USING LBNL THERM FOR ENERGY MODELING

AN OVERVIEW

15 November 2015

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THERM is a... computer program developed at Lawrence Berkeley National Laboratory (LBNL)...Using THERM, you can model two-dimensional heat-transfer effects in building components such as windows, walls, foundations, roofs, and doors...where thermal bridges are of concern. THERM's heat-transfer analysis allows you to evaluate a product's energy efficiency and local temperature patterns, which may relate directly to problems with condensation, moisture damage, and structural integrity... You can view results from THERM in several forms, including U-factors, isotherms, heat-flux vectors, and local temperatures.

--From the "Therm 2.0: Program Description", June 1998, Copyright Regents of the University of California.

QUANTIFYING HEAT TRANSFER

Building envelopes are constructed of different, multi-layered assemblies. Walls typically have at least three layers: An interior surface, a middle that may act structurally and thermally, and an outside surface, which is the primary weather protection layer.

Windows and doors are typically placed in walls, and they, too, are multi-layered. Windows have frames that may be complex shapes in themselves, and they have glazing, which may be an assembly of glass, coatings and air spaces.

Designers in cold climates are interested in optimizing their building envelopes to resist heat transfer between the inside and the outside of a building. Insulation layers are the primary components of exterior envelopes that mitigate heat transfer. However, the heterogeneous nature of wall assemblies complicates the evaluation of a wall's thermal properties. Designers are familiar with thermal breaks in the form of metal studs and other leak points, but how does one quantify the effects of these discontinuities? We know that a six-inch metal stud wall with six-inch fiberglass batts performs less well than a homogeneous plane of six-inch batts, but how much less? We know aluminum window frames perform less well than fiberglass frames and thermally broken aluminum frames, but how much less?

These are not trivial questions. A simple way to quantify the actual thermal resistance of heterogeneous assemblies can be quite useful. The program Therm does this.

2-D THERMAL ANALYSIS

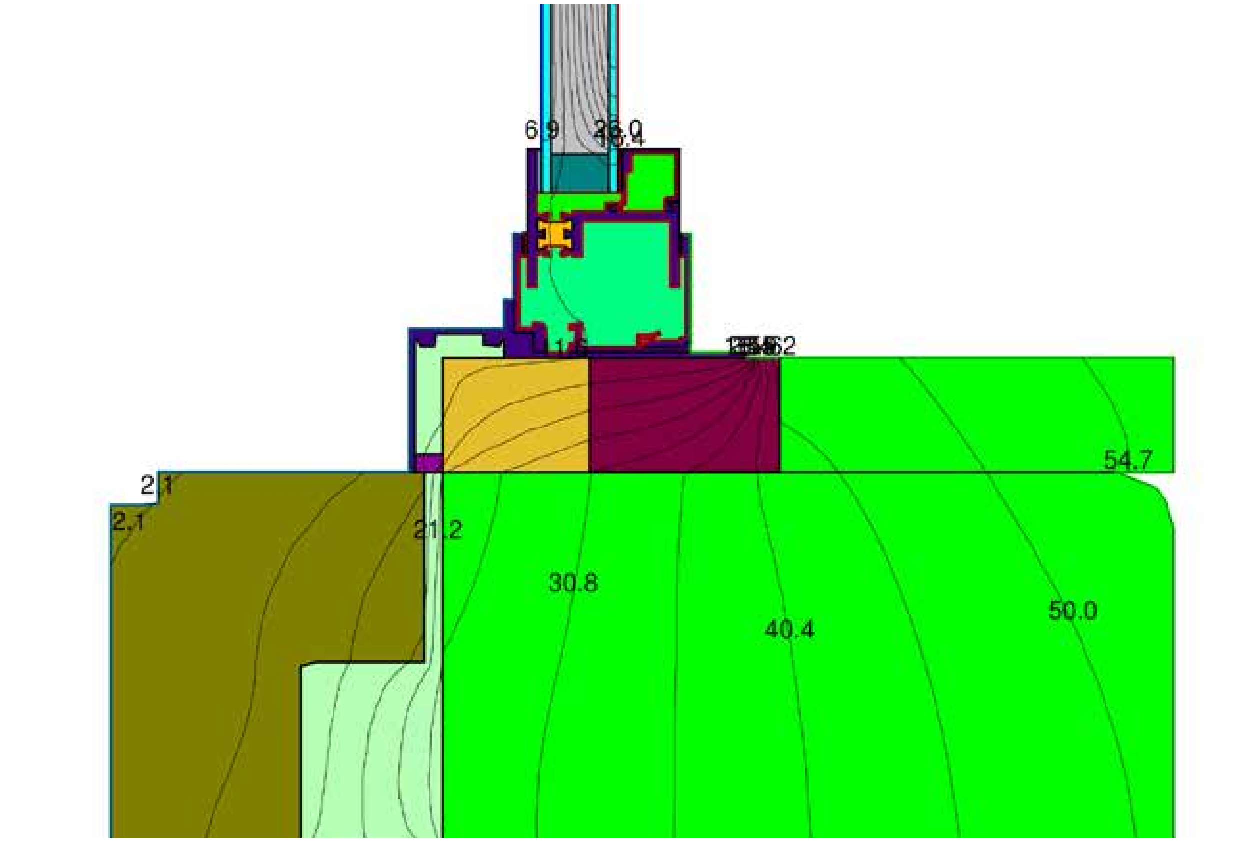
Therm is a finite-element analysis program for studying heat transfer. Even though buildings are three-dimensional, and in fact operate in a four-dimensional world, Therm's ability to calculate two-dimensional heat transfer is valuable. The designer creates a two-dimensional section of a three-dimensional assembly. Fortunately with buildings, most three-dimensional assemblies are extrusions of two-dimensional shapes. Window perimeters can be accurately described as extrusions. Stud walls are not extrusion in a horizontal direction, but they are often extrusions in a vertical direction. This paper does not describe how to use Therm; suffice it to say the images that follow were created by drawing two-dimensional representations of three-dimensional building assemblies within the Therm program.

WINDOW OPENINGS

We first used Therm to help compare different options for insulating an uninsulated masonry building. Our client wanted to replace leaky windows in the building. An energy analysis showed only replacing the windows had disappointing results. Replacing the windows and insulating opaque walls would produce better results. We were also interested to find out the best way to treat the window opening. Our plan was to replace windows located near the outer surface of exterior walls, and provide insulation on the interior surface of exterior walls.

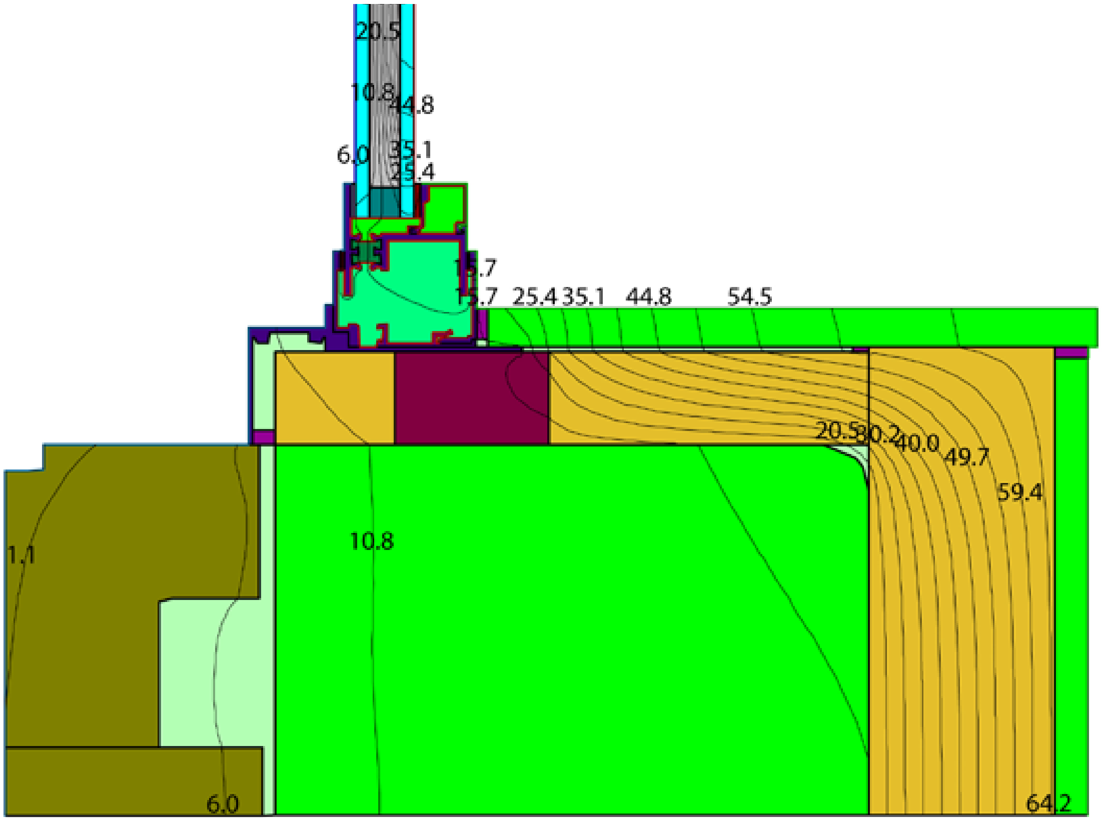
The following images show Therm results for the window jamb condition using three scenarios: (A) Window replacement only, (B) window replacement with uninsulated gypsum board furring on interior walls, and (C) window replacement with insulated gypsum board furring on the interior walls.

Each of these three scenarios are modeled with an outside temperature of 0 degrees F, and



Model (1A): Uninsulated brick and concrete masonry wall.

Model (1B): Frame cavity (no insulation) on interior side of exterior wall.



Model (1C): Continuous XPS insulation on interior side of exterior wall

an inside temperature of 70 degrees F. Model (A) shows nearly parallel lines of temperature isoclines, or lines of same temperature, through the masonry assembly. The temperature on the outside face of brick is around two degrees F. The temperature on the inside face of masonry is around 50 degrees F.

Model (B), showing uninsulated furring of the interior wall, raises the interior wall surface temperature to around 60 degrees F. This is a significant improvement. It also shows the temperature at the interior face of masonry has dropped to about 40 degrees F. Model (B) thus raises a red flag concerning potential condensation on the inside surface of the masonry.

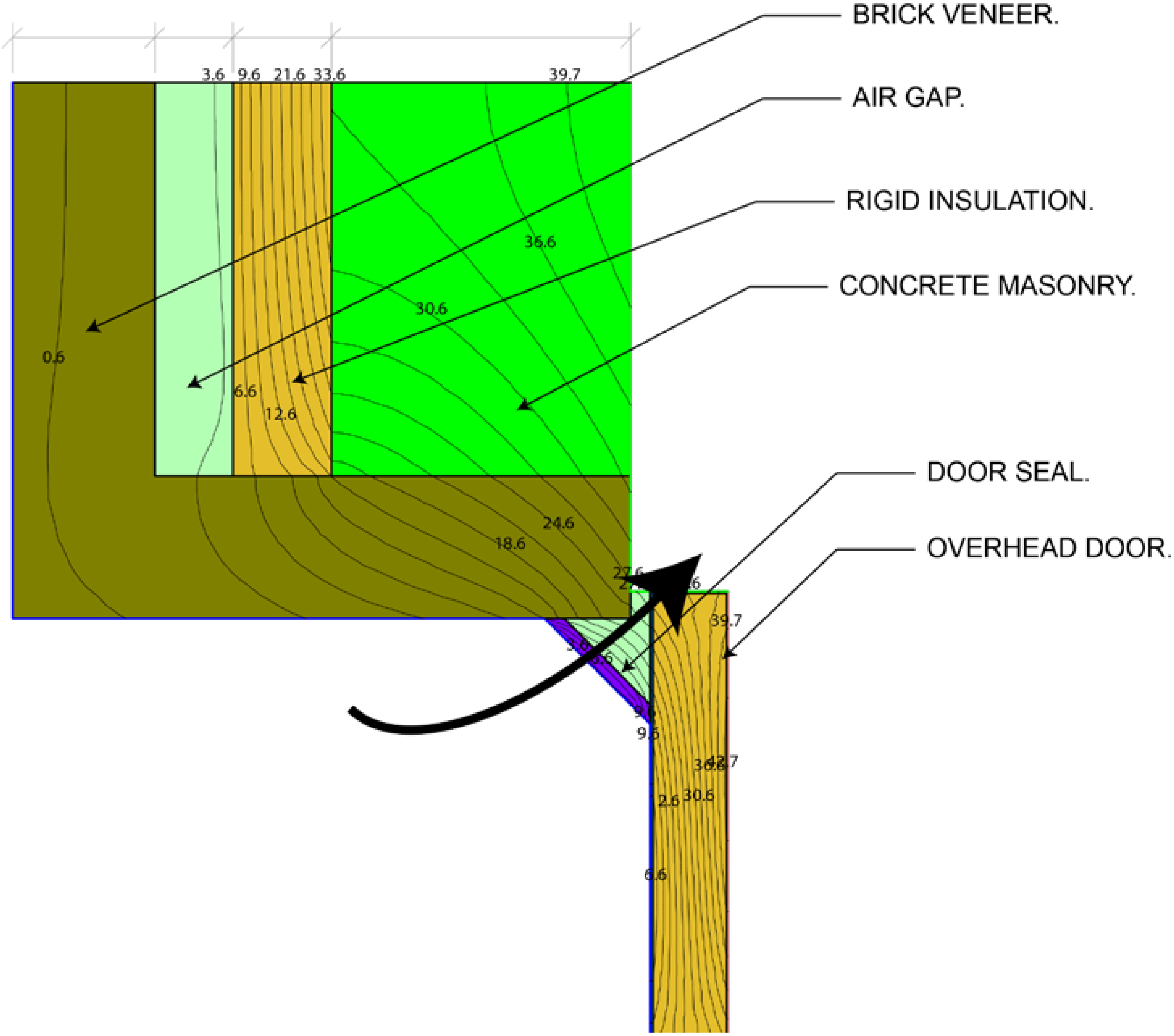
Model (C), showing extruded polystyrene (XPS) insulation behind gypsum board furring, has remarkably different thermoclines. The inside surface of masonry is around 12 degrees F. and the inside surface of gypsum board is around 65 degrees F. Nearly all the thermoclines are packed inside the insulation.

Interesting things are happening at the window to jamb connection as well, and they point to the importance in getting insulation wrapped around the jamb and right up against the window itself. The remarkable confluence of thermoclines at the inside bottom line of the window in (A) means that point is where a lot of heat is meeting a lot of cold. The thermoclines are much more evenly spaced in (C), where the jamb has been insulated.

OVERHEAD DOOR OPENINGS

The importance of insulation continuity at the jamb can also be illustrated for overhead doors. These openings are difficult, if not impossible, to make energy efficient due to the difficulty in controlling infiltration at the door to frame intersection. Overhead doors slide past their seals on their way up, and nobody (yet) has made an overhead door with a tight seal.

Overhead doors therefore present difficulties with regard to air infiltration, but their openings can be designed to reduce conduction losses.

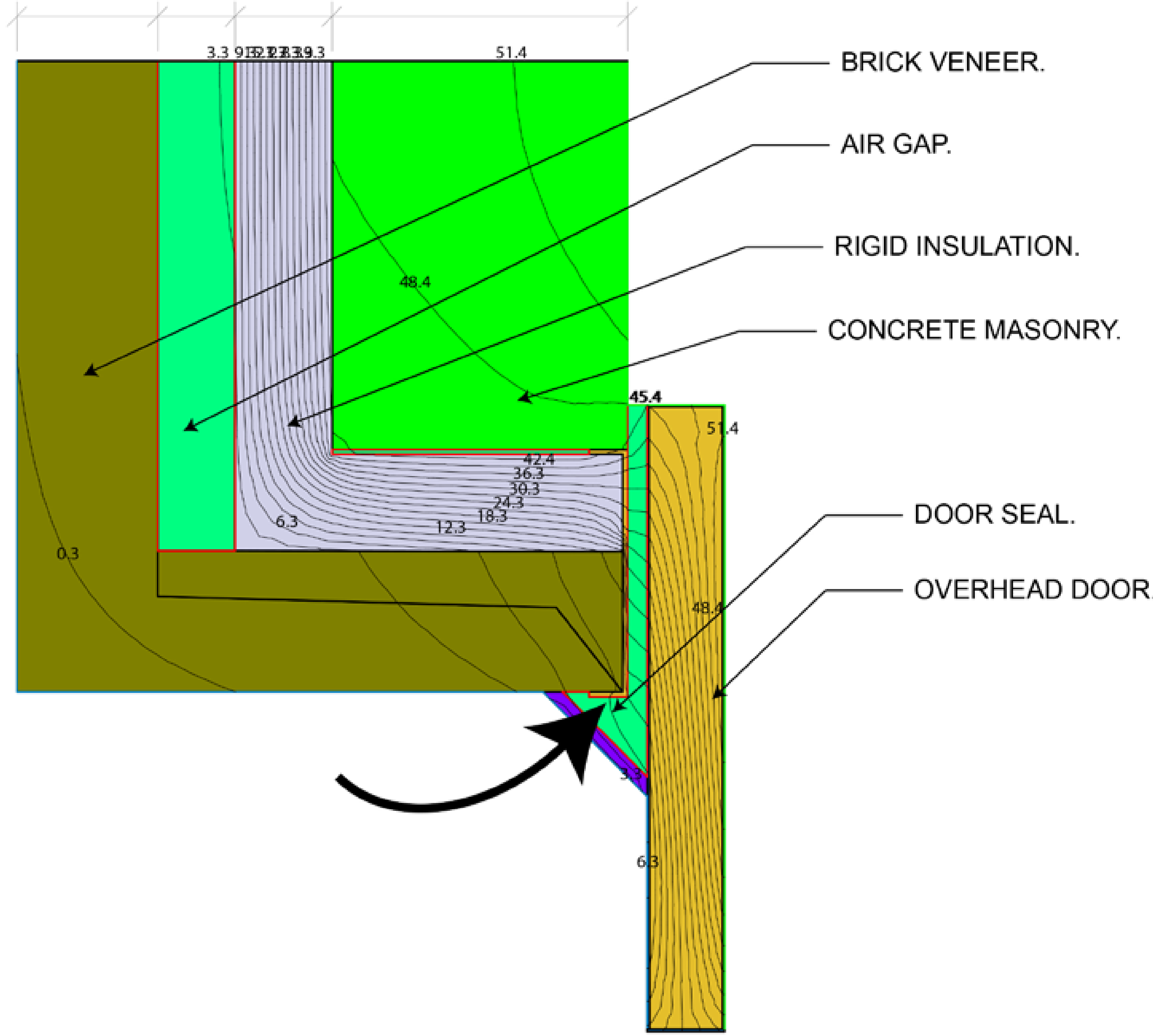


Model (2A): Overhead garage door, typical jamb detail.

In the two images that follow, we modeled a typical overhead jamb detail, and an improved detail. The improved detail brings wall insulation onto the jamb plane, right up to the overhead door. The door plane is essentially two inches of rigid insulation in a sandwich panel, so its thermoclines prove there is nothing lacking for energy efficiency in the door itself.

In the improved Model (2B), thermoclines are also evenly distributed and spaced apart in the air gap between the door and the exterior wall. This indicates the lengthened air gap itself is contributing to increased thermal performance. Model (2A) shows the inside surface of the exterior wall at the edge of the door is about 24 degrees F in the base case. Model (2B) shows the inside surface of the exterior wall at the edge of the door is about 45 degrees in the improved case. There is still some cold coming through between the door and the wall, but it is clear Model (2B) is visibly improved.

The visualization of thermoclines is in fact one of the major benefits that comes with Therm modeling. A designer could draw thermoclines



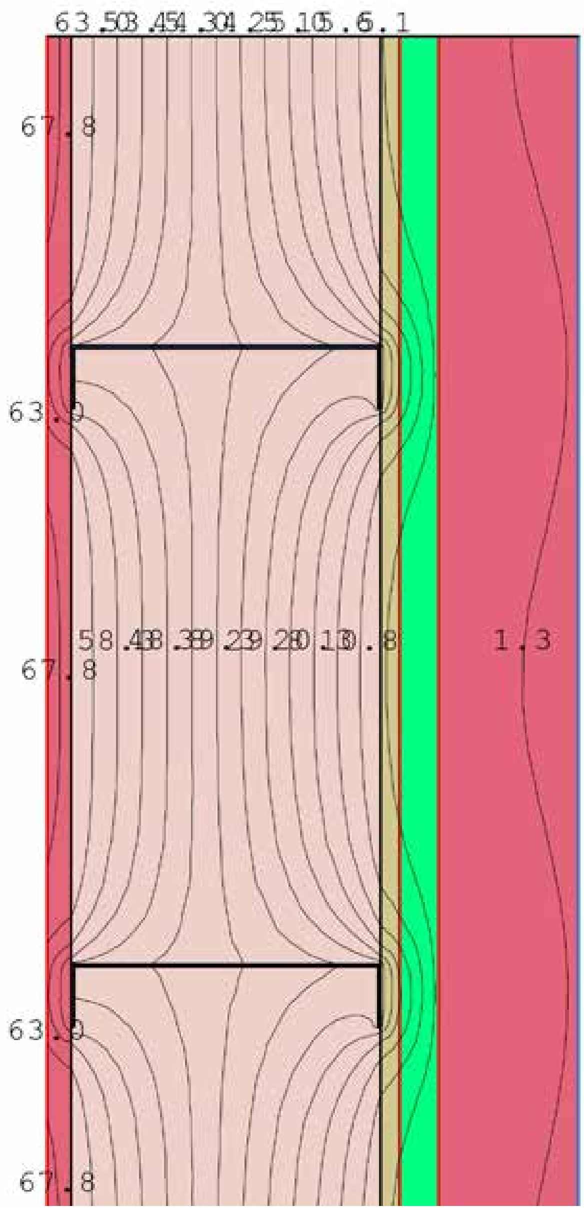
Model (2B): Overhead garage door, improved jamb detail.

on top of a detail by hand and potentially produce an accurate picture of heat flow. It would be difficult to quantify this heat flow, however, without doing quite a lot of math. Computational finite element analysis brings quantitative rigor and an amount of certainty to the analysis of heat flow through complex geometries involving many layers of different materials.

THERM VALIDATION

As with all computational models, it is fair to ask how closely Therm models are to the real world. Validation of simulation models is a huge issue, and Therm has not escaped the validation efforts of scientists and industry. It turns out Therm has been validated extensively:

THERM and WINDOW simulation models are generally accurate to within 1%. However, considering that we normally model "drawings" and not actual products (meaning that drawing is usually not a perfect representation of the actual product), it is accepted that simulation and test results should be accurate to within



Model (3A): Metal stud-backed veneer brick.

10%. NFRC has CPD no has several hundred thousand validations between simulation and testing (yes, this is not a typo) and all products have validated to within 10%.

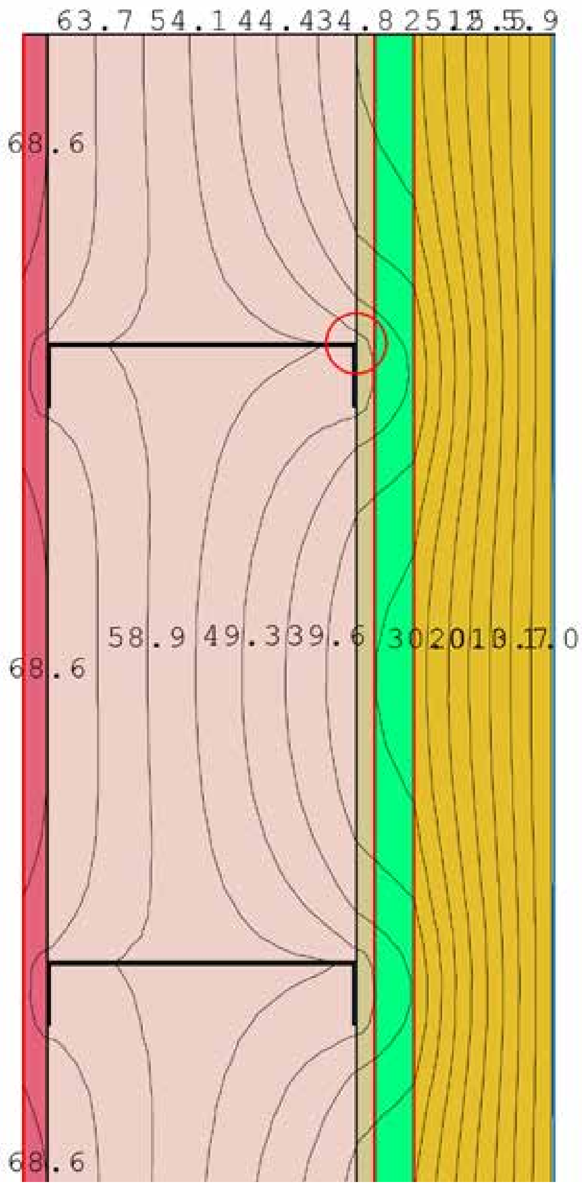
--Charlie Curcija, Lawrence Berkeley National Laboratory.

METAL STUD WALLS

Therm's ability to investigate thermal breaks in exterior walls useful to understand conditions at openings, as the previous two examples have shown. Therm is also useful when just looking at the field of the wall.

Designers often wonder what the U-value is for an entire wall, not just the insulation layer. This can usually be done by simply adding up the U-values of each layer. Modeling uniformly constructed walls in Therm can validate this additive process.

Therm is especially useful in determining the overall U-value of non-uniformly constructed walls, such as stud walls. This common form of construction has a middle layer of framing members spaced more or less evenly apart, with insulation placed between the framing layers. Cavity insulation is known to be less effective than continuous insulation, and this is largely due to the discontinuous nature of cavity insulation. Cavity insulation also suffers from increased



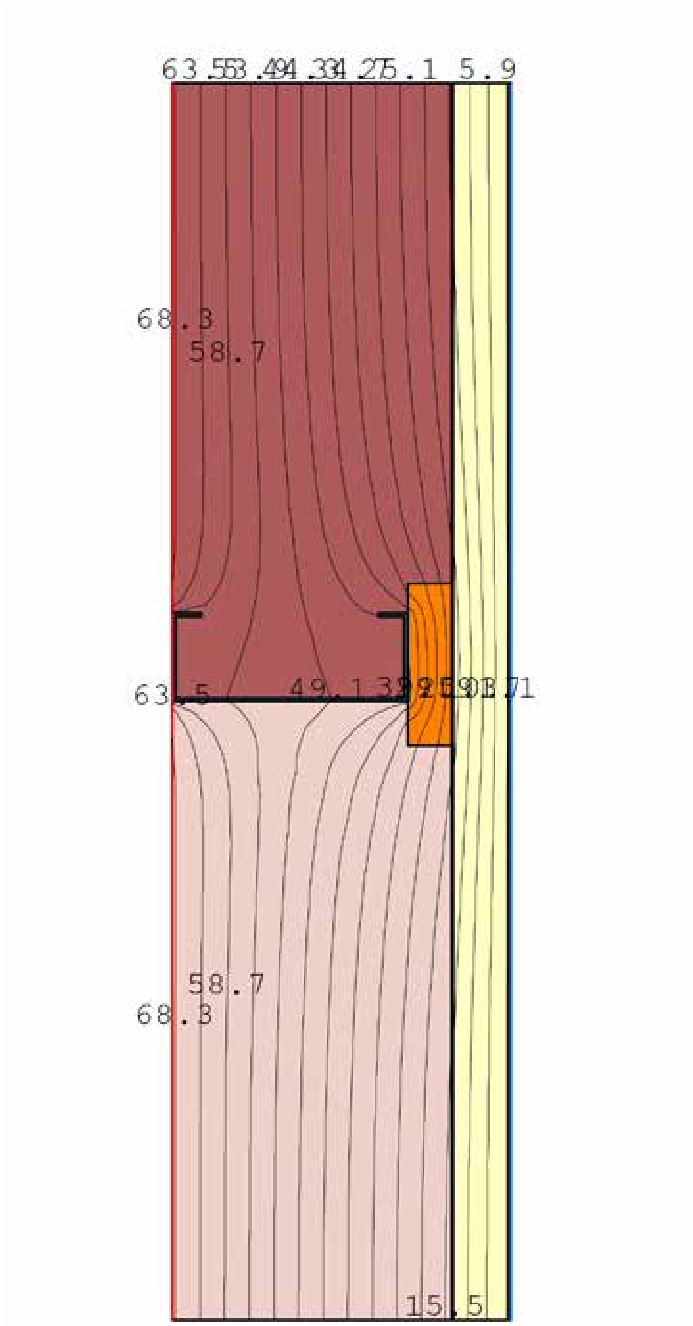
Model (3B): Metal stud-backed exterior continuous insulation.

risk of installation problems, particularly with hand-placed batts. Still, even blown-in forms of insulation like cellulose, fiberglass and polyurethane suffer from discontinuity.

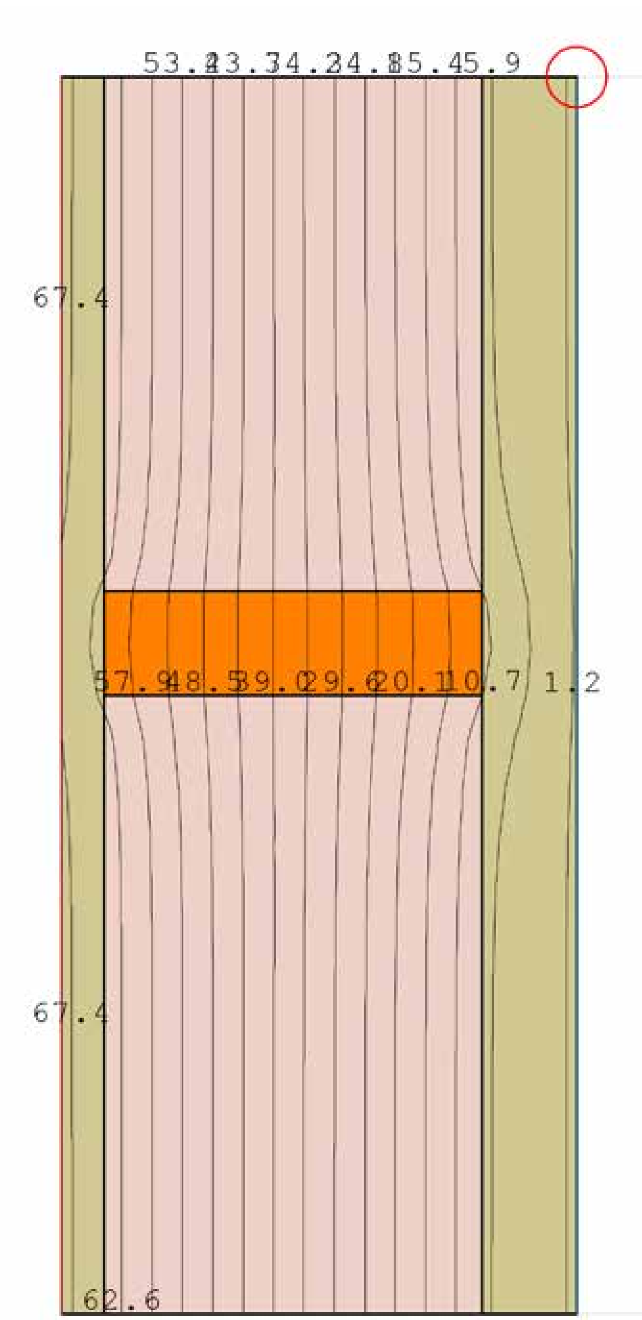
The effect of metal stud framing on wall thermal efficiency is pronounced, as shown in the following two images. Model (3A) shows metal stud-backed brick veneer. Model (3B) shows metal studs in back of XPS insulation. This system could be an EIFS (exterior insulation finish system) or any number of claddings covering a continuous insulation layer.

The thermally dismal brick in Model (3A) lets cold come in to the outside flange of the metal stud, where the stud acts as a conductor. In this image, the wall cavity is eight inches. While noticeable differences in heat transfer exist between the stud locations and between studs, the difference is not terrible. The temperature swing on the inside wall surface is only about five degrees.

In Model (3B), the brick has been replaced by XPS. This wall shows a one-degree difference in inside wall temperature. In other words, the thermal break occurring at the metal stud is almost non-existent. This also suggests that when continuous insulation is used on the outside of a metal stud assembly, placing



Model (4A): Comparison of two cavity insulation types.

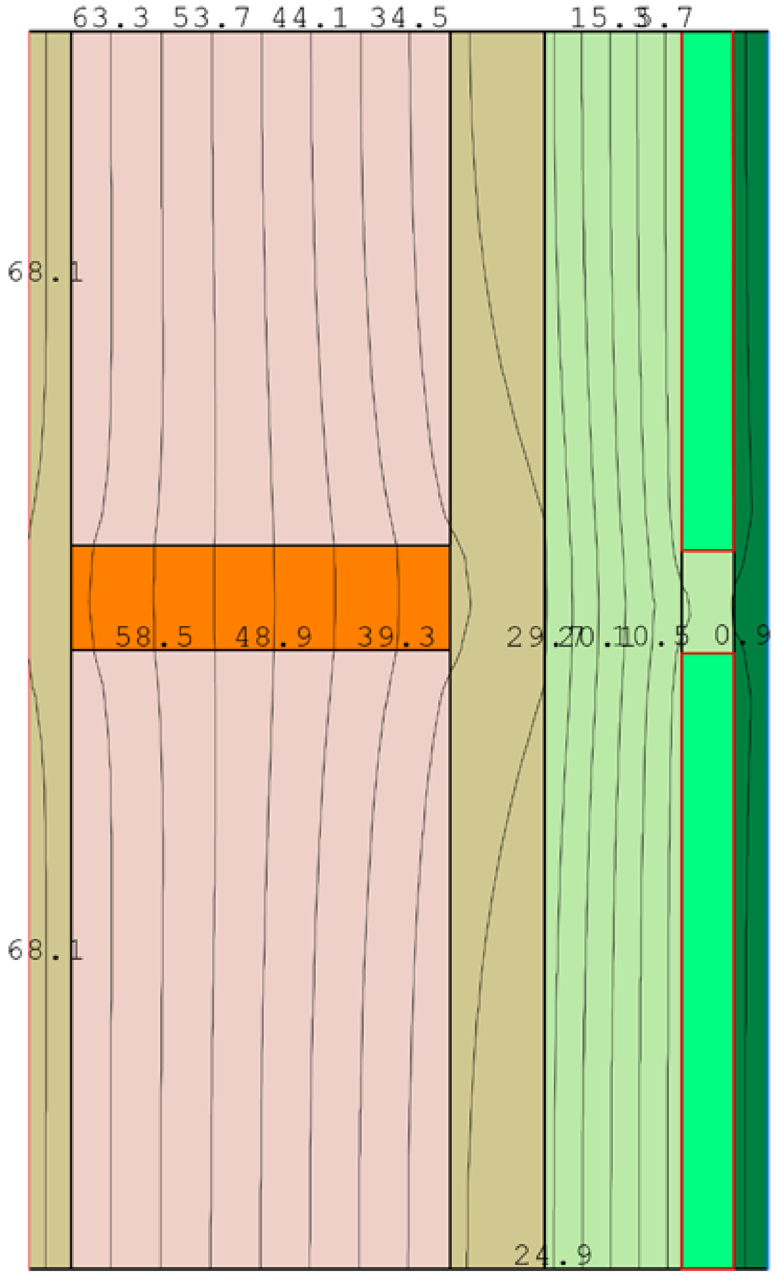


Model (5A): Existing wood framed wall. R-value = 19.

fiberglass batts between studs has negligible effect.

COMPARING MATERIALS

Therm can be used to quickly compare the effects of different material choices in an assembly. For instance, what is the difference between using fiberglass batts versus mineral wool batts as cavity insulation? Therm can be a clunky program to use, since its modeling tools are primitive, to be kind. However, one or two clicks of a mouse is all it takes to swap out one material for another. In Model (A), a metal stud cavity assembly is shown with fiberglass batts above, and mineral wool below. As expected, the differences are negligible. One must keep in mind when modeling and analyzing with Therm that a model is an idealized version of a physical assembly. Perfectly tight fits with batts almost never occur. Thus the difference between blown in fiberglass and fiberglass batts may not be negligible even though the materials have



Model (5B): Continuous insulation added to existing wood framed wall. R-value = 32.

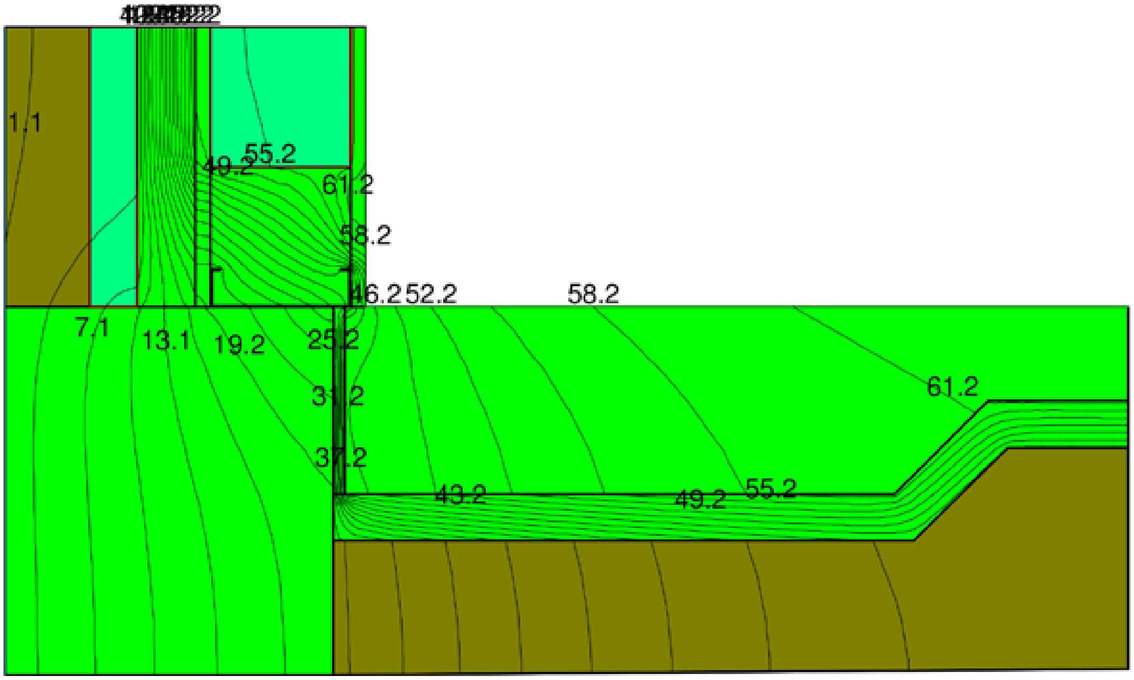
identical idealized thermal properties.

ENERGY RETROFIT PROJECTS

Therm can provide some quantitative back-up for justifying energy retrofit projects. In the next series of images, we show the effect of adding continuous insulation to the exterior side of a wood-framed exterior wall.

Model (5A) shows the existing wall, composed of 2x6 wood studs and fiberglass insulation. The wood stud itself does not do much to change isotherms, meaning its effect on the overall U-value of the wall is negligible. Compared to Model (5B), the inside wall surface temperature is not that much different, either.

Large differences do show up with the surface temperature of the inside surface of the exterior sheathing. This is the surface prone to condensation. Adding continuous insulation has increased the surface temperature from around 10 degrees F. to around 38 degrees F. This is a



Model (6A): Base case metal stud backed veneer brick on concrete foundation.

huge difference.

Not shown in the graphic, but available for display inside the Therm program is the overall U-value of the modeled assembly. In Model (5A), the U-value is just about 1/19, or R-19. In Model (5B), the U-value is 1/32, or R-32. This again is a huge increase.

FOUNDATION DESIGN

We have also looked at Therm when investigating ways to reduce thermal bridging at foundations. This is a common area of concern in cold-weather design. We often see well-constructed walls with continuous insulation that stops at the top of slab. This means the entire height of exposed foundation wall is a thermal weak link in the envelope. Many designers are hesitant to bring the continuous insulation plane to grade because of a lack of good ways to cover that insulation where it meets grade. Most cladding manufacturers do not want their cladding to touch the ground, let alone extend beneath grade.

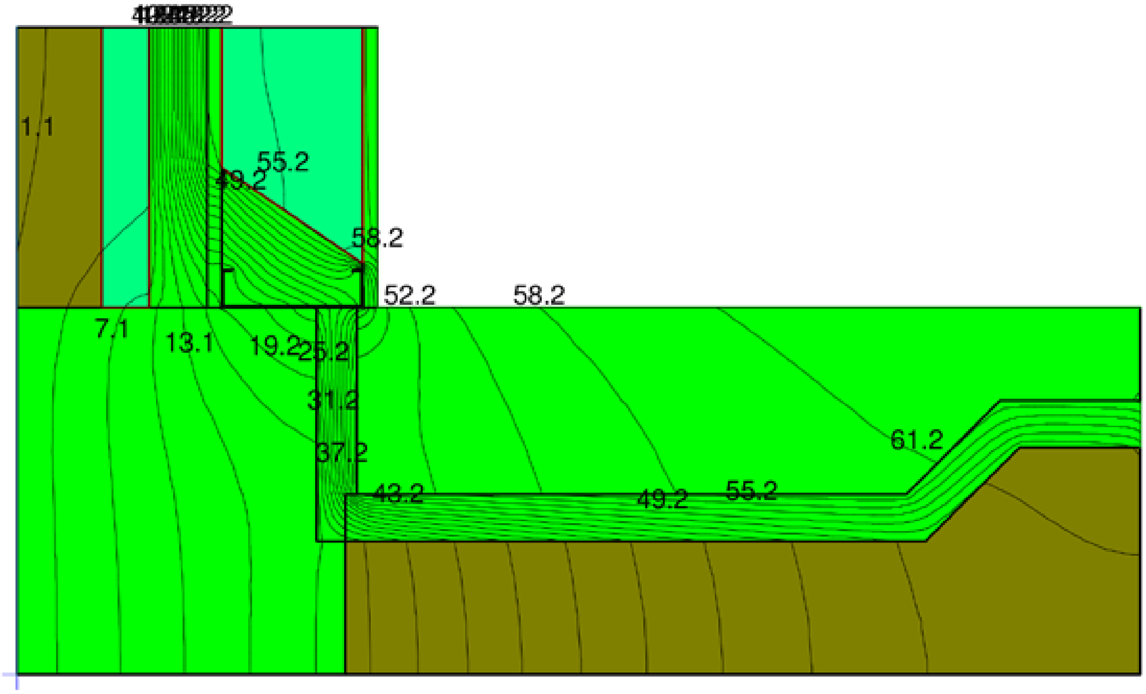
One common solution is to bring the insulation plane inboard at the foundation. Model (6A) shows a metal stud-backed brick veneer wall on top of a concrete foundation. Foundation is place under the interior slab on grade, and a half-inch layer of rigid insulation separates the slab from the perimeter foundation wall. The designer has shown spray polyurethane insulation at the base of the metal stud cavity in an attempt to connect insulation layers. The perimeter of the slab is around 30 degrees F.

Model (6B) shows the effect of increasing the thickness of insulation between the foundation wall and slab. The slab perimeter temperature is now around 50 degrees.

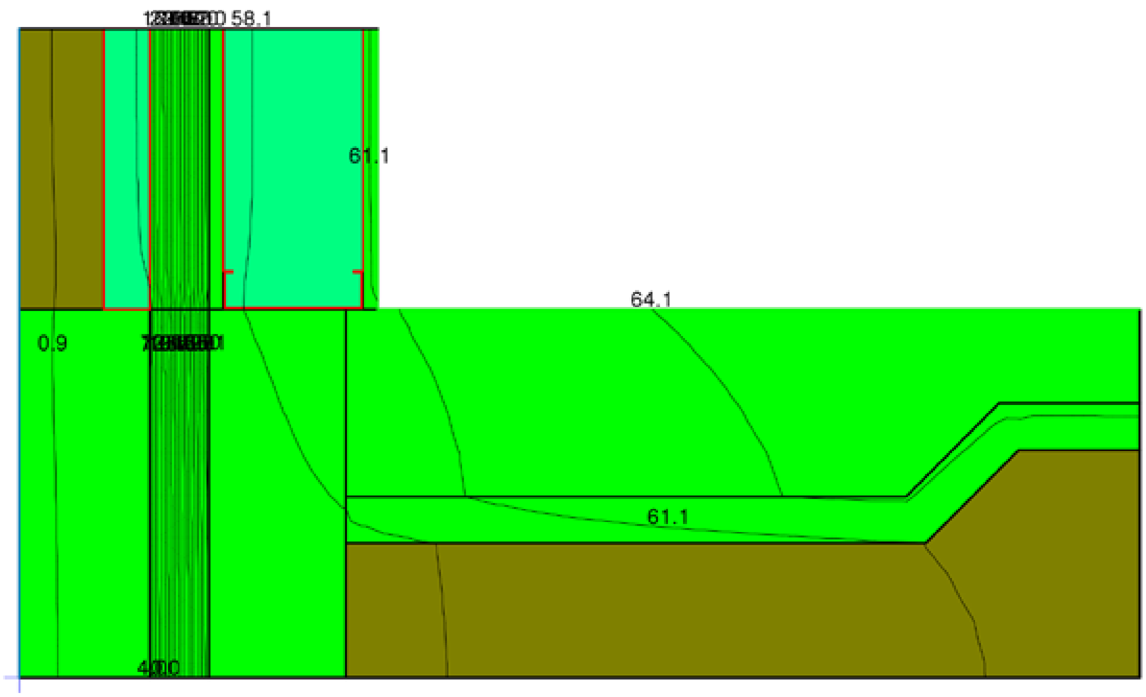
Model (6C) shows the effect of continuing the wall's rigid insulation plan straight down through the foundation wall. This "split foundation" can be done, although it obviously makes structural engineers nervous. From a thermal point of view, this innovation works wonders. The slab perimeter temperature is now 61 degrees, only three degrees colder than the slab temperature a foot or so into the room.

CONCLUSION

We have been investigating the thermal performance of exterior assemblies using Therm for around ten years. In that time, the program itself has not changed dramatically, although the software supports more types of assembly than before. We have found the program gives us meaningful reason to stand behind certain details, and helps show the weak links in details



Model (6B): Increased insulation between slab and foundation wall.



Model (6C): Thermally broken foundation.

that still require work.

Having Therm in our repertoire of software tools has been effective in improving our work, and in showing clients how we are being attentive to building envelope performance.

Sealander Architects hopes this article has proved helpful.

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