21	Fr	Fr	Fr	Fr	Fr	OK	OK	OK
	16	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK
	10	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
-18	21	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	16	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	10	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
-23	21	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	16	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	10	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
-29	21	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	16	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	10	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr

*This table summarizes information presented in Tables 5A through13A, and it is specific to flat panel ICFs with a minimum of 50 mm expanded polystyrene on each side of the concrete core and exposed perimeter surfaces covered with R_{SI}-0.4 insulation. See Tables 5A to 13A for additional information or for other placement situations. In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.
†Indicates the quantity of Type I/II cement per cubic meter of concrete.
‡Indicates the concrete temperature as placed in the ICFs.

Table 5A. Freezing Potential for "4-in." Flat Panel ICF Walls at "Clear Wall" Locations (SI Units)[*]

Temperature, °C		230 kg/m³ [†]				280 kg/m³ [†]				330 kg/m³ [†]				390 kg/m³ [†]			
Air, average	Concrete, initial[‡]	ICF R_{SI}-value				ICF R_{SI}-value				ICF R_{SI}-value				ICF R_{SI}-value			
		1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5
4	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-1	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-7	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-12	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-18	21	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	4	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
-23	21	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	16	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	10	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	4	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
-29	21	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	16	Fr	Fr	OK	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	10	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK
	4	Fr	Fr	Fr	OK	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK

[*] In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

[†] Indicates the quantity of Type I/II cement per cubic meter of concrete.

[‡] Indicates the concrete temperature as placed in the ICFs.

Table 6A. Freezing Potential for "6-in." Flat Panel ICF Walls at "Clear Wall" Locations (SI Units)*

Temperature, °C		230 kg/m^3†				280 kg/m^3†				330 kg/m^3†				390 kg/m^3†			
Air, average	Concrete, initial‡	ICF R_{SI}-value				ICF R_{SI}-value				ICF R_{SI}-value				ICF R_{SI}-value			
		1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5
4	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-1	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-7	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-12	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-18	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-23	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-29	21	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	4	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK

*In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

†Indicates the quantity of Type I/II cement per cubic meter of concrete.

‡Indicates the concrete temperature as placed in the ICFs.

Table 7A. Freezing Potential of Flat Panel ICFs at a Wood Buck with Uninsulated Anchor Bolts (SI Units)*

Temperature, °C		230 kg/m³†		280 kg/m³†		330 kg/m³†		390 kg/m³†	
Air, average	Concrete, initial‡	ICF wall size		ICF wall size		ICF wall size		ICF wall size	
		"4-in."	"6-in."	"4-in."	"6-in."	"4-in."	"6-in."	"4-in."	"6-in."
4	21	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK
-1	21	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK
-7	21	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK
	4	Fr	OK	OK	OK	OK	OK	OK	OK
-12	21	Fr	OK	Fr	OK	OK	OK	OK	OK
	16	Fr	OK	Fr	OK	Fr	OK	OK	OK
	10	Fr	OK	Fr	OK	Fr	OK	OK	OK
	4	Fr	Fr	Fr	OK	Fr	OK	Fr	OK
-18	21	Fr	OK	Fr	OK	Fr	OK	Fr	OK
	16	Fr	Fr	Fr	OK	Fr	OK	Fr	OK
	10	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
-23	21	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK
	16	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	10	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
-29	21	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	16	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	10	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr

*In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

†Indicates the quantity of Type I/II cement per cubic meter of concrete.

‡Indicates the concrete temperature as placed in the ICFs.

Table 8A. Freezing Potential of a 100-mm Flat Panel ICF at an Insulated Edge (SI Units)*

Temperature, °C		230 kg/m^{3}†			280 kg/m^{3}†			330 kg/m^{3}†			390 kg/m^{3}†		
Air, average	Concrete, initial‡	Added insulation, R_{SI}-value§			Added insulation, R_{SI}-value§			Added insulation, R_{SI}-value§			Added insulation, R_{SI}-value§		
		0.4	0.7	1.1	0.4	0.7	1.1	0.4	0.7	1.1	0.4	0.7	1.1
4	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-1	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-7	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-12	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-18	21	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	4	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	OK	OK	OK
-23	21	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	10	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK
-29	21	Fr	Fr	Fr	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	16	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	OK	Fr	OK	OK
	10	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK

*In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

†Indicates the quantity of Type I/II cement per cubic meter of concrete.

‡Indicates the concrete temperature as placed in the ICFs.

§Additional insulation covering the steel anchor bolt and the wood buck as described in the text. These results are based on the addition of insulation to an ICF with an R_{SI}-2.8 K·m^{2}/W.

Table 9A. Freezing Potential of a 150-mm Flat Panel ICF at an Insulated Edge (SI Units)[*]

Temperature, °C		230 kg/m^3[†]			280 kg/m^3[†]			330 kg/m^3[†]			390 kg/m^3[†]		
Air, average	Concrete, initial[‡]	Added insulation, R_{SI}-value[§]			Added insulation, R_{SI}-value[§]			Added insulation, R_{SI}-value[§]			Added insulation, R_{SI}-value[§]		
		0.4	0.7	1.1	0.4	0.7	1.1	0.4	0.7	1.1	0.4	0.7	1.1
4	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-1	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-7	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-12	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-18	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
-23	21	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	4	Fr	Fr	Fr	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
-29	21	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	10	Fr	Fr	Fr	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	4	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK

[*]In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

[†]Indicates the quantity of Type I/II cement per cubic meter of concrete.

[‡]Indicates the concrete temperature as placed in the ICFs.

[§]Additional insulation covering the steel anchor bolt and the wood buck as described in the text. These results are based on the addition of insulation to an ICF with an R_{SI}-2.8 K·m^2/W.

Table 10A. Freezing Potential for 100-mm Flat Panel ICF Walls at a Corner (SI Units)*

Temperature, °C		230 kg/m³†				280 kg/m³†				330 kg/m³†				390 kg/m³†			
Air, average	Concrete, initial‡	ICF R_{SI}-value				ICF R_{SI}-value				ICF R_{SI}-value				ICF R_{SI}-value			
		1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5
4	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-1	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-7	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-12	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-18	21	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	4	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
-23	21	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	16	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	10	Fr	Fr	OK	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	4	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
-29	21	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	16	Fr	Fr	OK	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	10	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	Fr	OK	OK

*In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while " Fr " indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for " Fr " will occur.

†Indicates the quantity of Type I/II cement per cubic meter of concrete.

‡Indicates the concrete temperature as placed in the ICFs.

Table 11A. Freezing Potential for "6-in." Flat Panel ICF Walls at a Corner (SI Units)*

Temperature, °C		230 kg/m^3†				280 kg/m^3†				330 kg/m^3†				390 kg/m^3†			
Air, average	Concrete, initial‡	ICF R_{SI}-value				ICF R_{SI}-value				ICF R_{SI}-value				ICF R_{SI}-value			
		1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5	1.4	2.1	2.8	3.5
4	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-1	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-7	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-12	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-18	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-23	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
-29	21	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	4	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK

*In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.
†Indicates the quantity of Type I/II cement per cubic meter of concrete.
‡Indicates the concrete temperature as placed in the ICFs.

Table 12A. Freezing Potential of "4-in." Flat Panel ICFs at a Lintel (SI Units)[*]

Temperature, °C		230 kg/m^3[†]			280 kg/m^3[†]			330 kg/m^3[†]			390 kg/m^3[†]		
Air, average	Concrete, initial[‡]	Added insulation, R_{SI}-value[§]			Added insulation, R_{SI}-value[§]			Added insulation, R_{SI}-value[§]			Added insulation, R_{SI}-value[§]		
		0.4	0.7	1.1	0.4	0.7	1.1	0.4	0.7	1.1	0.4	0.7	1.1
4	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-1	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-7	21	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	4	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
-12	21	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	16	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	10	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK
-18	21	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	16	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	10	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
-23	21	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK	Fr	OK	OK
	16	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK
	10	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
-29	21	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	16	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	10	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr

[*]In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while " Fr " indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for " Fr " will occur.

[†]Indicates the quantity of Type I/II cement per cubic meter of concrete.

[‡]Indicates the concrete temperature as placed in the ICFs.

[§]Additional insulation covering the steel anchor bolt and the wood buck as described in the text. These results are based on the addition of insulation to an ICF with an R_{SI}-2.8 K·m^2/W.

Table 13A. Freezing Potential of "6-in." Flat Panel ICFs at a Lintel (SI Units)[*]

Temperature, °C		230 kg/m^3[†]			280 kg/m^3[†]			330 kg/m^3[†]			390 kg/m^3[†]		
Air, average	Concrete, initial[‡]	Added insulation, R_{SI}-value[§]			Added insulation, R_{SI}-value[§]			Added insulation, R_{SI}-value[§]			Added insulation, R_{SI}-value[§]		
		0.4	0.7	1.1	0.4	0.7	1.1	0.4	0.7	1.1	0.4	0.7	1.1
4	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-1	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-7	21	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	4	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
-12	21	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	16	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	10	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	4	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
-18	21	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	16	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	10	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	4	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
-23	21	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	16	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	10	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK	Fr	OK	OK
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK
-29	21	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	16	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK	Fr	OK	OK
	10	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK
	4	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK

[*]In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

[†]Indicates the quantity of Type I/II cement per cubic meter of concrete.

[‡]Indicates the concrete temperature as placed in the ICFs.

[§]Additional insulation covering the steel anchor bolt and the wood buck as described in the text. These results are based on the addition of insulation to an ICF with an R_{SI}-2.8 $K{\cdot}m^2/W$.

Table 4B. Summary Freezing Potential of Flat Panel ICFs for all Locations (U.S. Customary Units)*

Temperature, °F		380 pcy†		470 pcy†		560 pcy†		660 pcy†	
Air, average	Concrete, initial‡	ICF wall size		ICF wall size		ICF wall size		ICF wall size	
		4-in.	6-in.	4-in.	6-in.	4-in.	6-in.	4-in.	6-in.
40	70	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK
30	70	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK
20	70	Fr	OK	OK	OK	OK	OK	OK	OK
	60	Fr	Fr	Fr	OK	OK	OK	OK	OK
	50	Fr	Fr	Fr	OK	Fr	OK	OK	OK
	40	Fr	Fr	Fr	Fr	Fr	OK	OK	OK
10	70	Fr	Fr	Fr	Fr	Fr	OK	OK	OK
	60	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK
	50	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
0	70	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	60	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	50	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
-10	70	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	60	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	50	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
-20	70	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	60	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	50	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr

*This table summarizes information presented in Tables 5A through13A, and it is specific to flat panel ICFs with a minimum of 2 in. expanded polystyrene on each side of the concrete core and exposed perimeter surfaces covered with R-2 insulation. See Tables 5A to 13A for additional information or for other placement situations. In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

†Indicates the quantity of Type I/II cement per cubic yard of concrete.

‡Indicates the concrete temperature as placed in the ICFs.

Table 5B. Freezing Potential for 4-in. Flat Panel ICF Walls at “Clear Wall” Locations (U.S. Customary Units)*

Temperature, °F		380 pcy†				470 pcy†				560 pcy†				660 pcy†			
Air, average	Concrete, initial‡	ICF R-value				ICF R-value				ICF R-value				ICF R-value			
		8	12	16	20	8	12	16	20	8	12	16	20	8	12	16	20
40	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
30	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
20	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
10	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
0	70	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	40	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
-10	70	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	60	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	50	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	40	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
-20	70	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	60	Fr	Fr	OK	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	50	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK
	40	Fr	Fr	Fr	OK	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK

*In the body of the table ”OK” indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while “Fr” indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for “Fr” will occur.

†Indicates the quantity of Type I/II cement per cubic yard of concrete.

‡Indicates the concrete temperature as placed in the ICFs.

Table 6B. Freezing Potential for 6-in. Flat Panel ICF Walls at "Clear Wall" Locations (U.S. Customary Units)*

Temperature, °F		380 pcy†				470 pcy†				560 pcy†				660 pcy†			
Air, average	Concrete, initial‡	ICF R-value				ICF R-value				ICF R-value				ICF R-value			
		8	12	16	20	8	12	16	20	8	12	16	20	8	12	16	20
40	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
30	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
20	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
10	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
0	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-10	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-20	70	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	40	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK

*In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while " Fr " indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for " Fr " will occur.

†Indicates the quantity of Type I/II cement per cubic yard of concrete.

‡Indicates the concrete temperature as placed in the ICFs.

Table 7B. Freezing Potential of Flat Panel ICFs at a Wood Buck with Uninsulated Anchor Bolts (U.S. Customary Units)[*]

Temperature, °F		380 pcy[†]		470 pcy[†]		560 pcy[†]		660 pcy[†]	
Air, average	Concrete, initial[‡]	ICF wall size		ICF wall size		ICF wall size		ICF wall size	
		4-in.	6-in.	4-in.	6-in.	4-in.	6-in.	4-in.	6-in.
40	70	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK
30	70	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK
20	70	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK
	40	Fr	OK	OK	OK	OK	OK	OK	OK
10	70	Fr	OK	Fr	OK	OK	OK	OK	OK
	60	Fr	OK	Fr	OK	Fr	OK	OK	OK
	50	Fr	OK	Fr	OK	Fr	OK	OK	OK
	40	Fr	Fr	Fr	OK	Fr	OK	Fr	OK
0	70	Fr	OK	Fr	OK	Fr	OK	Fr	OK
	60	Fr	Fr	Fr	OK	Fr	OK	Fr	OK
	50	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
-10	70	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK
	60	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	50	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
-20	70	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	60	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	50	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr

[*] In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

[†] Indicates the quantity of Type I/II cement per cubic yard of concrete.

[‡] Indicates the concrete temperature as placed in the ICFs.

Table 8B. Freezing Potential of a 4-in. Flat Panel ICF at an Insulated Edge (U.S. Customary Units)[*]

Temperature, °F		380 pcy[†]			470 pcy[†]			560 pcy[†]			660 pcy[†]		
Air, average	Concrete, initial[‡]	Added insulation, R-value[§]			Added insulation, R-value[§]			Added insulation, R-value[§]			Added insulation, R-value[§]		
		2	4	6	2	4	6	2	4	6	2	4	6
40	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
30	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
20	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
10	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
0	70	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	40	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	OK	OK	OK
-10	70	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	50	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK
-20	70	Fr	Fr	Fr	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	60	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	OK	Fr	OK	OK
	50	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK

[*]In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates conditions where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

[†]Indicates the quantity of Type I/II cement per cubic yard of concrete.

[‡]Indicates the concrete temperature as placed in the ICFs.

[§]Additional insulation covering the steel anchor bolt and the wood buck as described in the text. These results are based on the addition of insulation to an ICF with R-16.

Table 9B. Freezing Potential of a 6-in. Flat Panel ICF at an Insulated Edge (U.S. Customary Units)*§

Temperature, °F		380 pcy†			470 pcy†			560 pcy†			660 pcy†		
Air, average	Concrete, initial‡	Added insulation, R-value§			Added insulation, R-value§			Added insulation, R-value§			Added insulation, R-value§		
		2	4	6	2	4	6	2	4	6	2	4	6
40	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
30	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
20	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
10	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
0	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
-10	70	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	40	Fr	Fr	Fr	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
-20	70	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	50	Fr	Fr	Fr	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	40	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK

*In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates condition where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

†Indicates the quantity of Type I/II cement per cubic yard of concrete.

‡Indicates the concrete temperature as placed in the ICFs.

§ Additional insulation covering the steel anchor bolt and the wood buck as described in the text. These results are based on the addition of insulation to an ICF with R-16.

Table 10B. Freezing Potential for 4-in. Flat Panel ICF Walls at a Corner (U.S. Customary Units)*

Temperature, °F		380 pcy†				470 pcy†				560 pcy†				660 pcy†			
Air, average	Concrete, initial‡	ICF R-value				ICF R-value				ICF R-value				ICF R-value			
		8	12	16	20	8	12	16	20	8	12	16	20	8	12	16	20
40	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
30	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
20	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
10	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
0	70	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	40	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
-10	70	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	60	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	50	Fr	Fr	OK	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	40	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
-20	70	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	60	Fr	Fr	OK	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK
	50	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	Fr	OK	OK	Fr	OK	OK	OK
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK	OK	Fr	Fr	OK	OK

*In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while " Fr " indicates condition where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for " Fr " will occur.

†Indicates the quantity of Type I/II cement per cubic yard of concrete.

‡Indicates the concrete temperature as placed in the ICFs.

Table 11B. Freezing Potential for 6-in. Flat Panel ICF Walls at a Corner (U.S. Customary Units)*

Temperature, °F		380 pcy†				470 pcy†				560 pcy†				660 pcy†			
Air, average	**Concrete, initial‡**	**ICF R-value**				**ICF R-value**				**ICF R-value**				**ICF R-value**			
		8	**12**	**16**	**20**	**8**	**12**	**16**	**20**	**8**	**12**	**16**	**20**	**8**	**12**	**16**	**20**
40	**70**	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
30	**70**	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
20	**70**	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
10	**70**	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
0	**70**	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
-10	**70**	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
-20	**70**	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK
	40	Fr	Fr	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK	Fr	OK	OK	OK

*In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates condition where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

†Indicates the quantity of Type I/II cement per cubic yard of concrete.

‡Indicates the concrete temperature as placed in the ICFs.

Table 12B. Freezing Potential of 4-in. Flat Panel ICFs at a Lintel (U.S. Customary Units)*

Temperature, °F		380 pcy†			470 pcy†			560 pcy†			660 pcy†		
Air, average	Concrete, initial‡	Added insulation, R-value§			Added insulation, R-value§			Added insulation, R-value§			Added insulation, R-value§		
		2	4	6	2	4	6	2	4	6	2	4	6
40	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
30	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
20	70	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	40	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
10	70	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	60	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	50	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK
0	70	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	60	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	50	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
-10	70	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK	Fr	OK	OK
	60	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK
	50	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
-20	70	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK
	60	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	50	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr

*In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while "Fr" indicates condition where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for "Fr" will occur.

†Indicates the quantity of Type I/II cement per cubic yard of concrete.

‡Indicates the concrete temperature as placed in the ICFs.

§Additional insulation covering the steel anchor bolt and the wood buck as described in the text. These results are based on the addition of insulation to an ICF with R-16.

Table 13B. Freezing Potential of 6-in. Flat Panel ICFs at a Lintel (U.S. Customary Units)[*]

Temperature, °F		380 pcy[†]			470 pcy[†]			560 pcy[†]			660 pcy[†]		
Air, average	Concrete, initial[‡]	Added insulation, R-value[§]			Added insulation, R-value[§]			Added insulation, R-value[§]			Added insulation, R-value[§]		
		2	4	6	2	4	6	2	4	6	2	4	6
40	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
30	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
20	70	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	40	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
10	70	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	60	Fr	OK	OK	Fr	OK	OK	OK	OK	OK	OK	OK	OK
	50	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	40	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
0	70	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK	OK	OK	OK
	60	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	50	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	40	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
-10	70	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK	Fr	OK	OK
	60	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	50	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK	Fr	OK	OK
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK
-20	70	Fr	Fr	Fr	Fr	Fr	OK	Fr	OK	OK	Fr	OK	OK
	60	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK	Fr	OK	OK
	50	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK	Fr	Fr	OK
	40	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	Fr	OK

[*]In the body of the table "OK" indicates conditions where the concrete is predicted to achieve sufficient strength before freezing, while " Fr " indicates condition where the concrete is predicted to freeze before reaching the required critical strength. Concrete should not be placed if the conditions for " Fr " will occur.

[†]Indicates the quantity of Type I/II cement per cubic yard of concrete.

[‡]Indicates the concrete temperature as placed in the ICFs.

[§]Additional insulation covering the steel anchor bolt and the wood buck as described in the text. These results are based on the addition of insulation to an ICF with R-16.

SUMMARY AND CONCLUSIONS

Concrete construction during cold-weather conditions requires special considerations to ensure that concrete achieves a minimum critical strength prior to freezing. Work by others indicates that if concrete freezes prior to reaching a compressive strength of 3.5 MPa (500 psi), ultimate strength reductions of up to 50% can occur. Similar work has also shown that after the concrete reaches this critical strength, the length of time or (lowest) temperature at which the concrete is frozen has no effect on the compressive strength after it thaws.

Concrete walls can be constructed in all seasons with reusable formwork, however, during cold weather, measures required to prevent freezing can greatly increase the cost and time of construction. This places significant practical limits on the length of the residential construction season. To keep production crews busy through the winter, large builders often excavate and place many foundations before freezing weather occurs. This results in a large capital expenditure or excessive number of "spec" homes for the builders.

Due to their inherent insulating capacity, insulating concrete forms (ICFs) offer the ability to safely construct concrete walls at temperatures below that of concrete walls cast in reusable forms. This ability extends the construction season, potentially extending it into the coldest periods of winter. However, due to a lack of available information, some building code officials and others often require that ICF walls be constructed utilizing the typical cold-weather concrete practices that were developed for concrete walls cast in reusable forms. This can result in unnecessary construction costs and delays.

To determine the lowest temperature at which ICF walls can be constructed, a series of ICF walls were constructed and monitored during sub-freezing conditions. Walls were constructed to simulate conditions at various locations in a typical residential wall, such as at the center of a wall, at a window or door penetration, and on a frozen footing.

Data collected from testing of the "clear wall" areas indicated that concrete can be placed without special precautions to prevent freezing damage at temperatures much lower than that allowed for concrete walls cast in reusable forms. Results of testing of the concrete in an area "adjacent to a wood buck" indicated that exposed steel anchor bolts needed to be insulated to prevent freezing damage to the concrete. Data collected for ICF concrete placed on a frozen footing were somewhat contradictory. Measured compressive strengths were acceptable, however, recorded temperatures indicated that concrete in direct contact with the frozen footing prematurely froze, thus damaging the concrete.

Data from the monitoring of walls were used to validate computer models. Results were extrapolated with the computer models to a wide variety of placement conditions that considered initial concrete temperatures as low as 4°C (40°F), air temperatures as low as -30°C (-20°F) and four typical concrete mix designs. A variety of areas in a typical building with ICF walls were modeled. These areas included the "clear wall" area, an area adjacent to a wood buck with exposed steel anchor bolts, an identical area where the anchor bolts and wood buck were insulated, corners of ICF walls, and a typical lintel.

In general, results indicated that concrete can be placed in ICF walls at temperatures much lower than that allowed for concrete walls cast in reusable forms. In some cases, depending on the air temperature, concrete temperature, and location in a wall, some special precautions and restrictions will be required. See the tables above for details.

Concrete should not be placed on a frozen footing. Because the volume of ICF concrete that is in direct contact with the footing is much less than the volume of the footing, the footing will freeze the fresh ICF concrete, thus compromising the structural integrity of the wall. Footings and the protruding reinforcing steel should be kept above freezing, and the surface of the footing should be insulated as with concrete walls cast in reusable forms. This insulation may be required for an extended period of time because concrete develops strength considerably slower at low temperatures.

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