Technical Brief

ASHRAE 90.1 energy codes and accurate R-value determination for precast wall panels

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Determining the R-value of a precast concrete insulated wall system is not only imperative to meet code, it is essential information for calculating the correct size of the HVAC system and predicting annual energy expenditures.

The overall compliance of a building design with the energy codes is beyond the control or responsibility of the precast concrete manufacturer, but the insulated precast concrete wall is an integral component of the system. They rely on the figures presented by the precaster based on how the panel is to be engineered and fabricated. The primary factors determining R-value—the depth of the insulation, the thermal transfer properties of wythe connectors and the presence of solid zones—are not visible in a completed wall panel.

The codes can be complicated and are constantly being updated. And new exterior wall technologies and complex designs and fenestrations can make it challenging to ascertain performance.

This brief will assist you in determining the R-value of a precast insulated wall panel by helping you understand how the various components influence thermal performance and what questions to ask precast concrete manufacturers to ensure they are using the proper, most accurate formulas and meeting code requirements in the design and manufacturing process.

Which codes should I use?

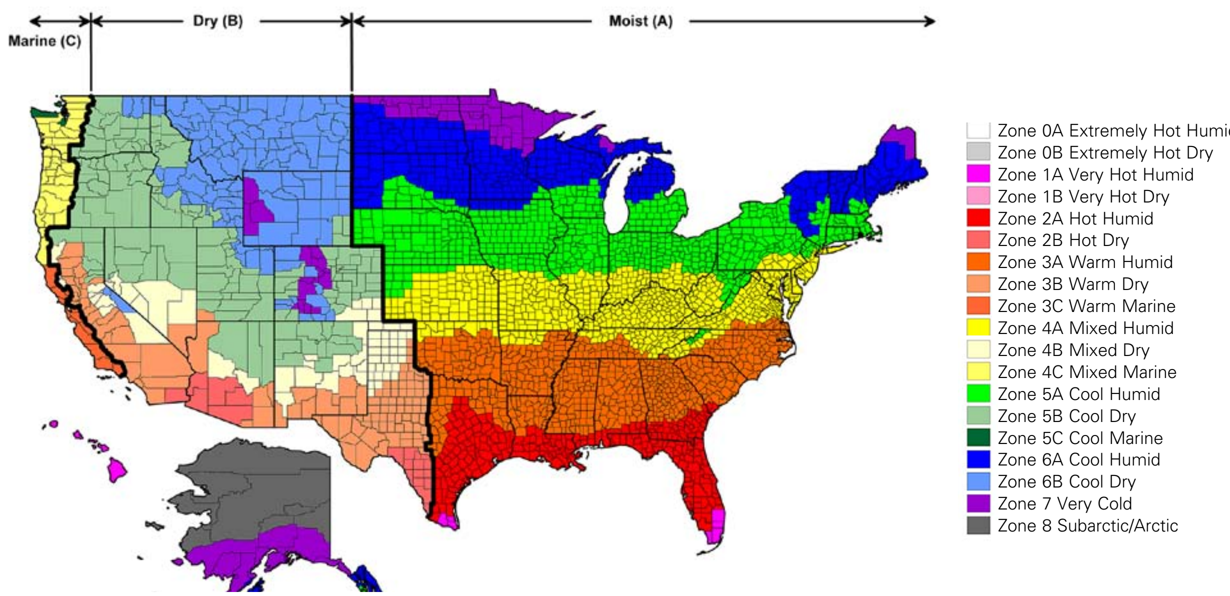
While building codes vary across jurisdictions, the current (most often used) standard is **2012/2015 IBC—[A] 101.4.6 Energy.** It states:

> The provisions of the International Energy Conservation Code shall apply to all matters governing the design and construction of buildings for energy efficiency. The International Energy Conservation Code® (IECC®) contains provisions for the efficient use of energy in buildings by regulating the design of building envelopes for thermal resistance and low air leakage, and the design and selection of mechanical systems for effective use of energy.
>
> The IECC® is adopted by reference in this section, as well as other sections in this code, as the enforceable document for regulating these systems.

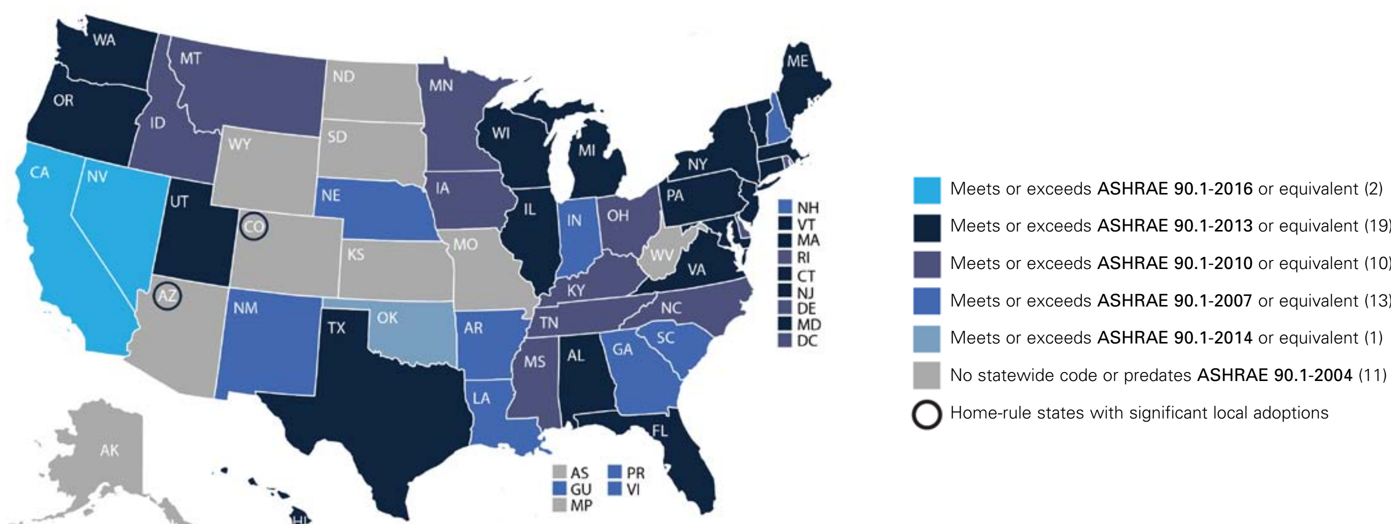
Further, **2012/2015 IBC [E] 1301.1.1 Criteria** confirms that "buildings shall be designed and constructed in accordance with the International Energy Conservation Code." The process flow for compliance is outlined below.

To start, determine the relevant code and climate zone where the project is located (figure 1). This will be used to determine the envelope requirements.

Figure 1 ASHRAE 90.1 Climate Zone Map and Statewide Commercial Energy Codes Map



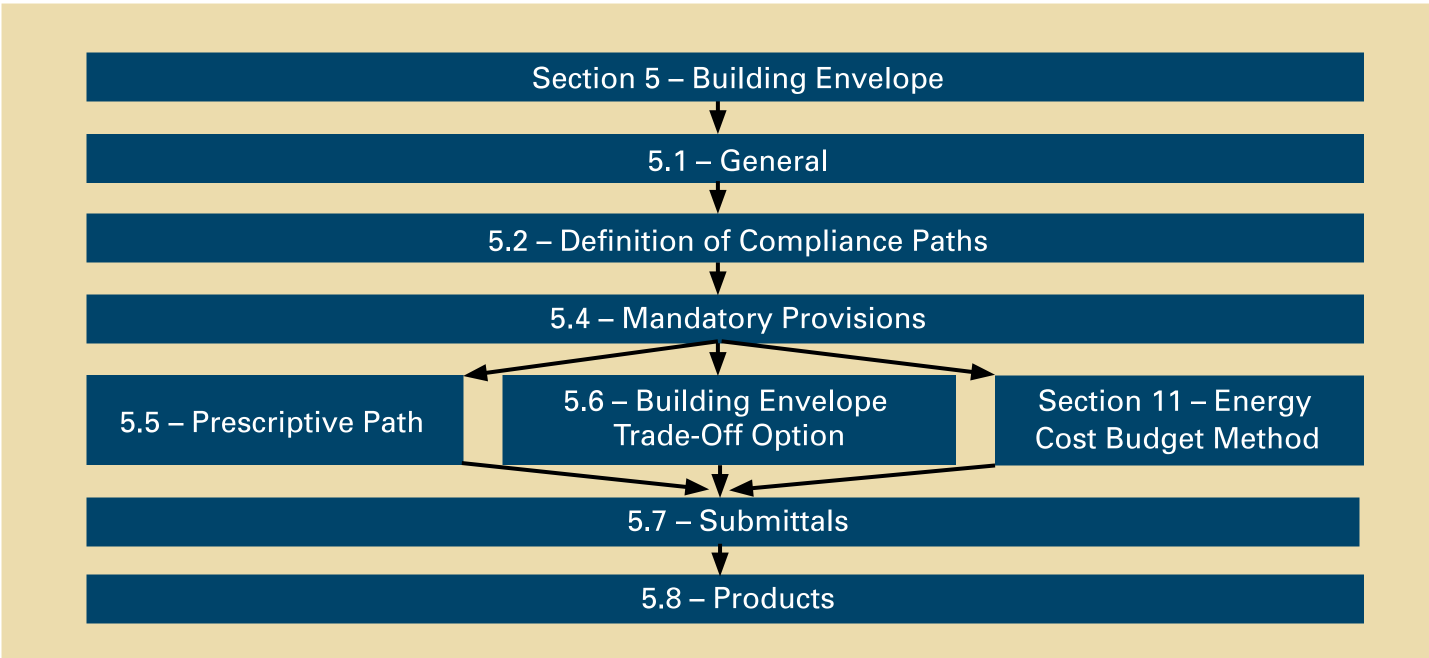
Current climate zone map as of 2015



Current effective statewide commercial energy codes map as of 2018

http://bcapcodes.org/code-status/commercial/

Figure 2 2012 IECC [C]401.2 Application



Then we'll look at **2012 IECC [C]401.2 Application**, which reads: Commercial buildings shall comply with one of the following: (2015 IECC has slightly different wording).

1. The requirements of ANSI/ASHRAE/IESNA 90.1.
2. The requirements of IECC Sections C402, C403, C404 and C405. In addition, commercial buildings shall comply with either Section C406.2, C406.3 or C406.4.
3. The requirements of IECC Section C407, C402.4, C403.2, C404, C405.2, C405.3, C405.4, C405.6 and C405.7. The building energy cost shall be equal to or less than 85 percent of the standard reference design building.

Moving from top to bottom (see figure 2 above), the relevant portions of section 5.4 (mandatory provisions) reads:

5.4.1 Insulation. Where insulation is required in Section 5.5 or 5.6, it shall comply with the requirements found in Sections 5.8.1.1 through 5.8.1.10.

5.4.3 Air Leakage … Precast concrete is an acceptable air barrier.

As you move to the next step of the process, you have one of three options.

The middle option (Building Envelope Trade-Off Option) reads: 5.6.1 The building envelope complies with the standard if:

a. the proposed building satisfies the provisions of Sections 5.1, 5.4, 5.7, and 5.8 and

b. the envelope performance factor of the proposed building is less than or equal to the envelope performance factor of the budget building.

Precasters may not have readily available information about other envelope components (like fenestrations, openings, doors, roofing, etc.) and how they may ultimately be integrated into the envelope at this stage of design and therefore may not be able to provide an accurate envelope performance factor.

The far right option in the chart (Energy cost budget method) reads:

11.1.1 Energy Cost Budget Method Scope. The building Energy Cost Budget Method is an alternative to the prescriptive provisions of this standard. It may be employed for evaluating the compliance of all proposed designs except designs with no mechanical system.

Again, precasters are supplying only a portion of the exterior wall and can provide information about their section of the envelope, which can be used in modeling.

Which leaves precasters with the far left option, the prescriptive approach, to assess the performance of the wall.

The Prescriptive Approach

The ASHRAE 90.1 requirement is to follow IECC Section 402 (Building Envelope Requirements) to assess the performance of insulated precast panels.

Section 5.5 (Prescriptive Building Envelope Option) reads: 5.5.1 For a conditioned space, the exterior building envelope shall comply with either the nonresidential or residential requirements in Tables 5.5-1 through 5.5-8 for the appropriate climate.

There are two methods of looking at the building thermal envelope; R-value and U-factor. (Remember that U-Factor is the reciprocal of R-value.)

In fact, subsection 5.3.1.2 (Above-Grade Wall Insulation) states: There are four classes of above-grade walls--mass walls, metal building walls, steel-framed walls, and wood and other walls. (Editor’s note: insulated precast panels fall into the "other" category and are considered mass walls.) Like roofs, the criteria for walls are expressed in two ways. First, minimum R-value criteria are given for the insulation alone. This is the easiest way to comply with the requirement. The alternative is to comply with the U-factor requirement for the overall assembly, including thermal bridges. The U-factor method must be used when one or more of the wall constructions in a class do not comply with the requirement and area-weighted averaging is necessary. The U-factor method may also be appropriate when a wall construction is significantly different from those used to generate the default U-factor tables in the Appendix.

U-value is preferred because you may not have the same insulation thickness throughout the panel. The insulation could be thinner at the edges. Some panel designs could feature a pilaster. Some are designed with solid zones. Or the wythe connectors could contain materials that might be a thermal bridge.

Table C402.1.2 Opaque Thermal Envelope Assembly Requirements[a]

CLIMATE ZONE	1		2		3		4 EXCEPT MARINE		5 AND MARINE 4		6		7		8	
	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R
Roofs																
Insulation entirely above deck	U-0.048	U-0.048	U-0.048	U-0.048	U-0.048	U-0.048	U-0.039	U-0.039	U-0.039	U-0.039	U-0.032	U-0.032	U-0.028	U-0.028	U-0.028	U-0.028
Metal buildings	U-0.044	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.031	U-0.031	U-0.029	U-0.029	U-0.029	U-0.029
Attic and other	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027	U-0.021	U-0.021	U-0.021	U-0.021	U-0.021	U-0.021	U-0.021
Walls, Above Grade																
Mass	U-0.142	U-0.142	U-0.142	U-0.123	U-0.110	U-0.104	U-0.104	U-0.090	U-0.078	U-0.078	U-0.078	U-0.071	U-0.061	U-0.061	U-0.061	U-0.061
Metal building	U-0.079	U-0.079	U-0.079	U-0.079	U-0.079	U-0.052	U-0.052	U-0.052	U-0.052	U-0.052	U-0.052	U-0.052	U-0.052	U-0.039	U-0.052	U-0.039
Metal framed	U-0.077	U-0.077	U-0.077	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.057	U-0.064	U-0.052	U-0.045	U-0.045
Wood framed and other	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.051	U-0.051	U-0.051	U-0.051	U-0.036	U-0.036
Walls, Below Grade																
Below-grade wall[b]	C-1.140	C-1.140	C-1.140	C-1.140	C-1.140	C-1.140	C-0.119	C-0.119	C-0.119	C-0.119	C-0.119	C-0.119	C-0.092	C-0.092	C-0.092	C-0.092
Floors																
Mass	U-0.322	U-0.322	U-0.107	U-0.087	U-0.076	U-0.076	U-0.076	U-0.074	U-0.074	U-0.064	U-0.064	U-0.057	U-0.055	U-0.051	U-0.055	U-0.051
Joist/framing	U-0.066	U-0.066	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033
Slab-on-Grade Floors																
Unheated slabs	F-0.73	F-0.73	F-0.73	F-0.73	F-0.73	F-0.73	F-0.54	F-0.54	F-0.54	F-0.54	F-0.54	F-0.52	F-0.40	F-0.40	F-0.40	F-0.40
Heated slabs	F-0.70	F-0.70	F-0.70	F-0.70	F-0.70	F-0.70	F-0.65	F-0.65	F-0.58	F-0.58	F-0.58	F-0.58	F-0.55	F-0.55	F-0.55	F-0.55

a. Use of opaque assembly *U*-factors, *C*-factors, and *F*-factors from ANSI/ASHRAE/IESNA 90.1 Appendix A shall be permitted, provided the construction complies with the applicable construction details from ANSI/ASHRAE/IESNA 90.1 Appendix A.

b. Where heated slabs are below grade, below-grade walls shall comply with the *F*-factor requirements for heated slabs.

The next step is **Normative Appendix A—Rated R-Value of Insulation and Assembly U-Factor, C-Factor, and F-Factor Determinations**

According to A1.1, the U-factors, C-factors, F-factors, and heat capacities for typical construction assemblies are included in Sections A2 through A8. And according to A1.2, if the building official determines that the proposed construction assembly is not adequately represented in Sections A2 through A8, the applicant must determine appropriate values for the assembly using the assumptions in Section A9. An assembly is deemed to be adequately represented if:

a. the interior structure, hereafter referred to as the base assembly, for the class of construction is the same as described in Sections A2 through A8 and

b. changes in exterior or interior surface building materials added to the base assembly do not increase or decrease the R-value by more than 2 from that indicated in the descriptions in Sections A2 through A8. (Insulation, including insulated sheathing, is not considered a building material.)

As noted earlier, insulated precast concrete walls are classified as above-grade walls (Section A3) and mass walls (Section A3.1). Specifically:

A3.1.1 General. For the purpose of Section A1.2, the base assembly is a masonry or concrete wall. Continuous insulation is installed on the interior or exterior or within the masonry units, or it is installed on the interior or exterior of the concrete … U-factors are provided for the following configurations:

a. Concrete wall 8 in. normal weight concrete wall with a density of 145 lb./ft3.

A3.1.2 Mass Wall Rated R-Value of Insulation

A3.1.2.4 Where rated R-value of insulation is used for concrete sandwich panels, the insulation shall be continuous throughout the entire panel.

A3.1.3 Mass Wall U-Factor

A3.1.3.1 U-factors for mass walls shall be taken from Table A3.1-1 or determined by the procedure in this subsection.

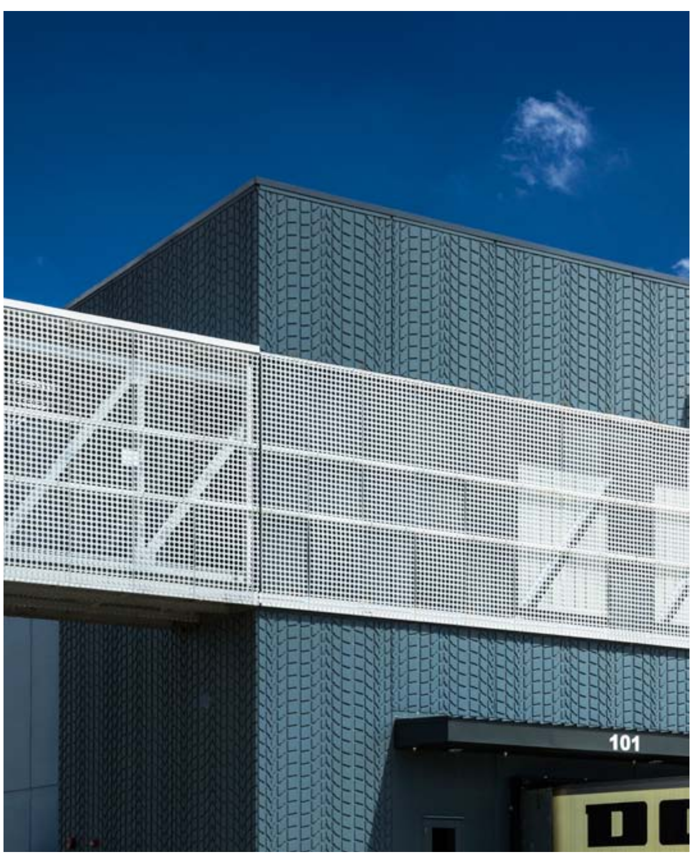
Based on the chart below—insulated precast panels can adequately be represented by the tables in section A3. Utilizing section A9, a modeling calculation, is NOT necessary.

Table A3.1-1 Assembly U-Factors for Above-Grade Concrete Walls and Masonry Walls

Framing Type and Depth	Rated R-Value of Insulation Alone	Assembly U-Factors for 8 in. Normal Weight 145 lb/ft^3 Solid Concrete Walls	Assembly U-Factors for 8 in. Medium Weight 115 lb/ft^3 Concrete Block Walls: Solid Grouted	Assembly U-Factors for 8 in. Medium Weight 115 lb/ft^3 Concrete Block Walls: Partially Grouted (Cores Uninsulated Except here specified)
No Framing	R-0	U-0.740	U-0.580	U-0.480
	Ungrouted Cores Filled with Loose-Fill Insulation	NA	NA	U-0.350
Continuous Insulation Uninterrupted by Framing				
No Framing	R-1.0	U-0.425	U-0.367	U-0.324
No Framing	R-2.0	U-0.298	U-0.269	U-0.245
No Framing	R-3.0 1" Insulation	U-0.230	U-0.212	U-0.197
No Framing	R-4.0	U-0.187	U-0.175	U-0.164
No Framing	R-5.0	U-0.157	U-0.149	U-0.141
No Framing	R-6.0	U-0.136	U-0.129	U-0.124
No Framing	R-7.0 2" Insulation	U-0.120	U-0.115	U-0.110
No Framing	R-8.0	U-0.107	U-0.103	U-0.099
No Framing	R-9.0	U-0.097	U-0.093	U-0.090
No Framing	R-10.0	U-0.088	U-0.085	U-0.083
No Framing	R-11.0 3" Insulation	U-0.081	U-0.079	U-0.076
No Framing	R-12.0	U-0.075	U-0.073	U-0.071
No Framing	R-13.0	U-0.070	U-0.068	U-0.066
No Framing	R-14.0	U-0.065	U-0.064	U-0.062
No Framing	R-15.0 4" Insulation	U-0.061	U-0.060	U-0.059
No Framing	R-16.0	U-0.058	U-0.056	U-0.055
No Framing	R-17.0	U-0.054	U-0.053	U-0.052
No Framing	R-18.0	U-0.052	U-0.051	U-0.050
No Framing	R-19.0	U-0.049	U-0.048	U-0.047
No Framing	R-20.0	U-0.047	U-0.046	U-0.045
No Framing	R-21.0	U-0.045	U-0.044	U-0.043
No Framing	R-22.0	U-0.043	U-0.042	U-0.042

Solid Modeling

There is no need to do a 3D model of system if you follow the codes. AltusGroup has had the manual calculations verified by hiring Resolve Analytics to do a 3D Finite Volume Solids model of several wall panels using STAR-CMM+ software. They used the heat transfer coefficients that are required in the Appendix, which shows the U-Factors and R-Values for various components and the formula for the calculations. If you follow the calculations from ASHRAE and use known heat transfer theory, formulas and data, the 3D modeling results are similar to the results of the manual calculations, the results of which are shown in the modeling samples on pages 9–10.



Modeling will not produce significantly higher R-Values (or U-Factors) if done correctly. If you incorrectly model something, you will get incorrect data. There are no magical formulas to make a 3D model do something different than normal life. The laws of thermodynamics are not variable and do not change.

Appendix to R-Value determination for precast wall panels

3-D modeling methodology and results utilizing ASHRAE 90.1 Appendix A9: determination of alternate assembly U-Factors, C-Factors, F-Factors, or heat capacities

A9.1 General. Component U-factors for other opaque assemblies can be determined in accordance with Section A9 only if approved by the building official in accordance with Section A1.2. The procedures required for each class of construction are specified in Section A9.2. Testing must be performed in accordance with Section A9.3. Calculations shall be performed in accordance with Section A9.4.

A9.2 Required Procedures. Two- or three-dimensional finite difference and finite volume computer models must be an acceptable alternative method to calculating the thermal performance values for all assemblies and constructions listed below. The following procedures can also be used to determine all alternative U-factors, F-factors, and C-factors.

A9.2 b. Above Grade Walls
1. Mass walls: testing or isothermal planes calculation method or two-dimensional calculation method. The parallel path calculation method is not acceptable.

A9.4 Calculation Procedures and Assumptions. The following procedures and assumptions must be used for all calculations. R-values for air films, insulation, and building materials are taken from Sections A9.4.1 through A9.4.3, respectively. In addition, the appropriate assumptions listed in Sections A2 through A8, including framing factors, shall be used.

A9.4.1 Air Films. Prescribed R-values for air films are as follows:

R-Value	Condition
0.17	All exterior surfaces
0.68	Interior vertical surfaces

A9.4.1.1 Exterior surfaces are areas exposed to the wind.
A9.4.1.2 Semi-exterior surfaces are protected surfaces that face attics, crawlspaces, and parking garages with natural or mechanical ventilation.
A9.4.1.3 Interior surfaces are surfaces within enclosed spaces.
Using this method, AltusGroup contracted with Resolved Analytics to provide a 3D Finite Volume Solids model of several wall panels using STAR-CMM+ software.

Sandwich Wall Panel Modeling Example

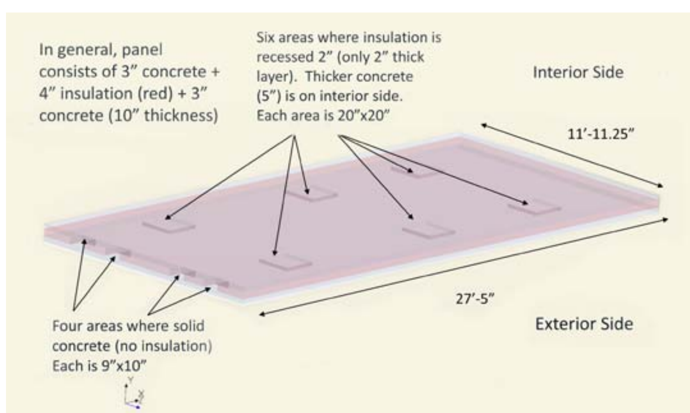
Initial Geometry:
Wall Panel provided in dwg."180284.Panels" shows a 27-5" x 11'-11.75" x 10" panel consisting of a 3-4-3 arrangement of concrete-insulation-concrete

Boundary Conditions:
- Case 1, Summer: Ambient External Temperature = 100°F & Internal Temperature = 70°F
- Case 2, Winter: Ambient External Temperature = 20°F & Internal Temperature = 70°F
- Convective film coefficients were also applied as per below:
  - Internal film coefficient = 0.68 [°F*ft*hr/BTU]
  - External film coefficient = 0.17 [°F*ft*hr/BTU]

Analysis Approach:
- Steady state model whereby the above temperature delta is applied across the panel and the heat flux (Q) is measured as an output that will provide the target delta T.
- From this Q value (along with the panel area and delta T), the overall heat transfer coefficient "U" can be determined such that $U=\frac{Q}{A+dT}$
- The panel's R-value is then found to be the inverse of U: $R=\frac{1}{U}$

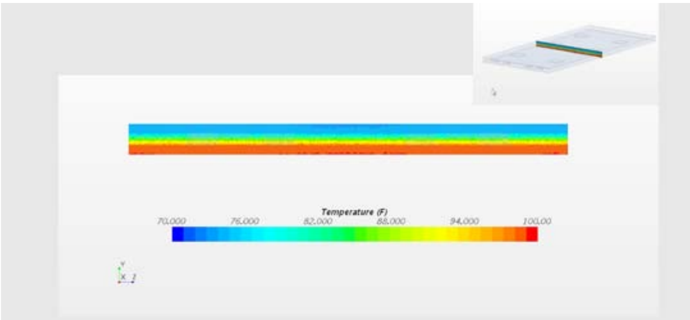
Concrete:
- "R per inch": 0.06 [°F*ft²*hr/(BTU*in)]
- Corresponding K value: 1.389 [BTU/(°F*Ft*hr)]
- Density: 139.8 lb/ft3

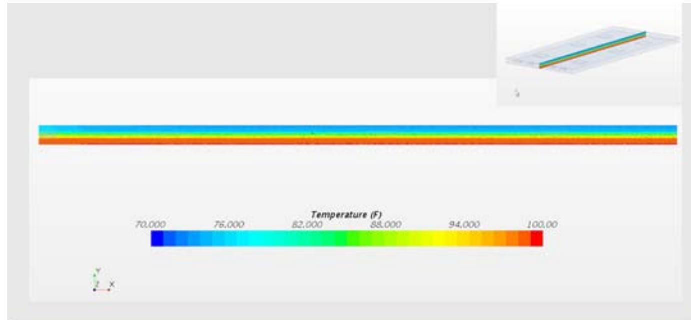
Insulation: (EPS)
- "R per inch": 3.85 [°F*ft²*hr/(BTU*in)]
- Corresponding K value: 0.02165 [BTU/(°F*Ft*hr)]
- Density: 1.9 lb/ft³



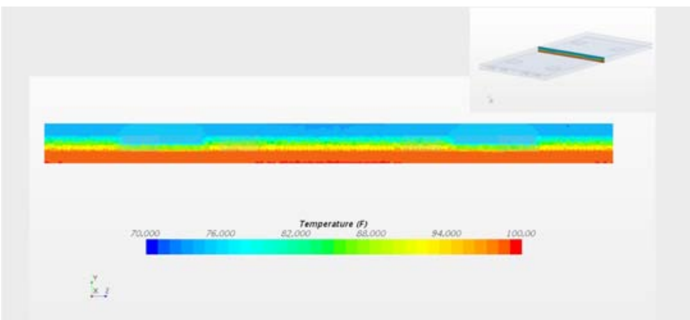
Appendix

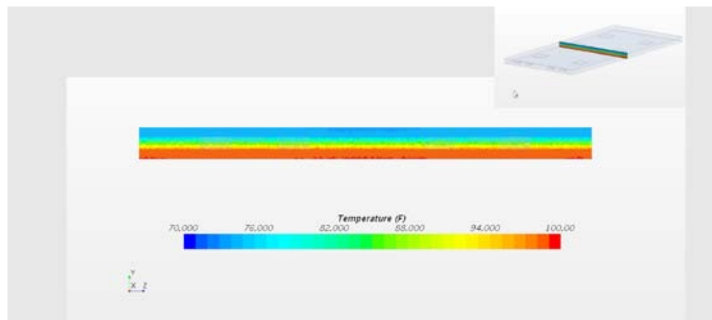
Summer—Full Thickness Zone



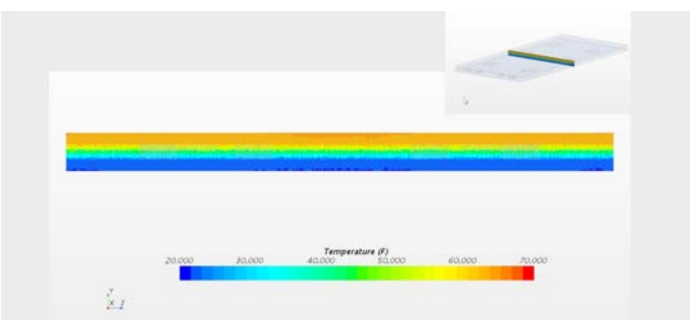


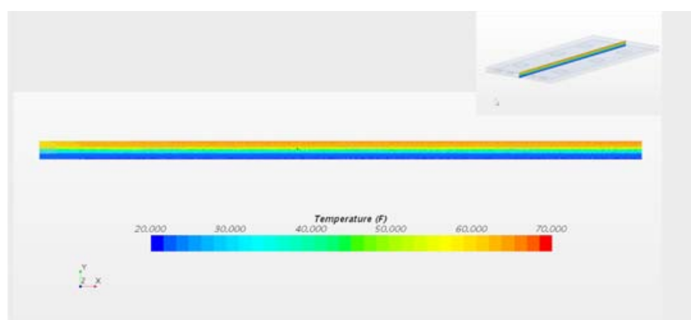
Summer—Reduced Thickness Zone



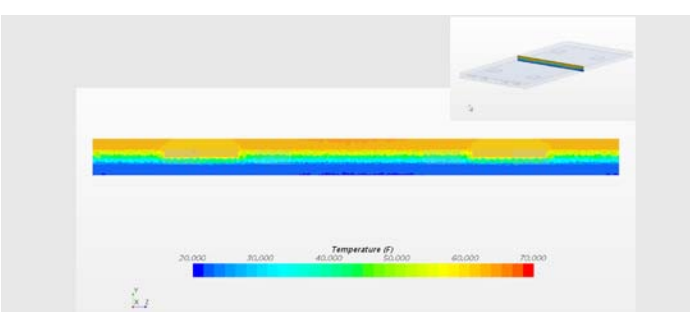


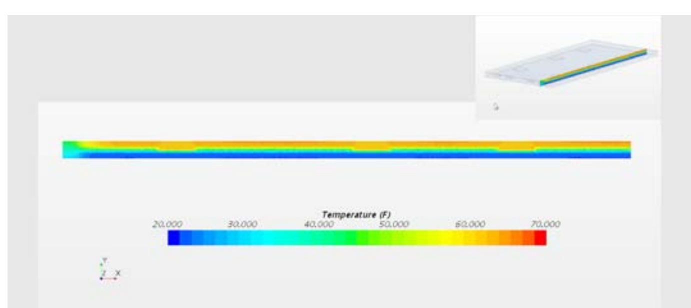
Winter—Reduced Thickness Zone





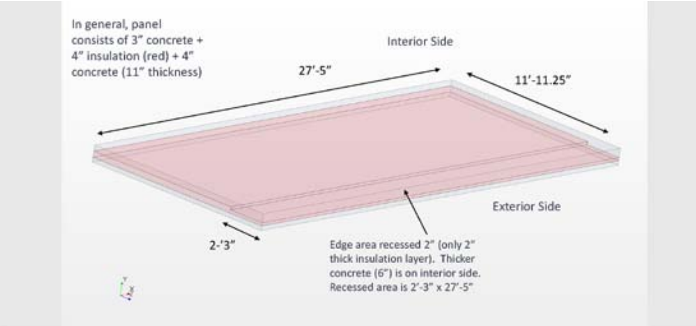
Winter—Reduced Thickness Zone

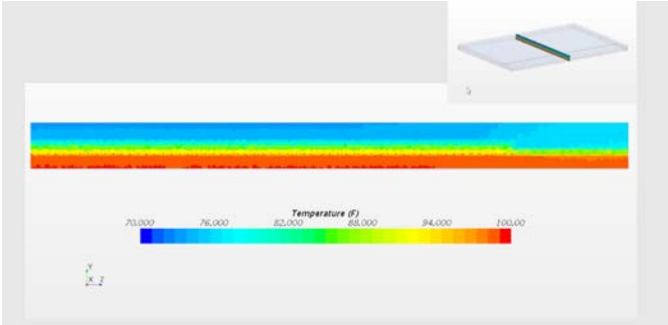




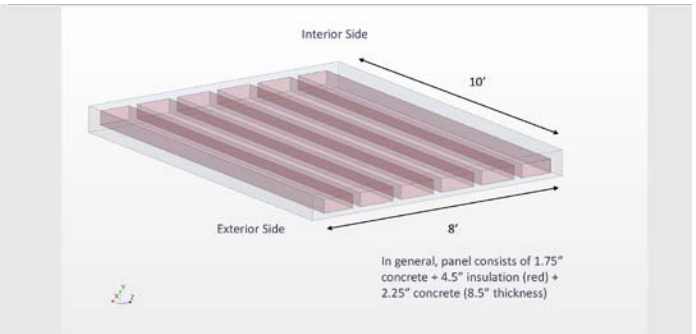
Appendix

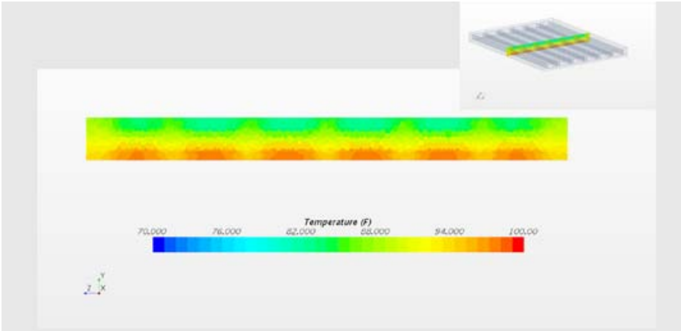
Alternative 1





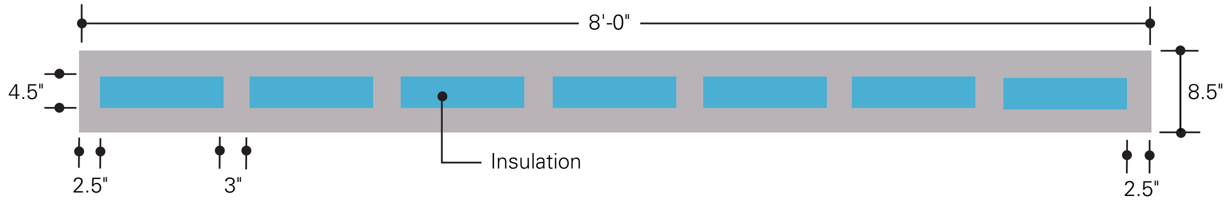
Alternative 2





3D modeling by Resolve Analytics

Final analysis of panel modeling



	Calculated Heat Transfer, Q [BTU/min]	Area [ft2]	Delta T [°F]	U [BTU/(hr*ft²*°F)]	R [ft²*°F*hr/BTU]
Case 1 (Summer)	10.03	327.29	30	0.0613	16.32
Case 2 (Winter)	16.7	327.29	50	0.0612	16.33

	Calculated Heat Transfer, Q [BTU/min]	Area [ft2]	Delta T [°F]	U [BTU/(hr*ft²*°F)]	R [ft²*°F*hr/BTU]
Alternate #1 (3-4-4 with Edge Recess)	9.99	327.29	30	0.061	16.38
Alternate #2 (1.75-4.5-2.25 VC panel)	8.32	80	30	0.208	4.81

Previous Calculations	Overall R Values
KP Panel W107	16.65
Hollow Core Panel w/insulation	4.59

Conclusion

Modeling requires the use of known heat transfer equations and known R-values for materials. The modeling will produce similar results to manual calculations.

Incorrect modeling will produce incorrect results and will provide misleading information. Modeling does not (and should not) change the thermodynamics of the panel and how it will perform.

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