Building Enclosure Institute. Inc
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Field Guide to Tell Thermal Simulations Apart – DRAFT

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Contents

Audiences

This "field guide" is intended for a reviewer of thermal simulation results to learn how to tell good ones from bad ones, as well as the people who produce these submittals to help them improve their work product.

It was written by a building enclosure consultant with over 25 years of experience, starting with energy rating, façade engineering, building enclosure commissioning, diagnosing facades, spearheading 3D thermal simulations in the U.S., and eventually running a nonprofit dedicated to research and education in the field, which allowed to devote enough time to produce this document for your use.

What are Thermal Simulations and Why They Came to Being?

Global concerns about energy use resulted in requirements for testing. Assemblies are generally tested to verify how resistant they are to heat flow, and whether there would be any sweating cold spots.

Thermal simulations are cheap substitutes of physical testing. Such testing required building actual assemblies, glazing them with different glass panes, heating and cooling them in controlled conditions, while recording an array of thermal sensor outputs. Now all that could be done in a computer instead.

Buildings nowadays are built based on two sets of thermal simulations: the whole energy building simulation meeting the broader energy requirements, and thermal simulations of assemblies meeting more detailed requirements. The former is based on data from the latter ones (on which we focus in this paper), so the process is out of sequence. The probability of error is multiplied, explaining why similar procedure is not allowed in any other engineering e.g. structural , disciplines.

The thermal testing requirements are driven by codes and these sometimes result from political as opposed to real world considerations. The market applies such heating energy concerns unevenly, as they depend primarily on local cost of energy and severity of local climate. The former tends to fluctuate, bringing the energy costs into the picture from time to time, not necessarily in pace with the construction.

Geographical Applications – US only.

This guide is exclusively for a reviewer of reports produced by Americans.

The market generally would tend to self-regulate testing quality in cold countries with high heating costs. A poor specification or a bad thermal simulation report, such as one of those described in this paper, could not be easily ignored in a northern country, or even on a tropical island relying on a limited supply of shipped fuel.

United States is not one of them. Even during a fuel crisis, the cost of energy was still relatively minor compare with other economies. It may explain the observed indifference about quality of those reports, exhibited on examples cited in following chapters.

Compliance

The observed general poor performance of buildings constructed seemingly in compliance with increasingly stricter energy building codes, or meeting commercial certifications such as LEED could be a result of such an indifference, among other factors.

The disparity between such elevated standards and the common practice produced a challenging situation: in this author's experience, all genuine attempts of designing and producing a building actually meeting these strict standards were proven futile on many levels: neither designers, nor contractors were able and willing to cooperate, as discussed in chapters below.

Reviewer's Risk Assessment

With many thermal reports observed to be substandard, and responding to often nonsensical project specifications, as shown below, with the actual enforcement extremely unlikely, solutions fundamentally misunderstood, and execution even less likely, a reviewer would be justified to let those inferior submittals pass, and focus on other higher-value tasks, as is the observed common practice.

However low is the risk, it still exists. Although rare, even in a warm country like the U.S. there could be a damaging internal condensation. More often, occupants could complaint about poor thermal comfort, and HVAC system designers would prove that it was properly sized, putting the inflated thermal numbers of a building shell in focus.

A particular challenge would come from a combination of a U.S.-prepared report for a project located in either a cold country, or with high energy prices, or both. See chapter "Apparent Authority."

Different levels of risk apply to different buildings. Residential buildings are sometimes full of chronic complainers, highly sensitive about their property, who would challenge all performance aspects regardless of the actual quality. On the other hand, commercial, public, hotel, school, transportation, etc. building are examples of buildings that are often almost risk-free.

Therefore, you as a reviewer are well advised to focus only on large discrepancies, and residential buildings. The former is discussed below.

Big Picture – Fit For Use

A reviewer needs to focus on a big picture: Is it fit for its intended use? How to find it out?

There is this holy grail called "Owner's Performance Requirements" or OPR that is supposed to give a response to this question, but majority of project I've seen didn't offer anything useful in this respect, so it's often a reviewer's job to recreate them.

At this point, it really helps to ask the original designer and occupants of the previous building (or similar buildings in the neighborhood), what were the major issues, or the reasons for its replacement, if this was the case. It's mind boggling how often a building is replaced only to replicate the previous defects, because the original reason for the need of its replacement were forgotten.

E.g. You will hear from the museum staff that they could not keep up with towels and water hogs to wick the condensation at window and door sills, or airport crew would complaint about cold drafts, and freezing floor at their work stations, and repetitive flooding from a frozen sprinkler pipe every couple of winters, office workers would complain about unbearable heat near windows, or homeowners would complaint about mold and mildew, etc. If these problems return in the new building, regardless how modern and beautiful, there would be an outcry of disappointment.

Buildings take a long time to design and build, and there is sometimes a high turnover in architectural offices. There may be a forensic report sitting deep somewhere in the project folder, documenting such complaints, ask for it.

Skip U values and R values for now. In the end, you will find out the hard way that no one really cares about, nor is able to implement the thermal resistance requirements, regardless how good their declared intentions may be. Don't sweat it, take it from me, I learned the hard way. Just skip it as much as practicable. If you are determined, I wrote about the subject in the subsequent chapters below to let you judge for yourself. Do review substitutions, making sure that whatever would end up installed had at least the nominal U and R values equal or better than whatever was originally specified.

One needs to develop resistance to dwell on minor discrepancies and errors, but I never learned it, so the majority of examples that follow would go into a minute detail.

Math

While you do it, focus on a big picture: If you are an American reviewer, chances are that you are as mathematically challenged as authors of these reports, with all due respect, so let me help you a little:

1) Round everything to whole degree. Don't let the precision suggested by numbers quoted in reports intimidate you, it's all smoke and mirrors anyway. Most such reports come with 10% standard error, and the base meteorological unit is one degree C or K, which is almost two degrees F. Therefore, dwelling on any numbers smaller than that, particularly fractions of degrees F, is just unproductive.

2) For your purpose, it's best to convert everything to resistance, where bigger equals better. When you see a U value, invert it, creating a reciprocal. Example: U-2 would become R-0.5, etc. What you would get is close enough to R-value. (Read the exception in point #5 below.) You would get e.g. R-3 for a window, R-15 for a wall, and R-30 for a roof, making it easier to understand their hierarchy, as follows:

3) These numbers are assigned to different partitions for a reason. Heat loves to transfer through horizontal partitions such as roofs, explaining why their resistance values are needed relatively high e.g. R-30 or R-40. Heat is less eager to transfer horizontally through e.g. walls, so roughly half as much resistance is needed there, say R-15. These opaque assemblies are generally easy and inexpensive to insulate, but glazing is expensive, so an exception is made for fenestration, and therefore e.g. an R-3 window would be allowed.

A "baseline" building needs these to be kept in certain proportions: E.g. obviously, a skylight is the most challenging assembly, combining the need for higher resistance with the higher cost, so it should take no more than 5% of roof area, windows should take no more than 50% of wall area, etc.

Designers often won't meet these prescriptive values, and they would try to "trade" e.g. fully glazed walls for a more insulated roof. Heat energy would just pick the path of least resistance, and therefore an over insulated roof over a glass shed does not good. Building shells don't work like that, and their budget seldom would allow for more expensive glazing to make up for it, so designers would trade some electric lighting or HVAC technology improvements instead, in the end certifying some numbers in the whole building energy calculation worksheet that they passed onto their mechanical team.

These numbers you would need to find out, because based on them HVAC systems were designed, so if they were not met, human comfort would suffer. (You could see it on thermal images in subsequent chapters showing e.g. 5◦C interior surface temperatures.) Once occupants start to complaint, HVAC would be run at full power, and when it doesn't work, it could be replaced with more powerful components. Disregard all other numbers shown in miscellaneous places in the documentation, such as specifications, OPR, drawings, etc, because they are just derivatives that may or may not be coordinated.

4) Deciphering the numbers. Once you found the whole building energy calculation data for your reference, chances are these numbers would have little to do with the projects, and their harvesting would be challenging to say the least. I used to run those whole building simulations, and they are sometimes not worth the paper on which they are printed, sadly enough, but we won't talk about them here.

Assigning the numbers to specific assemblies is the first task in order. Let me give you an example: let's say that you are e.g. reviewing a submittal of a thermal report of a curtain wall, and you even found the U-value certified by the designer as applicable to the above-grade walls on its respective elevation to be 1/10, that you inverted to R-10 for simplicity.

You compared it to the submitted curtain wall's report stating it achieved approximately 0.3 U-value, converted it to get R values, which is R-3, and it is obviously less than R-10. What's wrong?

It's because designers love to bundle those numbers nowadays. Therefore, R-3 glazing, in a 50% wall to window ratio wall, would require R-17 wall, so you would go on to the next step of your investigation, verifying whether it's actually so, and here comes your next issue, as follows:

A 50/50 assembly composed of R-1 glazing and R-19 opaque wall could also become an R-10 wall. Heat would just pick the path of least resistance, so such an extreme area-weighting is inaccurate, explaining why such bundling is incorrect.

5) In point #2 above, you converted everything in R values, so you would be tempted to think that a wall packed with R-20 insulation is good enough to meet the R-17 requirement. This is seldom true. The nominal R-values of thermal insulation that you normally see in submittals of opaque materials would be typically badly spoiled by thermal bridging before the true thermal resistance of such assembly is known.

There are many tables of prescriptive values (often useless), as well as detailed calculations (too complicated) that you could use, but the simple crude rule of thumb for walls with steel studs or furring on the side of the thermal insulation is to simply divide it by two, which is good enough for this example.

So, your R-20 insulated wall could yield approximately R-10, matching the number certified by the architect, but inferior in comparison to the bundle comprised of R-3 curtain wall.

By this time, the wall's structure could be already standing, and its depth was insufficient to pack almost twice as much insulation into it. There is sometime some good-intentioned but poorly-designed and even poorer-executed effort to counter this issue. E.g. an architect re-designed it adding some custom "thermal breaks" to decouple those cold-bridges, but oriented along the bridging, depriving them of any utility. Or they also penetrated flashing, required out of sequence installation, and the structural engineer threatened to quit over them. These attempts, although commendable, resemble attempts of reinventing the wheel, as mentioned in the introduction. In the field, they are either ignored, or misunderstood, or both, but add to the cost and delays. Or the specification was updated to require a more expensive curtain wall.

6) So, what's next? The subcontractor presumably responded to an early version of specification that required R-3, and even if designer hiked it later to make up for the inferior wall, the product submitted by the subcontractor met their contractual requirements, so you'd need to approve it. If you were a building enclosure commissioning agent, you would report the discrepancy to the owner, who perhaps would be able to trade this nonconformance for some favor or credit in the future.

This purely fictional scenario described above exemplified why it doesn't pay to focus on U-values. Any resemblance to actual events, people, and projects is purely coincidental, as is everything else here.

Big Picture - Moisture

Focus on moisture. People generally do care about water damage, mold, mildew, and condensation, if it affects them personally. It means that you'd need to focus on condensation risk assessment.

It's easier said than done. Sadly, almost all reports either misrepresented their results, or the project-specific conditions, or both, or simply admitted the failure, as shown in the following chapters below. You are advised to reject those submittals, but your chances to improve these conditions by rejecting them are negligible.

Therefore, in vast majority of cases, you should instead suggest broad damage control measures, such as e.g. deep through-wall flashing forming drainage pans to safely collect and drain away any condensate before it damages any moisture sensitive material.

These two considerations tend to act in opposite way: the more energy pumped into these conditions, the less condensation risk. Which is why e.g. a simple redesign such as shown in Fig. #58, or heat tracing is designed as a form of damage control to warm critical areas if everything else fails.

I wrote about the subject in the subsequent chapters below to let you judge for yourself, and included some typical remediation strategies.

How this guide was written and why.

After modeling, pre-processing, and simulating assemblies, I sometimes sadly came to realization that the results were inaccurate, and in at least one case I had to retract them, even though my client was never the wiser. This was painful for me, but I considered it a necessary learning experience. I spent countless hours trying to figure out why results of my simulations seemed illogical or self-contradictory, or in other words, why the results were not repeatable.

Learning thermal simulations and getting acquainted with unfamiliar software is a frustrating process that reveals the ultimate weakness of the process, summarized in proverbial: "*Garbage in, garbage out*."

In the process, I learned the hard way and memorized specific vulnerabilities, and how to avoid these issues. We won't discuss them here, but it helps to put things in perspective.

Sad results are ultimately observed by energy monitoring and thermal imaging. I was commissioned to conduct infrared imaging of as-built assemblies simulated in some of reports shown below, which confirmed that these reports' results were inaccurate.

This could serve as a warning of what happens when a contractor and architect rely on such unreliable reports, and made this "field guide" that much more interesting.

When I review a construction submittal, once in a while I stumble upon a thermal simulations report that either doesn't make any sense. Over the years I reviewed so many thermal reports, that I could spot what I saw as my initial weakness to be almost a regular business among others.

Moreover, these reports were almost never complete, omitting facts and data that could be used to verify their results. Also, more often than not, these reports did not reflect the respective drawings and specs, and the simulation could be only as good as data fed into it.

For over two decades in the business, in preparation to this work, I collected many bad examples, and I recently realized that I misplaced all of them. They are sitting somewhere on one of the countless backup drives or discs, and their lack is a good example why work like this should not be procrastinated upon.

However, stumbling on several particularly bad examples recently (you will notice that almost all bad examples here come from one or two reports, produced by one or two engineering firms on a recently built project), I thought I may produce this "Field Guide to Tell Thermal Simulations Apart." just based on these, as they combined almost all possible mistakes that I intended to write about. We will not name any names to protect the guilty.

Looking for good examples for comparison, I invariably ended with examples of my own work, which is also fairly sad reflection of the status quo, so I had no choice, but to present it here. To avoid any suspicion of self-dealing, I haven't done this work for several years, nor I intend to restart this part of my commercial practice.

In the end, this "short" field guide ended up quite long. Subtraction is more difficult than addition, so some of this material you may find repetitive or excessively detailed. Yet, what you have in front here is a draft, awaiting completion, and awaiting supplementing with the samples that are yet to be found on our hard drives.

This is a practical guide, intended for simplification of a task that many already find quite intimidating. Therefore, I stayed away from building physics here as much as possible. It's fairly well detailed in my "Thermal Engineering" seminar instead.

This "field guide" is intended for you, the reviewer of submittals, or perhaps one of my former competitors, to learn how to tell good ones from bad ones. Enjoy, and if you like it, send me a note. The email address is INFO (at) B-E-I.ORG.

It's educational material, not intended to create any bad feelings. Therefore, great effort was expended to anonymize all the bad examples. If you notice that any component remained that would allow for identification of a project, work, its author, or a company, please let me know, so we could conceal or otherwise cover it.

Low Hanging Fruit - Materials and Boundary Conditions and Their Assignments

The single area that is most vulnerable in any simulation and calculation is the materials and boundary conditions. Their values and assignments to specific components are crucial.

Solid Materials

The properties of materials are based on the standard EN12524 " Building Materials and Products - Hygrothermal Properties - Tabulated Design Values," referenced by NFRC. The project-based boundary conditions were used in order to model convective air film coefficients. Conductivities of air cavities were calculated based on CEN (European Committee for Standardisation) rules (EN ISO 6946 and EN ISO 10077-2. The materials used in the simulations of this project are listed below:

Name	Conductivity W/mK
Aluminum	160.00
Steel - Galvanized	62.00
Steel - Stainless	17.00
Glass Lime -Soda	1.00
Silicone Filled	0.50
Ethylene Propylene Diene Monomer (EPDM)	0.25
Mineral Wool Batt (assumed CW90)	0.035
Polyethylene Foam	0.034
Polyamide Nylon	0.25
Polyvinyl chloride (PVC)	0.19
Air Cavities	Calculated per CEN rule.
Glass Air Cavity	Calculated per the App.B

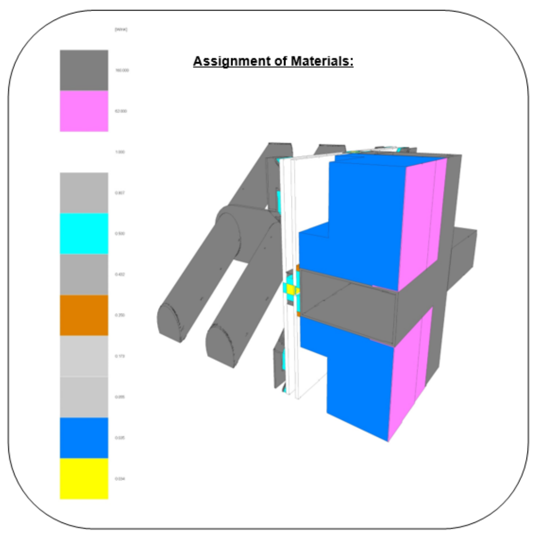


Fig. # 1 and 2. Here is a good example of data listing, either simply typed in a MS Word table, or pulled from software that are capable to produce such a legend automatically, such as e.g. Physibel's Solido. There is a list of materials and cavities, numbers assigned to them, and colors representing them on drawings, as well as explanation where these numbers came from. Its reading allows you to verify whether correct numbers were assigned to modeled components. You would normally also need a similar table for. boundary conditions, emissivities, glazing numbers, etc. This was a 3D simulation, with data validated by a 2D simulation, but in your typical 2D scenario you would also need to see "spoiled materials" for intermittent bridging. Courtesy of Building Enclosure Consulting Inc.

It's mind boggling to think about everything that could possibly go wrong with them. In order to jeopardize a simulation, it's enough to e.g. assign a material with lower thermal conductivity to a crucial component, e.g. glass spacer, or bump emissivity of a thermal break facing a cavity a little, or change characteristics of the air space, or assign a higher temperature to the interior enclosure model, or increase interior air speed, or decrease the exterior one, or calculate the bridging ratio in the third dimension incorrectly, etc. Glass units and breakers are also very tricky to get right.

How could you verify it? Almost every software produces a report that should allow a reviewer to verify its veracity, either simply by checking it, or even by reproducing the simulation. Some software does it better, some worse, e.g. Solido prints a map of colors, that allows for very easy verification. Therm's report skips the colors, and only prints the list; therefore, forcing a reviewer to re-model and re-simulate a detail, and requires use of shop drawings to verify assignment of the materials and boundaries. Some examples are shown below. Refuse to accept any reports that are missing this data.

Not to blow in my own horn (and to be clear, I haven't provided these services for several years, nor I plan to provide these services in the future), I would like to show it as a good example, because there simply aren't any others out there to show in such a light. If you received one of my simulations (such as the template under the link: http://bec-miami.com/sample%203D%20report.pdf), you were given all this necessary data and more: there are specs, glazing options, legible shop drawings, and color-coded material and boundary properties listed in respective appendices. See Figs. #1, 2, and 57.

In majority of cases, project-specific data is used, reflecting conductivities of actual materials, based on their testing results listed in their respective submittals. If these are unavailable, or the testing is a generic benchmark, the "standard" data is used, such as seen in Fig.#5 or #6. Same applies to external and internal climate conditions. Fig #34 and 46 illustrate some examples. In both cases, you will need to compare it with their respective sources.

Why? Because of the tendency to misrepresent these numbers seen in many reports this author reviewed. One of many such examples is shown in Fig. # 50. where two layers of a proprietary 3" thick insulation listed at nominal R17.4 each in their submittal, became R40.6. (17.4x2=34.8, and not 40.6) . Another example in Fig #4 shows an SPF insulation having 0.013 conductivity (in reality, its approximately 40% worse).

I observed as a general rule, that all these misrepresentations seen make them look better than they really are, suggesting a certain pattern. (If it were a matter of simple mistake, the pattern should be evenly distributed.)

Add to it the modelling errors, which could stem from many factors, such as: minor discrepancies resulting in lack of mating, differences between the model and the shop drawings, inaccuracies of shop drawings, lack of shop drawings and architecturals showing adjacent conditions, inferior architecturals, etc.

Poor meshing adds to the challenge, and these are just the simulation (or to be precise: pre-processing) errors. Poor meshing sometimes decouples two faces causing lack of mating, and makes a detail less conductive, resulting in too optimistic conclusions.

Economic Considerations and The Most Important Advice

Reports shown here as examples are generally characterized by a single very distinct trait: omission of authors' names and signatures. They are missing not because we concealed them for anonymity, but they were never there, and my old comments visible on those reports clearly flag this nonconformance. Also, all the nonconformance flags placed on those reports were universally ignored. You might have similar experience, and it's not limited to thermal simulations but also other engineering disciplines. Have you wondered why? I will shed some light on these curious circumstances below.

Reports quoted as examples here are also badly incomplete. However, the inclusion of all the necessary data makes reports quite large. My average report for a simple window job was 60 pages long. It may seem uneconomical, considering that the average revenue for such a job was less than $1k, and it came after a fully-blown 10-page long proposal was prepared and negotiated, back-and-forth communication took weeks, and countless hours were spent on weeding and retrieving the data.

In my case, it seemed like a perfect downtime filler, but it seldom turned-out to be so, as explained below.

The challenge of working at the bottom of the food chain, besides low financial incentives, is the impenetrable management structure filled with alternating layers of competent and incompetent people above you, in accordance to one of the Parkinson's Laws. Very often, some of them were displeased with the draft report I submitted to them and demanded that certain information was removed or altered, while others had a different view, and demanded that yet another fragment was removed or altered. I only succumbed to such demands by replacing them with lengthy disclaimers. I run a single-man shop, so I couldn't really refuse to sign my work, but I was often tempted.

The single most expensive component of a job was the time it took to get the information needed for the work: I would either be flooded with hundreds of pages and megabytes of irrelevant files in exotic formats requiring installation of yet another piece of software, or an upgrade of existing program, or both, or there would be scarcely any information made available in spite of looming deadlines, or a combination of the two coming in waves precisely when I was scheduled to be in the field on more demanding and better paying jobs, the dates that I typically announced to my clients weeks ahead to no avail.

The two most distinguishing characteristics of incompetent people are: 1) their inability to distinguish relevant from irrelevant, and 2) inability to think in long term and anticipate consequences. The lower you work in the food chain, the more you'd see of them, which explains frequent frustration of overqualified immigrants, who re-started their careers at the bottom of the career ladder. In the past, language barrier in combination with above-average technical qualifications caused immigrants to be overrepresented among software operators, modelers, and simulators. This natural selection on the other hand, may explain why the competent people among these layers were often frustrated, showed bad attitude, and it took a lot of concentrated effort to understand them.

The ultimate result was an emergency call made out of what should otherwise be a perfect leisurely-paced downtime filler. To overcome this challenge, I hired and trained an operator to fill for me when I didn't have the time. Then, I realized that as a result of this delegation, neither the quality was under tight control any more, nor this line of business made any financial sense any more. Around that time, the opposite process happened in some larger organizations (the only kind left in this field of work, as far as I know), they laid off expensive personnel, and their trainees assumed the work, in yet another illustration of Gresham's law: bad money drives out good.

I summarized this story above for a reason: it helps to understand other people's circumstances, and it indicates perhaps the most important challenge for a reviewer. How to demand quality, if they may not have financial incentives to spend any time on callbacks, they often bury their heads in sand instead, the quality control is almost nonexistent, and the extremely thin margins may make some of their companies strive for repetitive business, perhaps explaining why the data and results are almost always observed to be skewed one way only: the way that would please their clients.

Here is perhaps the single most important piece of advice in this paper: the answer is contained in the initial question: find out who was the unsigned author, get their mobile number, and get him or her on the phone.

You would find that people at the very bottom of the food chain have a very deep sense of decency and pride of ownership. If you make them talk, their frustration could overcome their rational considerations and restrains, and you may learn the actual reason why their name did not appear under their work. Record the conversation if possible, and get all the info you need during this single phone call, because it would be the only opportunity.

You just overstepped your authority, and crossed multiple layers, upsetting many people in the process. A swift communication ban almost always followed such a call.

U-factors

Name	Length in.	Basis	U-factor Btu/h-ft2-F
SHGC Exterior	2.69	Unknown	0.9130
Frame	2.72	Unknown	1.0309
Edge	4.53	Unknown	0.3101

Solid Materials

Name	Conductivity Btu/h-ft-F	Emissivity
Polyisobutylene (PIB)*	0.12	0.90
Aluminum Alloys (Anodized)*	92.45	0.80
Silica Gel (Desiccant) - Loose Fill*	0.02	0.90
Silicone*	0.20	0.90
Urethane - Thermal Break*	0.07	0.90
Aluminum (Painted)*	136.94	0.90
Aluminum (Anodized)*	136.94	0.80
spoiled air cavity	0.13	0.90
Ethylene Propylene Diene Monomer (EPDM)*	0.14	0.90
spoiled aluminum	125.37	0.90
Aluminum (Oxidized, Mill Finish)*	136.94	0.20
Spoiled EPDM	1.03	0.90
Polyamide (Nylon)*	0.14	0.90

Cavities

Name: Frame Cavity NFRC 100*
Gas Fill: Air
Convection Model: ISO 15099
Radiation Model: Standard

Poly ID	Heat Flow Dir	Side 1 Temp F	Side 1 Emis	Side 2 Temp F	Side 2 Emis	Dimension Horz. in.	Dimension Vert. in.	Nu #	Keff Btu/h-ft-F	Cavity Height in.
9	Horizontal	7.19	0.56	6.65	0.80	0.37	2.01	1.00	0.0233	N/A
1	Horizontal	56.29	0.80	18.61	0.80	0.50	0.42	1.20	0.0344	N/A
270	Horizontal	60.32	0.80	58.51	0.80	6.34	2.24	6.51	0.3242	N/A
72	Horizontal	50.43	0.81	32.00	0.82	1.48	0.46	1.47	0.0693	N/A
243	Horizontal	49.98	0.86	26.28	0.48	1.67	0.42	1.35	0.0580	N/A

Glazing Systems

Name	COG U-factor Btu/h-ft2-F	Overall Thickness in.	Cavity Height in.
Double Low-e Air SN62	0.29	0.97	39.37

Fig. # 3. Above is a standard LBNL Therm software report showing material and boundary data plus some goodies such as IGU numbers, standard error, and resulting U factors. Although limited, it allows to spot many errors. Demand one, it's free.

Its reading allows you to verify whether correct numbers were assigned to them. Note that emissivities are also listed here due to quasi-emulated radiation simulation implemented in Therm.

Look for e.g. "Spoiled air cavity," and "Spoiled EPDM," indicating weighted conductivities. This reading allows the reviewer to verify whether the spoiling was applied, as required by NFRC standard to approximate 3D conditions (therefore not needed in 3D simulations). Not seeing them should be a warning sign.

A reviewer is left guessing what material was assigned where, and unable to verify whether it was done correctly. What is missing is colors representing them on drawings, as this software (LBNL Therm) does not have such functionality. A modeler would have to type it e.g. in a MS Word table, as in the previous example, or in Fig. #60.

This is a standard report that comes with every Therm simulation, but even though it's so limited, this report has always been omitted from every report I have seen so far. In order to show such a correct example, I had to pull one of my old reports.
Courtesy of Build ing Enclosure Consulting Inc.

Table A.1 – *Material Properties*

Material	Thickness (In)	Thermal Conductivity (BTU/hr·ft·°F)	R-Value (hr·ft^2·°F/BTU)
Vertical and Horizontal Systems			
Interior Air Film[a]	-	-	R-0.7
Gypsum	5/8"	0.092	R-0.5
Stud Cavity Air Gap	4 1/8"- 5 5/8"	-	R-0.9
DOW SPF CM Series Sprayfoam	1 ½"	0.013	R-9.8
Steel Studs/Girts	18 gauge	35.8	-
Sheathing	5/8"	0.092	R-0.5
Polyiso Insulation	1.55"	0.022	R-10.1
Exterior Air Film[a]	-	-	R-0.7
[redacted] System			
Interior Air Film[a]	-	-	R-0.7
Gypsum	5/8"	0.092	R-0.5
Stud Cavity Air Gap	4 1/8"	-	R-0.9
DOW SPF CM Series Sprayfoam	1 ½"	0.013	R-9.8
Steel Studs	18 gauge	35.8	-
THERMAX Polyiso Insulation	1.55"-3"	0.022	R-10.1-R-19.0
Stainless Steel Bolts	0.216"	11.6	-
Steel vertical and horizontal rails	18 gauge	35.8	-
Isolator (Polyoxymethylene)	0.173"	0.12	
Exterior Air Film[a]	-	-	R-0.7

[a]Air film values are selected from table 1, p.26.1. of ASHRAE Handbook – Fundamentals depending on surface orientation

Fig. # 4. Here is an interesting example of manual data listing. There is a list of materials and boundary conditions, and numbers assigned to them, with some superfluous data that helps to visualize the assembly, and verify numbers (R values are easier to grasp, because bigger is better here). Having it included in the report is rare enough, and therefore commendable.

The advantage is obvious at the first glance, as it made spotting errors easy here: e.g., comparing the two roughly 1.5" thick insulations having both roughly R10, one cannot help but wonder how their conductivities could be so different. In fact, SPF conductivity is pushed roughly 40% on the optimistic side, which is disturbing, because the conductivity column represents values used in the model.

I observed generally that all misrepresentations seen in material data in such reports make them look better than they really are, suggesting a certain pattern. If it were a matter of simple mistake, the pattern should be evenly distributed.

What is also missing is colors representing these materials and boundaries on drawings, just as in the previous example.

There are no "spoiled" materials because it was a 3D simulation. The confusing "vertical and horizontal" title is just a misnomer, the entire set of simulations included only horizontal transfer.

However, if there was a vertical transfer (as in e.g. a skylight or a roof), an additional set of vertical-transfer-specific values would be necessary, something to keep in mind reviewing such data.

Names of the authors withdrawn to avoid any bad feelings. This came from a good, knowledgeable team, so it's probably just a typo, also it was one of the very few reports that was actually signed and sealed.

Page 5
EN 12524:2000

Table 1 - Design thermal values for materials in general in building applications

Material group or application		Density ρ kg/m^3	Design thermal conductivity λ W/(m·K)	Specific heat capacity c_p J/(kg·K)	Water vapour resistance factor μ dry	wet
Asphalt		2100	0,70	1000	50000	50000
Bitumen	Pure	1050	0,17	1000	50000	50000
	Felt / sheet	1100	0,23	1000	50000	50000
Concrete [a)]						
	Medium density	1800	1,15	1000	100	60
		2000	1,35	1000	100	60

Fig. # 5. Where did these numbers come from? One of the go-to standards is EN 12524 " Building Materials and Products - Hygrothermal Properties - Tabulated Design Values," copied here and referenced by NFRC. It's a long table full of numbers.

However, in majority of cases, project-specific data is used, reflecting conductivities of actual materials, based on their testing results listed in their respective submittals. In case of glazing, there would be a separate data for e.g. IGU spacers, etc.

Table 5-1. Environmental Conditions for NFRC Simulations for U-factor calculations.

Variable	SI Units	IP Units (reference only)
Outside Temperature	-18°C	0°F
Inside Temperature	21°C	70°F
Wind Speed	5.5 m/s	12.3 mph
Wind Direction	Windward	Windward
Direct Solar	0 W/m²	0 Btu/hr-ft²
Sky Temperature (Tsky)	-18°C	0°F
Sky Emissivity (Esky)	1.00	1.00

Fig. # 6. Where these numbers come from? If no site-specific climatic and location data are required, NFRC "Simulation Manual," lists environmental conditions for benchmark testing per the discussion about U-values in the text below. Copied from NFRC.

> Note 2: The NFRC benchmark conditions of our U -Value simulations (0°F /70°F) are more stringent than the winter environmental criteria (7°F /72°F) listed for this project in 018100/1.09/H.

Fig. # 7. Input data would differ between benchmark U-value, project-specific U-value, and condensation assessment, per the discussion about U-values in the text below. Project-specific criteria would often be more stringent, and the purpose of this note was to flag the opposite situation. Courtesy of Building Enclosure Consulting Inc.

Of those, the first two examples of mating and meshing are operators' domain, that happen exclusively during this stage, and are very difficult to spot even for an experienced operator. A simulation that yields different results based on the same model with the same parameters is one of the most unnerving discoveries. Some are software glitches that could persist for years, surviving multiple updates and upgrades.

There is plenty that could go wrong with this phase. It just illustrates the unspoken difference between the real testing and virtual testing. My experience running a real diagnostic after virtual testing was eye opening. Watching such a simulated, approved, and built façade later through a lens of thermal imager often brings severe disappointments.

The easiest verification method is to ask for the Therm model (file with THM extension) and play with it. The software is free, and fairly easy to learn. If the model includes glazing, the library file is too large for an email attachment. Sadly, although I often offered to share my THM files, I never heard back.

The bottom point is that a reviewer wouldn't be able to pick the two above issues, unless he or she embarks upon the re-modeling and re-simulation of the condition. The remaining ones are easier to spot, and we will focus on them below.

Differences between the model and the shop drawings.

This weakness is typically demonstrated by e.g. unrealistic modeling of system-specific components of a detail itself, particularly those components that are intermittent in the third dimension, e.g. beauty caps, glass spacers, certain thermal breaks, and fasteners.

The information e.g. that pressure bar fasteners and their breaks are spaced 12" o.c. or that there are only two glass short spacers along the length of the sill, or that horizontal aluminum extrusions are installed with gaps at mullion intersections to allow for unrestricted differential movement, or that certain snap-on caps are intermittent, would be fairly obvious to anyone familiar with the glazing trade, besides it comes with the system manual, and therefore the information is seldom repeated on shop drawings, unless some exception from the rule needs attention. It's not so obvious to the average thermal modeler, nor would he or she know where to look for it.

The average modeler and simulator may be seldom either experienced enough to understand how the detail and the surrounding conditions would look in the real world, or capable to search for or request the missing information, such as product catalogues and specs. Even if they were, their chances of actually receiving the project-specific information would be slim, as I describe in the next chapters.

Next issue is a model that poorly matches shop drawing. Some simplifications are necessary, such as rough faceting and division of complex shapes, particularly curves, but some others, e.g. omission of interior or exterior enclosures, would make a model completely irrelevant. E.g. Fig. # 35. shows obvious omissions of a suspended ceiling and a fire stop.

How to spot it? Look at shop drawings that served as the basis for modelling. These are often supplied in advance, and could be very different from the current version you have in front of you, giving you one more reason to verify it (see below).

The first mark of a poor simulation would be either omission of copies of shop drawings that served as a source (e.g. Figs. #11-13), or their reproduction would be illegible, and their versions and issuance and revision dates would be unreadable, or omitted. Unless you could figure out their version and retrieve them on your own, you would have nothing substantial to compare such a model with. If you are reviewing a report, there is a good chance that you also reviewed the shops, and are willing to do it, but it would add to your workload, besides differences between subsequent revisions may be very subtle. It's better to reject the submittal right away.

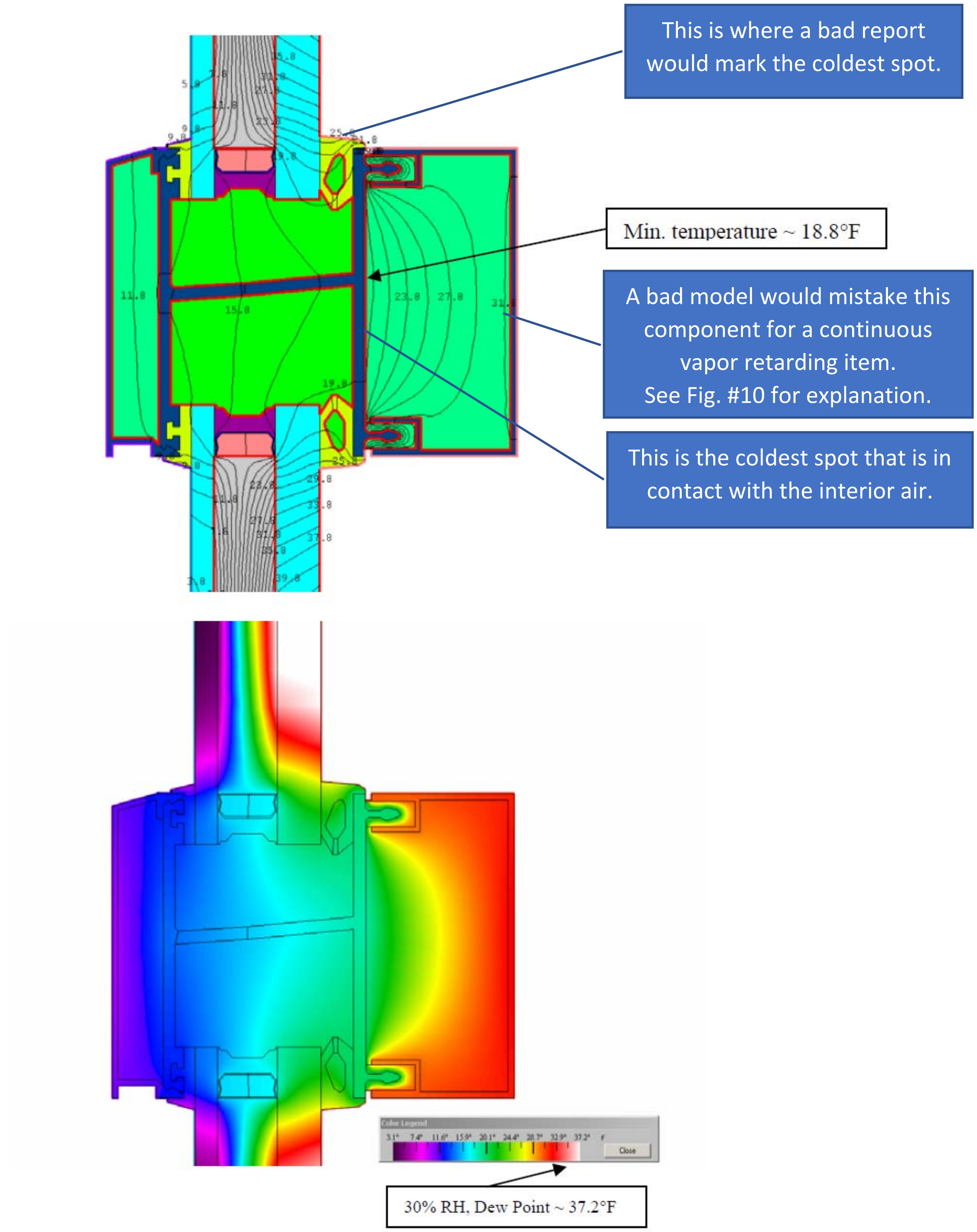
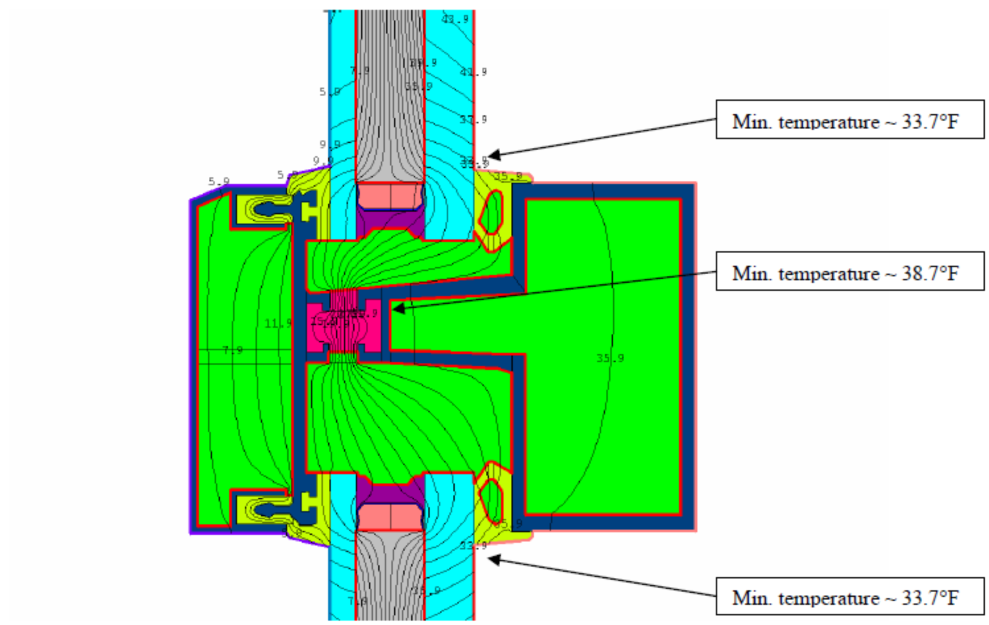


Fig. # 8. Above is a good example of picking the lowest temperature behind an intermittent component. Most reports I've seen would point to the relatively warmer glazing gasket instead, ignoring the concealed sweating surface of the horizontal mullion. In order to show such a correct example, I had to pull one of my old reports. Courtesy of Rafael Vinoly Architects.

curtain wall horizontal mullion with "pour and debridge" rigid PU thermal insulator
Ext. temp. -5°F, Int. temp. +70°F, **26% RH**, Dew point ~33.6°F



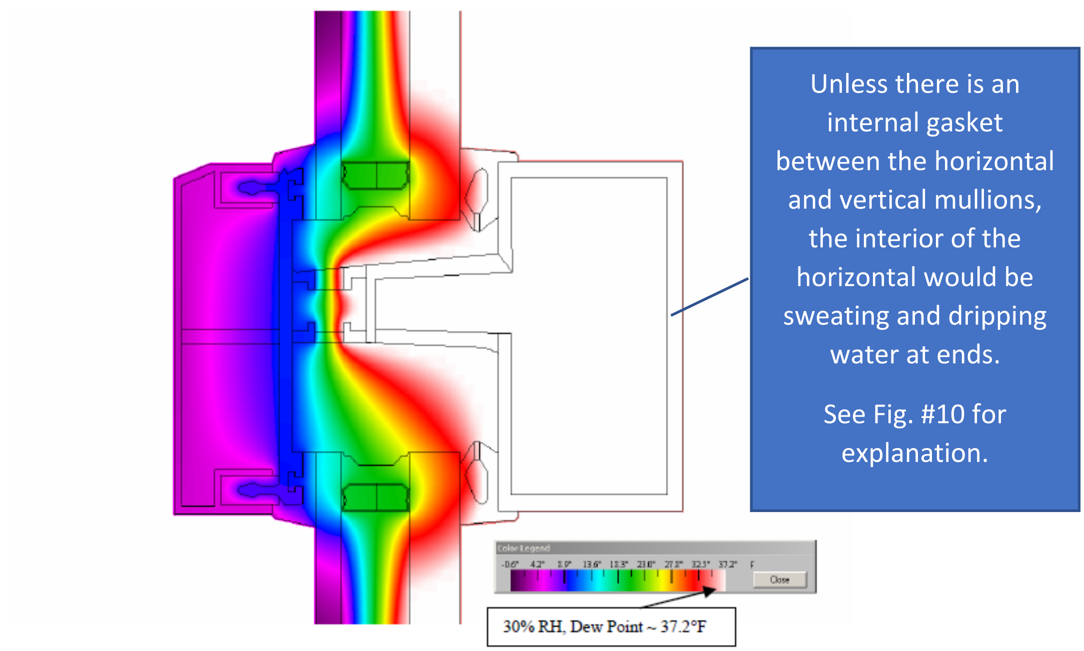


Fig. # 9. Above is another good example of picking the lowest temperature behind an intermittent component. Many reports I've seen would point to the relatively warmer glazing gasket, ignoring the concealed sweating interior surface of the horizontal mullion. Unless there is an internal gasket between the horizontal and vertical mullions (fairly standard in Europe, almost unheard of in the U.S. – see the next figure), the interior of the horizontal would be sweating and dripping water at ends. In order to show such a correct example, I had to pull one of my old reports. Courtesy of Rafael Vinoly Architects.

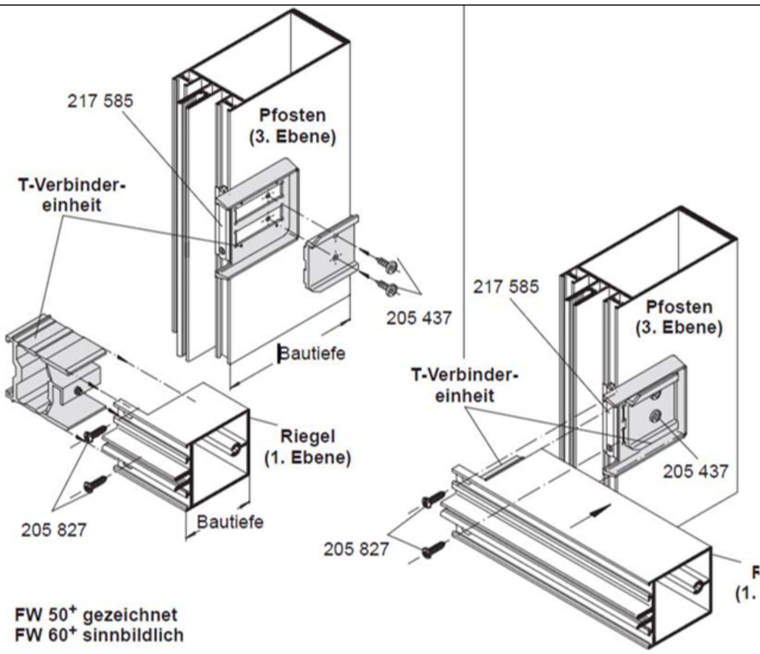


Figure 6. Examples of dedicated gaskets sealing mullion connections

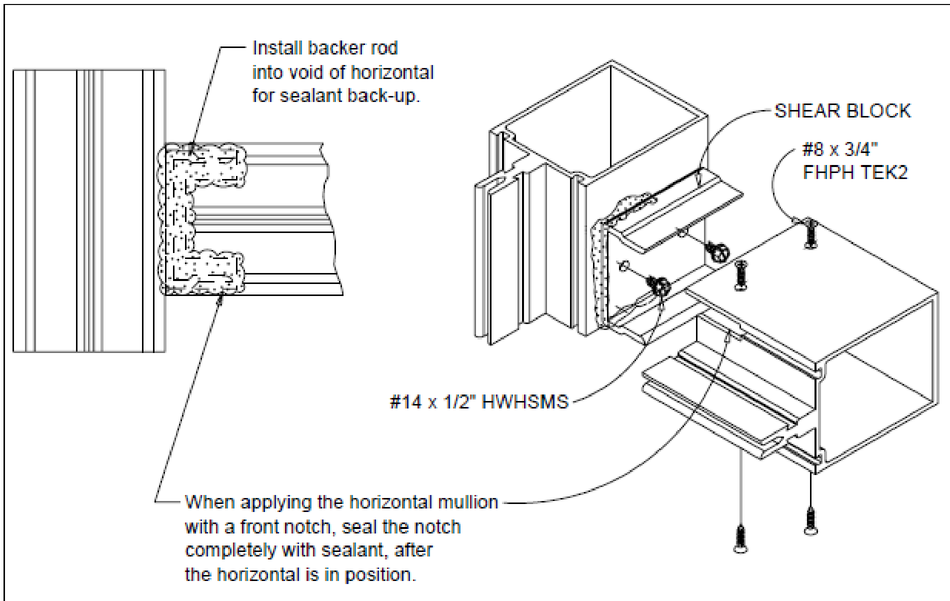


Fig. # 10. Examples of internal gasketing (above) between the horizontal and vertical mullions, and an unsealed gap left behind them (below). The former provides an air seal, the latter doesn't. If in doubt, assume the latter. Courtesy of Schuco and EFCO.

If you have the shop drawings, look at those components that are intermittent, and determine two things:

a) do they look like they are correctly represented (I will tell you how to verify it later), and

b) were they treated as an air barrier? E.g. did the modeler pick the lowest interior temperature in front or behind an interior beauty cap, in their condensation risk analysis? See Figs.#8, 9, 10, and #37 for typical examples.

Inaccuracies of shop drawings

Early shop drawing versions used for modeling are generally short lived, and therefore could be very different from the current version (see also the discussion above).

In addition, their drafter is limited with respect to the adjacent conditions, which are contractually required to be supplied in advance by the general contractor or design-builder, but seldom are, particularly during this early stage when modeling and simulations are typically done, ahead of every other building skin trade.

Customers recently became acutely aware that these transitions to adjacent conditions are crucial to their building performance, and therefore began specifically demanding their project-specific modeling and simulations, creating a confusion explained in the U-value chapter several pages below.

As the modeler and simulator is often separated by up to five levels from the owner 's rep making such a demand, with the two responsible parties often sitting in the middle of the communication chain, and having vested interest in different outcomes, results are invariably disappointing.

A modeler could not reasonably expect to get shop drawings of adjacent conditions, because he or she is placed at the bottom of the pecking order: neither privy to GC's contractual obligations to the owner, much less in position to demand that GC would fulfill these obligations to provide him or her with shop drawings of other trades. The GC on the other hand, even with best intentions could provide no such drawings, because the modeler is most likely employed far ahead before they would be drafted by other trades. Besides, their transitions would need to be engineered, and this work is seldom done at all.

Therefore, most often, an architectural detail would be used instead of a nonexistent shop drawing. A true simulation of an architectural detail almost invariably proved that the transition would not only fail in the real world, but would also hurt the results of the fenestration alone, by freezing its perimeters, as I often demonstrated in my seminars. I also discuss this issue in the U-value chapter later.

It makes the situation even more awkward for the subcontractor, who would either risk to challenge the architect's authority, potentially jeopardizing their future review, or silently submit the true result, hoping that no one would notice. Such a "fail" report often successfully passed all checks, was approved surprisingly enough, and assemblies based on it were produced and installed in the field. I will describe some of them in the future chapters. Fig.#22 shows such a product of mine.

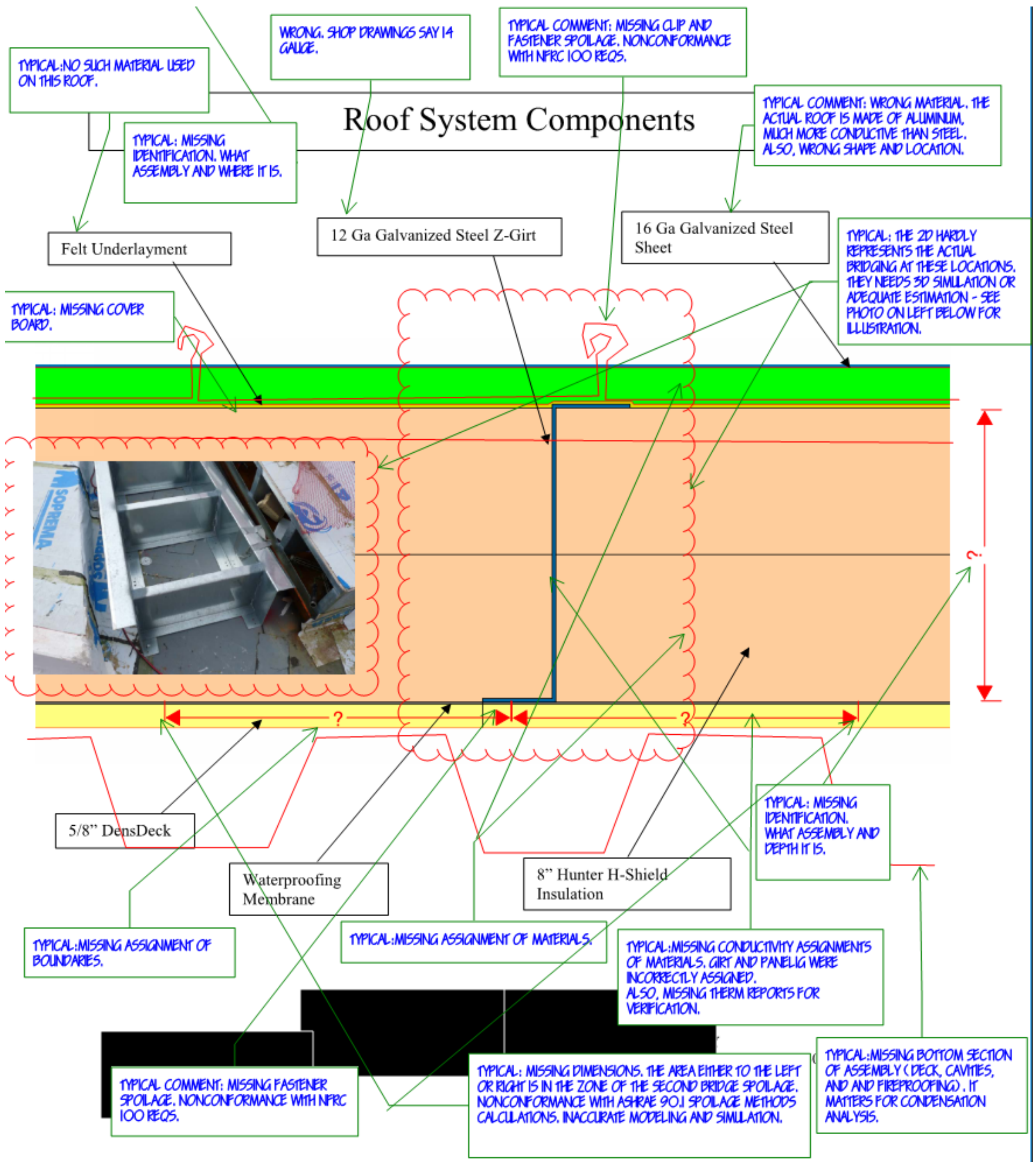
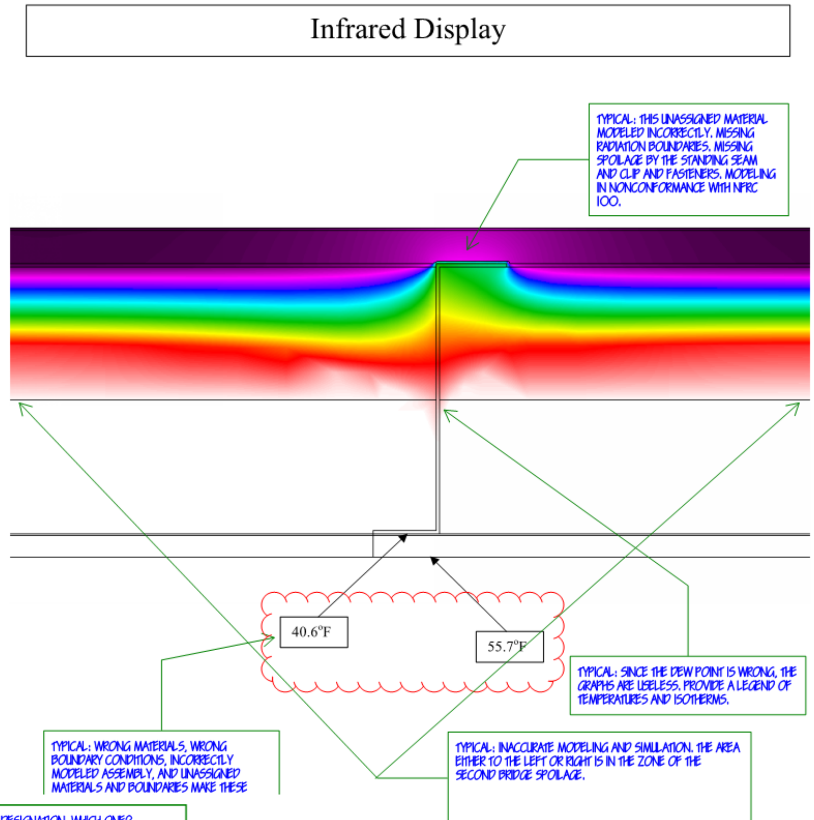


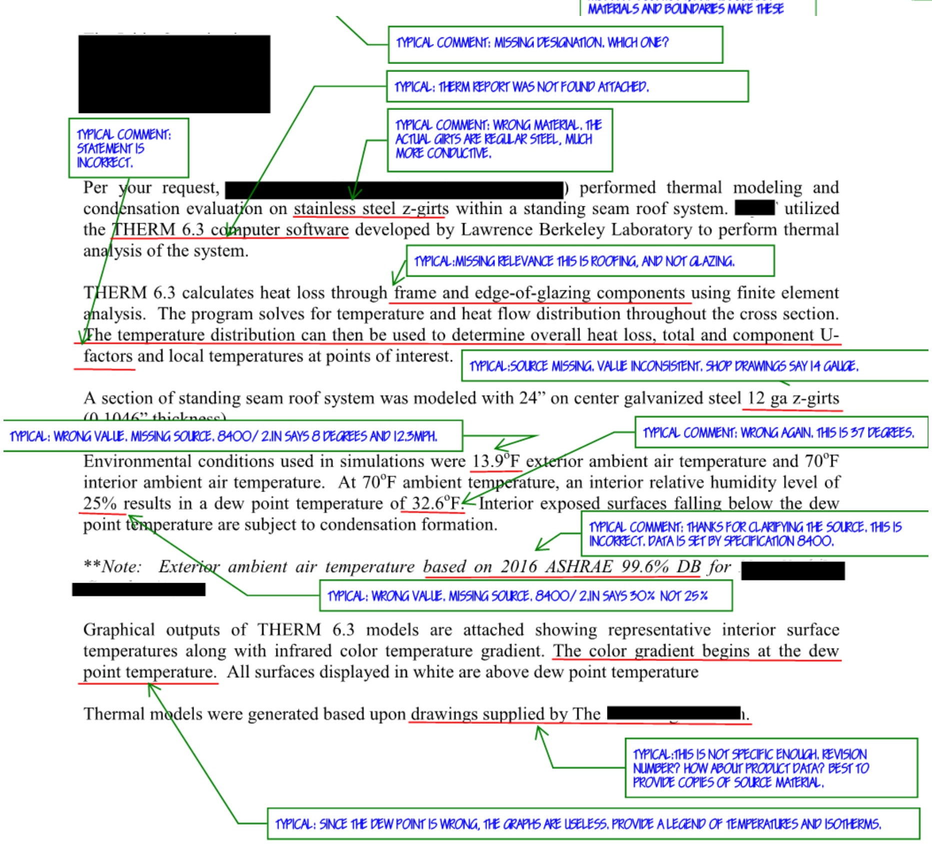
Fig. # 11. Examples of multiple departures from shop drawings: wrong materials, missing and imaginary components, wrong and missing assignments, etc. Multiple inaccuracies and internal inconsistencies are seen here, e.g. it's unclear whether the crucial girt was modeled with stainless steel as stated on the first page reproduced in Fig #13, or with galvanized steel as stated on the page reproduced above. The roofing is modeled with less conductive metal, magically hanging on a thick air cushion, and the cold bridging clips were omitted. The entire insulated deck assembly, as well as the suspended ceiling assembly below it, were omitted as well, explaining unrealistic results shown in Fig. #12. In this case, the submittals came long after the installation started, allowing to place a photograph of the actual installation on the reviewed submittal for comparison, always a bad sign. (*Btw. Design-Builder escorted me out of job site under pretense that I don't have a "scaffold license" that would entitle me to walk the stair tower, after I had a nerve to take these photographs and to ask to see the roofing submittal.*) Also, the dense perpendicular bridging made the 2D simulation irrelevant, as could be gleaned from the photo and Fig. #14. The report was unsigned, and I concealed the name of the company to protect the guilty.

Fig. # 12 Temperature map from the previous example, illustrating the caveat of utilizing color map cut at the Dew Point, if the Dew Point was incorrectly calculated as in this example (see Fig. #13). There still needs to be a color legend attached, coming standard from the software printout, which authors omitted in this report for reasons unknown.

The biggest giveaway of this simulation's result at odds with its model is the two temperature spreads: ~15◦F within a single gypsum board, and ~14◦F within the interior air film, suggesting that the remaining ~27◦F spread comes with R value of approximately R1, which would have to represent the entire roofing, the (unrealistic) air cavity, and the exterior air film. The math not only doesn't add up, but also, if the actual interior assemblies, with their thick fireproofing, were added to such a model, the temperature reading in this layer would fall dramatically.



See the figure#14 on the next page for the actual "Infrared Display" of this detail. See also Figs. #15-17 for attempts to replicate this result.



[redacted]

TYPICAL COMMENT: MISSING DESIGNATION. WHICH ONE?

TYPICAL: THERM REPORT WAS NOT FOUND ATTACHED.

TYPICAL COMMENT: STATEMENT IS INCORRECT.

TYPICAL COMMENT: WRONG MATERIAL. THE ACTUAL GIRTS ARE REGULAR STEEL, MUCH MORE CONDUCTIVE.

Per your request, [redacted]) performed thermal modeling and condensation evaluation on stainless steel z-girts within a standing seam roof system. [redacted]' utilized the THERM 6.3 computer software developed by Lawrence Berkeley Laboratory to perform thermal analysis of the system.

TYPICAL :MISSING RELEVANCE THIS IS ROOFING, AND NOT GLAZING.

THERM 6.3 calculates heat loss through frame and edge-of-glazing components using finite element analysis. The program solves for temperature and heat flow distribution throughout the cross section. The temperature distribution can then be used to determine overall heat loss, total and component U-factors and local temperatures at points of interest.

TYPICAL :SOURCE MISSING. VALUE INCONSISTENT. SHOP DRAWINGS SAY 14 GAUGE.

A section of standing seam roof system was modeled with 24" on center galvanized steel 12 ga z-girts (0.1046" thickness)

TYPICAL: WRONG VALUE. MISSING SOURCE. 8400/ 2.IN SAYS 8 DEGREES AND 12.3MPH.

TYPICAL COMMENT: WRONG AGAIN. THIS IS 37 DEGREES.

Environmental conditions used in simulations were 13.9°F exterior ambient air temperature and 70°F interior ambient air temperature. At 70°F ambient temperature, an interior relative humidity level of 25% results in a dew point temperature of 32.6°F. Interior exposed surfaces falling below the dew point temperature are subject to condensation formation.

TYPICAL COMMENT: THANKS FOR CLARIFYING THE SOURCE. THIS IS INCORRECT. DATA IS SET BY SPECIFICATION 8400.

***Note: Exterior ambient air temperature based on 2016 ASHRAE 99.6% DB for* [redacted]

TYPICAL: WRONG VALUE. MISSING SOURCE. 8400/ 2.IN SAYS 30% NOT 25%

Graphical outputs of THERM 6.3 models are attached showing representative interior surface temperatures along with infrared color temperature gradient. The color gradient begins at the dew point temperature. All surfaces displayed in white are above dew point temperature

Thermal models were generated based upon drawings supplied by The [redacted].

TYPICAL :THIS IS NOT SPECIFIC ENOUGH. REVISION NUMBER? HOW ABOUT PRODUCT DATA? BEST TO PROVIDE COPIES OF SOURCE MATERIAL.

TYPICAL: SINCE THE DEW POINT IS WRONG, THE GRAPHS ARE USELESS. PROVIDE A LEGEND OF TEMPERATURES AND ISOTHERMS.

Fig. # 13. How many things could possibly be wrong within a single, short report?

Multiple omissions: missing the actual Therm report, missing assignments, the report neither signed nor stamped, etc.

Interestingly, the incorrect Dew Point falls below the lower range of the standard error for the lowest temperature shown above (40.6◦F *90%+ 36.54◦F).

The thermal calculation page of this report reproduced in Fig. # 50. below indicated a severe case of dyscalculia: e.g. R 17.4 x 2 = R 40.6

All identifying marks were masked to protect the guilty.

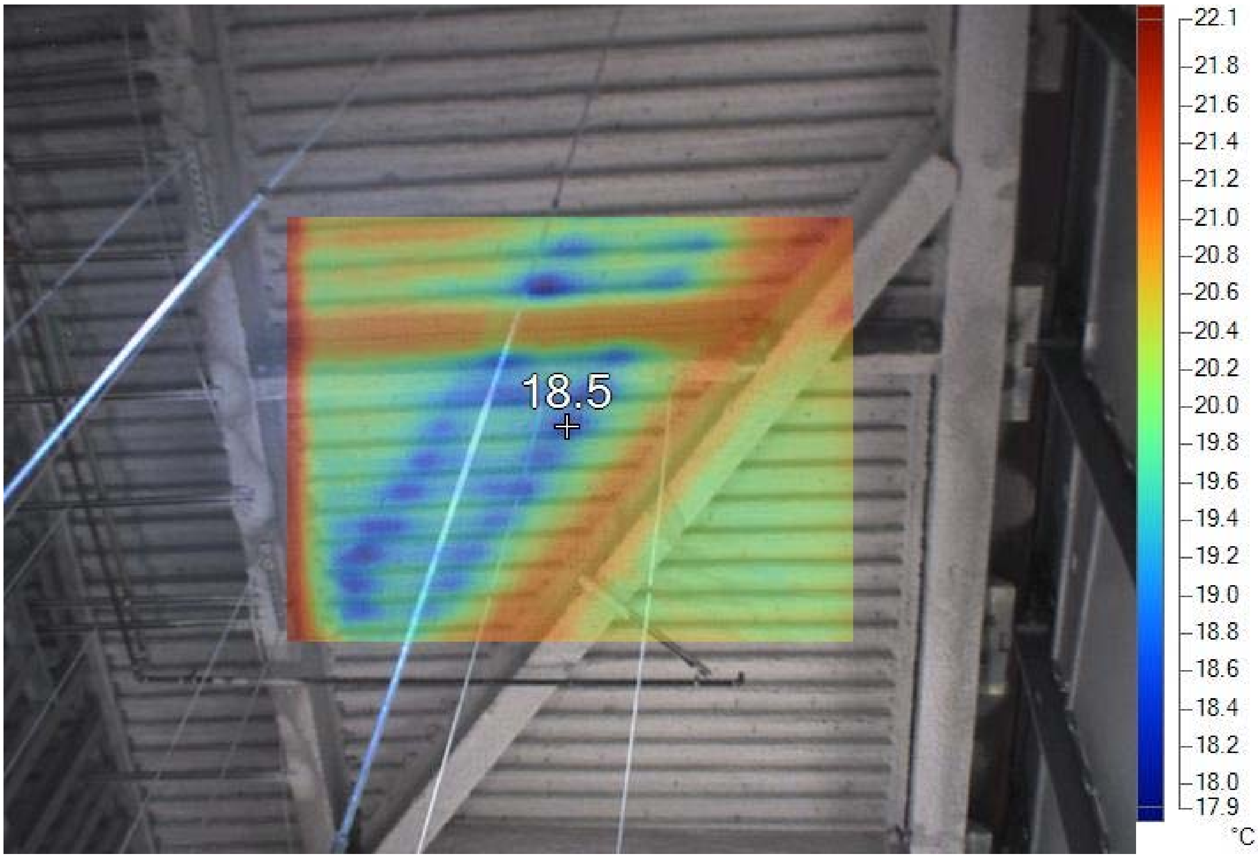


Fig. # 14. This is one of several actual infrared images taken under this fire-proofed composite roof deck during winter, showing the lowest surface temperature 64◦F (17.9◦C), while the outside calm ambient air ranged from 35◦F to 37◦F (0◦, +3◦C), where no suspended ceiling was installed.

Reference the simulation of this assembly shown in three previous figures, that showed the range of 40.6◦F -55.7◦F above the deck at the same location, simulated at exterior ambient temperature -10◦C (13.9◦ F), in Fig.#13, at an unspecified airspeed (most likely standard 12.3 mph). This simulation neither represented the actual conditions, nor its results were replicable as illustrated by our post-mortem autopsy attempts (see the following six Figs. #15-19).

The ultimate concern was a risk of a premature loss of section of steel fasteners attaching the roof girts to the deck, because they are embedded in a gypsum board, and this board is wetted by condensation, while gypsum accelerates steel corrosion. Therefore, this is a rare example in which an uncontrolled interior condensation could cause structural failure.

Extrapolation of these results prompted an extensive investigation in the spring: I installed temperature sensors tied to a datalogger above and below the steel deck in the blue region at a more typical location covered with the suspended ceiling, and a weather station above the roof to collect the site-specific weather data for comparison. However, the data from the next winter was never retrieved from our datalogger, because the next spring I was permanently banned from the site by the Design-Builder.

Courtesy of Building Enclosure Consulting Inc.

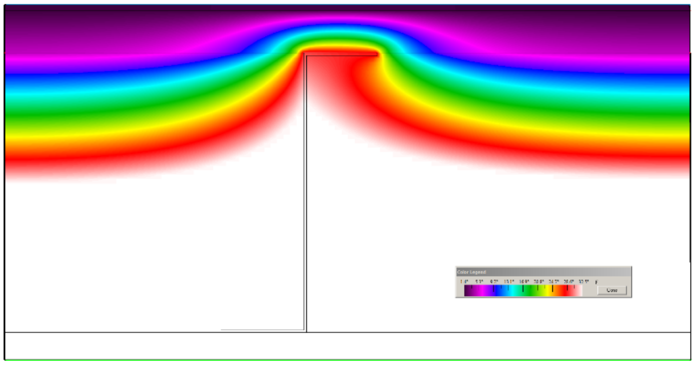


Fig. # 15. Refer to figures #12 above.

This is one of attempts to reproduce these results. It's how this simulation would look like, if the upper layer were assigned air cavity, as suggested by its light green color on Fig, #11.

The temp. range below the flange is 49F-55F, and the temperature map "pushes the rainbow" into the more insulative air cavity, at odds with the temperature map shown in Fig.#13.

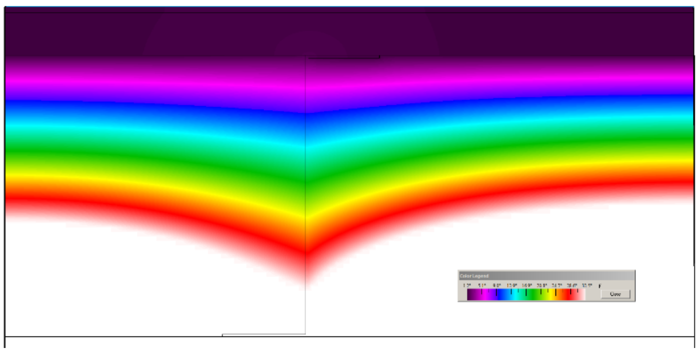


Fig. # 16. This is how this simulation would look like, if the upper layer were assigned galvanized steel, as suggested by the callout.

The temp. range below the flange is 38F -47F, and the temperature map "pushes the rainbow" down the conductive stem of the Z-girt, at odds with the temperature map shown in Fig.#13.

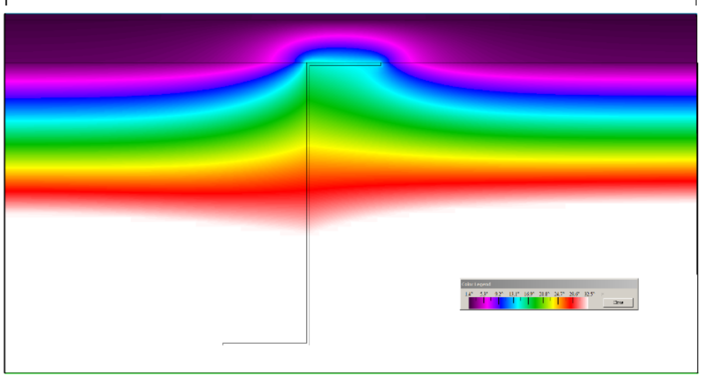


Fig. # 17. This is how this simulation would look like, were the upper layer assigned a sheetrock, as suggested by the front page.

The temp. range below the flange is 44F-51F, and the temperature map "pushes the rainbow" into the more insulative sheetrock, at odds with the temperature map shown in Fig.#13.

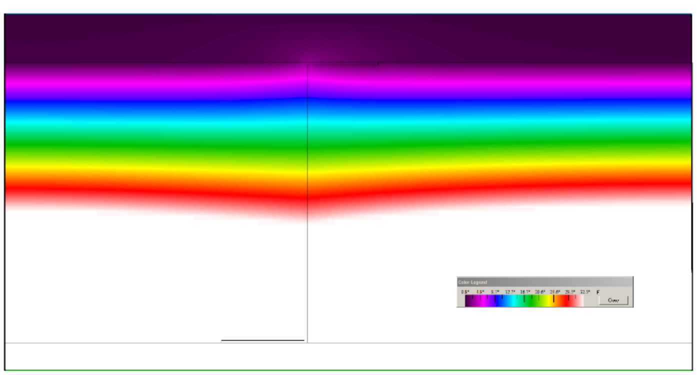


Fig. # 18. This is the closest we got to replicate the results shown on the temperature map that we ever got playing with the materials.

In order to get here, we had to assign the less conductive stainless steel to the Z girt, and the upper roofing layer was made of stone.

The temp. range below the flange is 53F-58F, making clear that the report was not accurate.

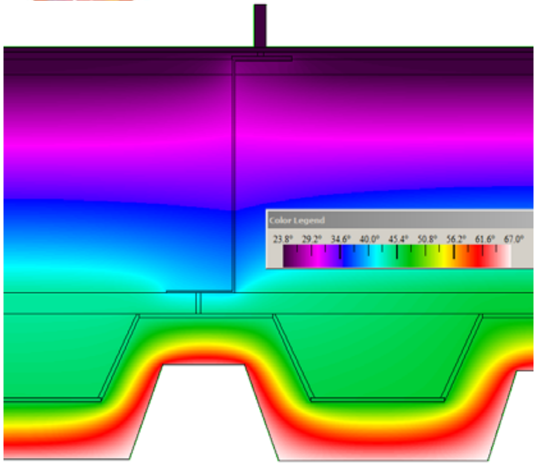


Fig. # 19. Refer to figures #11-18 above.

Here is a crude model of the more realistic scenario, modeled based on observations of the actual assembly, with actual materials, and in correct configuration to match the conditions at 36F outside, and showing the lowest 64F below the deck, as captured in the thermal imaging shown on Fig.#14 above.

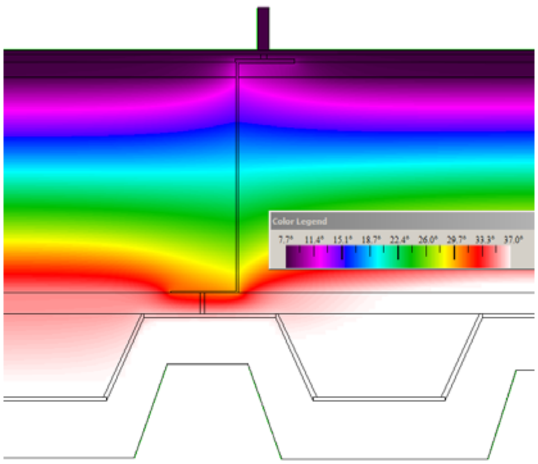


Fig. # 20. Here is the simulation based on the above model and the specified climate conditions (8◦F outside). The lowest temperature on the interior side of the air and vapor barrier is 30◦ F.

One needs to keep in mind the limitations of 2D simulation here. The highest risk would occur at locations of misalignments between the ridges of the deck and flanges of Z grits, as these are not parallel. Therefore, the deck was shifted in the next model, as follows:

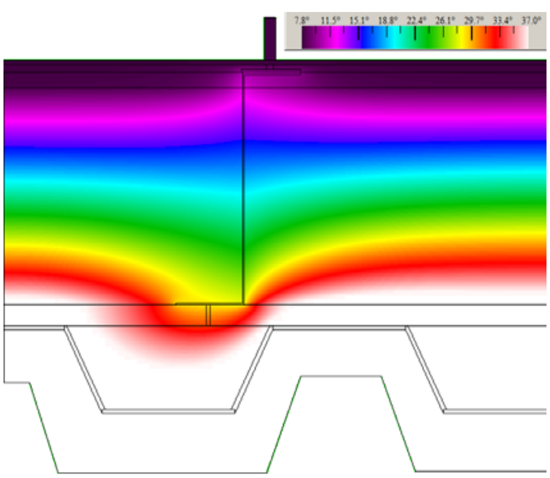


Fig. # 21. Here is the worst-case scenario for condensation risk analysis, the most realistic that was achievable on such a crudely built quick 2D model.

This model more accurately represented such the worst-case scenario, because it decoupled steel deck ridge from the Z girt's flange.

The lowest temperature on the interior side of the air and vapor barrier is 28◦F, indicating a clear condensation risk.

Such a challenge could actually be useful, as it would fulfill the actual reason for having such simulations done for the project-specific conditions, by showing how badly they spoil the pre-simulated "representative sample" results that come with the systems' benchmarks. The trouble is that generally this information comes too late regardless which construction stage it is. Once the primary design stage is over, any major changes would become very expensive, so very little could be accomplished in the delegated design stage. What would be best used as a design tool was instead applied to construction stage, proving the design was substandard, and could never meet the performance objectives set by the owner, embarrassingly enough.

The same could be said about many similar delegated design submittals. This is why it's subject to such games as described here. Some of them are described in my commissioning kick-off seminar.

Even more challenging situation happens when a modeler and simulator are asked to come to the party later, after construction started, often without required shop drawings. Some reports, such as the one shown on Fig.#11, 12, and 13 came after the construction has already started and therefore their function may be misinterpreted to justify defective installation after the fact, as proven by subsequent investigation seen in Figs. #14-21. The pressure inherent in such a situation, should subject results of such a report to more strict verification.

The Design Builder who approved this report, previously certified those inflated numbers for the whole building energy simulations, yet they barely met the project-required performance values, and he could not claim ignorance, because the building enclosure agent kept flagging them as inflated since DD stage, (the roofing was drawn hanging up in the air, where a heavy cold- bridging support was obviously needed, which the design could mitigate if it were addressed at this early stage).

On some projects, architects inflated these values several times, and irreversibly so, because even though the mineral wool is cheap, it takes a lot of space, and by the time of first reckoning, structure has often been already erected in the field, leaving no room for the thermal insulation in the design.

It helps to realize that few architectural offices could afford having expensive and anal-retentive left-brained professionals assigned to Design Development teams, so they are typically composed of right-brained designers.

All my early comments urging for more space for thermal insulation in DD phase were universally ignored by Design Builder. In later discussions, I was told privately that they did not understand my comments, and ignored them assuming that I was just some freaky chronic complainer. Someone making such unusual comments and suggestions couldn't possibly be sane. They assumed that I would not survive long enough on a project, much less actually run diagnostic testing on as-built assemblies. When these results proved their work substandard, Design Builder permanently banned my access to the construction site. If you are such a reviewer, you may prefer to let designers and builders save face instead.

LEED certifications could be revoked only if such misrepresentations were intentional, (https://www.greenbuildinglawupdate.com/2014/06/articles/leed/revocation-of-leed-certification/) perhaps explaining why architects either pretended that they never received my comments and calculations showing how their thermal values in the DD and CD stages were inflated, or flatly denied these data and calcs without any proof to the contrary.

Imagine the disastrous results if the true results were obtained from not only fenestration (e.g. Figs. #22-24, 30), but also other assemblies, such as heavily bridged roofing (e.g. Figs. #11-21) opaque walls, (e.g. Fig. # 35.), doors, exterior overhead slabs (e.g. Fig #37) , terraces, balconies, louvers, etc. As the true numbers started flowing in, it would become obvious how inflated were the certified numbers, and panic set in the design team. Their incentives were very clear at this stage, and their goal was damage control. This may explain why these reports were approved in spite of failure marks or nonconformance flags placed by an owner's commissioning agent.

Who should be held responsible for the later failure of an assembly constructed on basis of such an unsigned report with such obvious errors? Obviously, the reviewer who let them pass. However, there could be a rational behind this seemingly inexplicable act. Acting as a reviewer for a Design-Builder, a popular mode of project delivery nowadays, the project architect's fiduciary responsibility was not to the owner, but to the contractor. Therefore, digging himself deeper actually was a logical step at this stage. Our later testing results, including the thermal imaging shown in Fig.#14, were later dismissed under numerous creative excuses, as a figment of imagination. Condensation and energy loss were not considered serious enough, and the actual damages to the owner were difficult to assess. The low value of the "thermal" subject was also illustrated by the timing: I was banned only months later, after my boroscopic investigation discovered that some cladding panels were hung by half of their required anchors, mere weeks prior to the planned opening date.

The primary proof comes later in utility bills, that sometimes are paid individually by tenants, or the building gives owner much more urgent headaches, after the transition of the ownership, letting the statute of limitations run away. Which may explain also why I never heard about such a LEED revocation, even though LEED buildings were universally described by my clients as the very worst to maintain. The one described above is one of those.

The above examples came from the top of the pecking order, from the position of a commissioning agent working closely for an owner of the building. How do you expect an average modeler and simulator would do? I could tell you, because I was there, at the bottom of the food chain as well. Prior and during such simulations, when I modeled and simulated such conditions for glazing manufacturers and subcontractors, I had enough civil courage to pass this information up the chain, with two results: I was either relieved of my duties, or the performance requirements were silently waived. See the insert titled "Economic Considerations and The Most Important Advice," above. See also Fig. # 24 for examples of my acknowledgement of such a waiver. These exercises were very expensive for the subs who hired me.

Why? Before admitting a failure, an architect often submitted multiple alternative transition details, that I was asked to model and simulate in order to verify whether they would improve results. Needless to say, it often was a boring series of experiments with counterintuitive modifications, turning details into unrealistic Swiss watches featuring rare and expensive combinations of materials and technologies, and proving American architects generally do not show even elementary intuitive understanding of building physics. You may remember the results of the trivia called "Facade Engineering -Elementary Scientific Literacy for Architects" that I run when I lead Building Enclosure Council in Miami.

However, I wasn't born yesterday, so my contracts invariably anticipated and counted these iterations, multiplying a simple simulation's cost due to the time and aggravation involved in these experiments, explaining why these subcontractors seldom hired me again. See Fig #22: a sad example of a good client running out of money on iterations.

Condensation Risk

Based on the thermal simulations we conducted, and as indicated on the temperature maps reproduced above, we anticipate condensation would form at the following locations: 1) the cavities inside the spandrels, 2) the penetrations of stainless steel fins inside vertical mullions, 3) the 45° corner mullions shown on the drawing D13, and 4) at and around the interior glazing perimeter adjacent to shadow boxes and spandrels.

On basis of our skill, knowledge and experience, we recommended the following modifications in order to minimize this risk: 1) The spandrels would need to be sealed at all penetrations and mullion connections against the water vapor intrusion from the interior. 2) The brackets will be sweating and therefore will require sealing vertical mullions against the water vapor intrusion from the interior, and using a moisture-insensitive shim material. 3) The thermal-bridging corner aluminum profile at the D13 would need to be suppressed, 4) The mullions around spandrels and shadow boxes would need to be insulated, and the aluminum sheet at the edges of the spandrel panels would need to be trimmed short.

We were informed that these recommendations were subsequently introduced in the design.

Fig. # 22. Here is an example of client running out of money on iterations. If you are a reviewer, you do need the actual condition shown on shop drawings to be verified by modeling and simulations. Courtesy of Building Enclosure Consulting Inc.

SUMMARY

Our conceptual suggestions are summarized in the diagram below. They can be considered separately or in combination with each other.

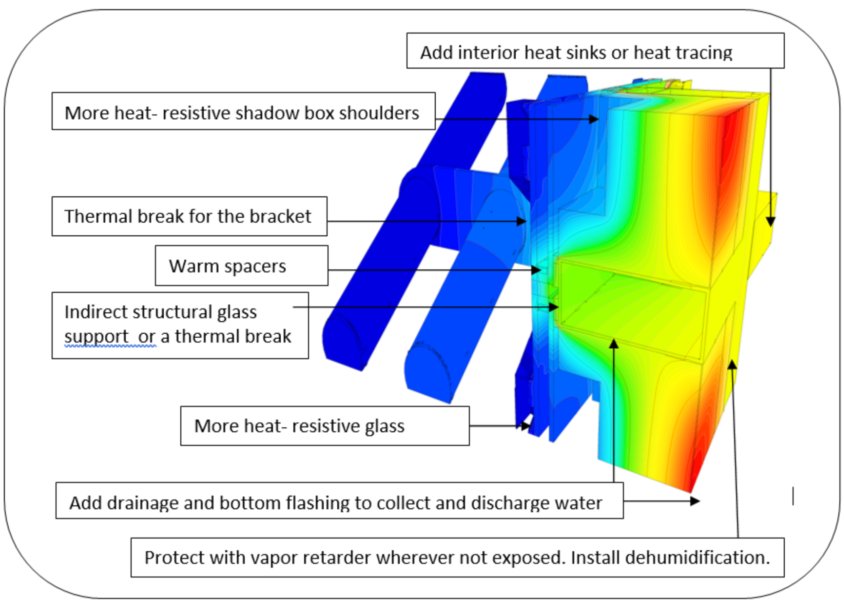


Fig. # 23. The ultimate result of such an exercise would normally be a report showing “fail” result with a list of suggestions for improvement. This is why this step should take place during design, not during construction, because it’s too late then. Courtesy of Building Enclosure Consulting Inc.

Excluded Transition Details.

In our initial review on 08/27/2012, we noted several conditions outside the curtain walls' perimeters which would impact the curtain walls' performance. I.e. we noted several details do not appear to provide the elementary continuity of facade heat-control layers (i.e. details 8/D7, 9/D8, 11/D9, 12/D9, 13/D10, 14/D10, 15/D11, 16/D11, 17/D12, 18/D12, 20/D14, 21/D15, and 22/D16), and we flagged transition details which do not appear to provide continuity of facade weather-resistance layers (i.e. D1-D2, D9-D12, D15, D16).

This is illustrated by the example of the detail 18/D12 is shown in Figure 11 of Appendix H.

Although these perimeter transition details affect the curtain walls' performance, their design was outside this contractor's scope; and therefore these details were excluded from our scope.

Hence, for the purpose of this study, they were substituted with the typical horizontal mullion 6/D6 acting as a jamb, and an imaginary symmetrical mullion acting as a jamb 22/D16, sill 21/D15, and head 20/D14 as shown in Figures 12 and 13 in Appendix H. We believe these substitute details would fairly represent the perimeter conditions if they were unspoiled by the design of the transitions of adjacent assemblies.

Note 1: We were instructed to disregard the boundary details thermally influenced by the conditions outside this contractor's scope, because such details simulated earlier (i.e. 11/D9 and 12/D9, 13/D10, 17/D12, 18/D12, and similar) were found to form condensation or frost on the interior surfaces.

Fig. # 24. Examples of not-so-diplomatically-worded disclaimers, following weeks of back-and-forth with designers through several levels of management. Architects eventually invariably waived specification requirements as opposed of improving the design. Courtesy of Building Enclosure Consulting Inc.

The ultimate result of such an exercise would normally be a report showing “fail” result with a list of suggestions for improvement, as seen in Fig. #23.

If you are a reviewer, you do need the actual condition shown on shop drawings to be verified by modeling and simulations, as opposed to accepting a failure mark issued with a bunch of recommendations.

Results of modeling and simulations of architectural transitions between two or more systems should be treated with utmost suspicion, as presented on examples above. Of course, unless the architectural transition is correctly designed, which in the U.S happens very rarely. See Fig. #25.

Interestingly enough, I have never seen a correct transition’s shop drawing ever developed at the GC’s level, where it should happen under the typical construction contract.

For comparison, in Europe, such transitions are developed in architectural documentation by specialized façade engineering firms, like one where I worked at the beginning of my career.

Don't let their initially expressed good intentions and genuinely-sounding declarations fool you, in my experience American designers and contractors were generally incapable to distinguish math and building physics from "green" marketing claims and pompous slogans. They genuinely believed that they are at the forefront of ecology and energy conservation, saving the planet one building at the time, and when confronted with hard facts such as actual testing results and comparisons, they either denied the reality, or pretended that nothing changed for sake of preserving their positions. Observing multiple projects for two decades, I believe both decisions were rational on their part, and you, as a reviewer would only loose time trying to point out that the king is naked.

In other words, if the thermal testing reports are made true, and the above performance requirements enforced, the construction would be brought to a virtual standstill, because there isn't enough know-how. It's not like we are trying to invent a wheel, it was already invented in other countries, while Americans still travel by sleds, so to speak.

In my practice, whenever I proposed tried and correct solutions from my façade engineering practice in Europe, they were invariably rejected, without even a hint of understanding how they actually solved the multiple overlapping performance requirements. It's almost as new synapses would be needed in order to comprehend them, and therefore such suggestions were never implemented.

Example: One large American manufacturer, from whose European branch's catalogue I actually copied some of those details, not only resisted implementing details bearing their own name and logo, but also asked me to cease and desist comparing their American and European details in my public seminars. Similar challenges were met by European manufacturers branching out in the U.S., they had to scrap their excellent transition details backed up by many decades of German and British engineering and testing and instead implement laborious, poorly performing details drawn by designers and suggested by contractors. It didn't help that their newly-hired local staff could not explain the benefits of those details. The logo and name could be the same, but those were different companies run by completely different people in different countries, with one of the teams much less knowledgeable than the other. For an interested reader, there are multiple references, such as in my seminar "Principle of Façade Design."

The above should serve as a warning. I wasted two decades on these facade transitions, and you would be well advised to avoid this path. Some success is seen in suggesting laborious workarounds instead, as we will discuss earlier.

Lack Of Shop Drawings and Architecturals Showing Adjacent Conditions.

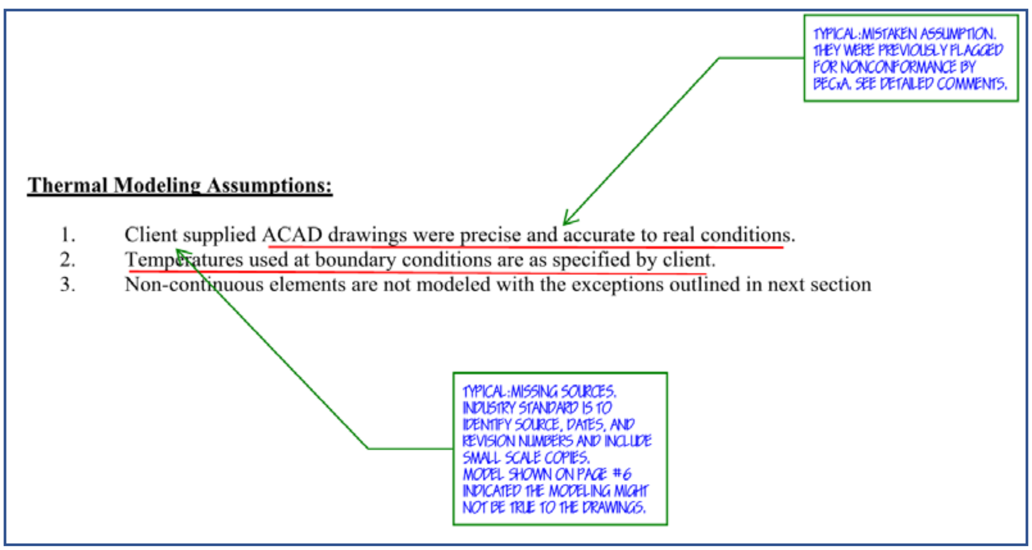
Example: Would this detail sweat if hidden behind a GWB partition or suspended ceiling? Would it sweat behind layers of mineral wool forming a firestop and restricting air movement? Is there an HVAC register, fan coil, or a supply pipe that could warm it up? Is the building exposed or located in dense development of similar size?

I briefly touched upon this subject in the paragraph above, in aspects limited to the drawing of transitions shown around e.g. fenestration perimeter. As one of my colleagues noticed, things got even worse due to BIM software, such as Autodesk Revit, that generally abolished "old-school" sectional façade details, making them unusable for any practical purposes.

More broadly, however, it touches on multiple other architectural aspects of adjacent spaces, such as e.g. an interior design, mechanical design, firestopping, plumbing, landscaping, etc. to name only a few. The interior design may bring surprises such as vapor impermeable materials and partitions beyond reach of the project architect, as some interiors would only be designed in the future, long after the shell is done. Even if it's done at the same time, its almost invariably designed by a different team, almost entirely right-brained.

In the most responsive and communicative projects, I never had any success of getting an actual response to my question from these designers or suggesting any specs. E.g. "*what is this carpets permeability, and could you add >0.5 perm rating requirement in your specs?*" would be met with blank stares, and the subject would be promptly changed. They just think differently, and their ears shut up the moment someone speaks numbers and units. Their entire industry doesn't work this way: their providers just don't know these numbers, this is why I published a short DIY procedure for exasperated architects and builders here: http://www.b-e-i.org/pemeability.pdf

Same is true with exterior conditions. E.g. a question "*Would there be any adjacent development that may affect this assembly (e.g. buildings or landscaping that could either shade or reflect sunlight or deflect wind?)*" would require reaching to someone far above their average pay scale, whose attention spans the entire neighborhood.



Thermal Modeling Assumptions:

1. Client supplied ACAD drawings were precise and accurate to real conditions.
2. Temperatures used at boundary conditions are as specified by client.
3. Non-continuous elements are not modeled with the exceptions outlined in next section

Fig. # 25. Even though the drawings weren't identified, nor attached, we could be sure they were neither precise, much less accurate, because all these sets left my desk densely marked with nonconformance flags.

Most likely these comments were not passed to the modeler and simulator.

In other cases, I learned our comments were received read, and even applauded.

Which is why, this and many other seemingly unreasonable or outright ridiculous examples shown in examples presented here could actually have a different function:

They could be interpreted as a cry for attention, or a thinly veiled "message in a bottle" targeted to the end reader of such a report, presumably more diligent and intelligent than the multiple layers between the two.

You, the reviewer, are the intended recipient of this message. Don't disappoint its author, pick up his phone and dial the number to learn the rest of the story. See the insert titled "Economic Considerations and The Most Important Advice," for further discussion.

Inferior Architecturals.

Inferior architectural drawing sets are a fact of life in the U.S. I touched upon this challenge in many paragraphs above, but here we would need to go even broader: to the lack of façade drawings with elementary information. Even a simple U value calculation requires an opening schedule, and that in turn requires a complete, dimensioned façade drawing, with interior conditions clearly marked.

Kudos to a U.S. construction project that has such a set. Some projects today rely so much on contractors that they don't even dimension their facades anymore, particularly if these are curved or otherwise irregular. Some creative designers designated roofs as "sloped walls," or bundled glazing with opaque assemblies to evade building code requirements. This is not just a Dilbert comic strip.

Then comes the next challenge: what interior conditions these portions of shell face? Many projects feature multiple interior mechanical zones, each with their own range of temperatures and humidifies, which would require individual calculations and simulations.

The average architect, even the professionals who work on CDs and in construction administrations is seldom able to answer such question, much less anyone had any foresight to place this information on drawings. If they did, they would discover that partitions between many conditions considered previously "interior" may also require hygrothermal performance verification on their own, being placed near e.g. interior zones that are left open to the exterior in the night, or glazed greenhouses.

In many other situations, the worst scenarios must be assumed or these conditions, because they would be designed and built later. This is typical in large commercial buildings, where tenants would fill shells with their own cores, as well as an exterior development would follow on many projects. Some are staged and phased, leaving the subsequent conditions open for future developments.

Verifiability

If you need to verify a submittal, some of the most important pieces of information you would need to do your job are the specifications, the energy model, shop drawings, material, and boundary data, with their respective assignments. These would allow to verify whether: 1) The modeled conditions properly reflect the respective shop drawings, 2) The values assigned to materials and boundaries reflect the actual materials intended for the project and the project conditions found in the specs, 3) Whether these materials were properly assigned to the discrete components shown in the model.

You, the reviewer would not be able to do your job properly, unless you get this info. If you are an architect on a design-bid-build project, you'd actually owe a fiduciary duty to the owner to get it prior to any review could be accomplished. The three latter items must come with the submittal. Do not feel pressed, just return the submittal to the contractor. See chapter titled "Low Hanging Fruit - Materials and Boundary Conditions and Their Assignments" for the discussion.

Majority of thermal reports come short in this department, particularly the material and boundary data and assignments. They are missing in almost every single submittal I ever reviewed. Specifications and shop drawings you could get from other sources, but data and assignments are a work product of this particular modeler and simulator. If they are not attached, the report becomes meaningless, because it's impossible to verify, much less replicate.

The colorful temperature map that many reports show as a sole product of work should not be considered a proof, because it could be developed and modified freely by stretching the data. Without the underlying data attached, you cannot even blame the author, you could only blame yourself for falling into the trap.

In respect of verifiability, Therm report only provides a list of data for materials and boundaries, but offers no tool to tell how they were assigned to which components of models. In this respect, it's fair to say that it is the worst software out there, but it's free of charge, provided to us for our taxpayer dollars, and unfortunately also adapted by the industry as the national standard. Ref. Fig.#3 and #60.

Even though its usefulness is limited, all reports I have reviewed had this portion omitted. Why would they not feel comfortable enough to publish the full Therm report? Why I never received the rest of the report, even when submittals were rejected? Possibly, because it would allow a reviewer to verify numbers shown there, and the authors did not feel confident enough to share their work to an extent that it could be verified.

Another frequent issue is readability. Many reports come almost illegible, e.g. Fig. #30 due to the inadequate scale of the crucial area dense with information. If it were physically copied, e.g. scanned, resolution would be lost, making it challenging to verify. These should be magnified, see e.g. Fig.#59 for a good example of an insert explaining the configuration of a dense "Swiss watch" area.

Many reports I saw were neither signed nor stamped, in nonconformance with respective requirements. Why did the author feel embarrassed to sign his or her work? You could answer this question yourself. Don't approve reports unless they are clearly signed. See the insert titled "Economic Considerations and The Most Important Advice" for the discussion.

Most reports would claim they were prepared by individuals not certified by NFRC, or they omit this subject entirely. See Fig. #43 for an example. Is it a big deal? It's a commercial certification called "NFRC Certified Simulator" that only applies to LBNL software suite, while some of the well-established work out there was commissioned and conducted on a much more complicated software, see the chapter titled "Software" below. I believe that it's the value of the work that should speak for itself. Sadly, those rare reports I reviewed that claimed to be prepared by certified simulators were not necessarily better. I am self-taught, never saw much value in getting certified, even though I run those simulations, and specialized in this subject for over quarter of century, but I was already technically overqualified when I arrived to the U.S. based on EESA assessment for NCARB at the time, so who am I to judge an American who may want to compensate their general education by learning some technical skills.

How to tell whether a simulation is inaccurate, even at the absence of the required data? There are some tell-tale signs, which I could show you in Figures #15-18 and #26-28.

I had in my library actual examples of incorrectly assigned materials spotted in different reports collected over the years for the purpose of instructing students, but could not find it anymore. Therefore, I pulled this almost two-decade old Therm model, that somehow still survived on my hard drive, and tweaked it for the purpose of this demonstration. Its intention is to show how to spot differences.

Materials generally conduct heat differently, and those that insulate are most likely to show greater temperature spread in section. On the temperature maps #26-28 below, you could observe "rainbows" of temperatures concentrated in few areas. One of the most distinguishable is the center of the cavity of the insulated glass unit, and that's why we would normally start there. This is where almost the entire exterior-interior differential is concentrated. As we move toward the glazing perimeter, we would encounter a glass spacer bridging this cavity, while also a large aluminum extrusion is sealed to its interior glass pane. The spacer bridges thermally the cavity, while the highly conductive extrusion through also conductive silicone seal delivers heat from the interior. The result are predictably cooler interior surfaces.

However, there would seldom be any "rainbow" seen in conductive materials, unless there would be some offset of thermal planes, or if they are bridging them by a small amount. E.g. the "rainbow" seen in the upper portion of the glazing spacer, made of silicone sealant, which is a conductive material is explainable, because it's a relatively thin piece of material bridging otherwise uninterrupted thermal plane.

If the modeler provided a heat flux map, this component would be shown "lit," as there is an intense flow of energy through it, marking these areas most susceptible for improvement.

If such a rainbow appeared in the silicone section between the inner glass pane and the aluminum extrusion, it would indicate wrong material assignment, substitution with unrealistically more insulating material. The inner corner of the bottom section through the concrete precast shows a "rainbow" going from purple to light blue. This is also understandable: this corner, although built of highly conductive concrete, is twice as exposed to the interior, as to the exterior, and facing a much higher conductive metal profiles, delivering heat faster, than relatively less conductive concrete could disperse it. What is unusual on this picture is the through-flashing pan located above the window head. If it were conductive metal, such as aluminum, it would "stretch the rainbow" further outside, because it's more exposed to the interior than to the exterior. You could see such an effect coming from the aluminum "Z" extrusion placed on the right side. There is a reason: this pan is made of stainless steel, which is a relatively "warm" material.

Similar considerations could be seen in attempts to reproduce Fig.#12 in Figs. #15-18. You would notice that the attempt in Fig. #17 was probably the closest, except that the simulation must have somehow misrepresented the heat balance, by pushing the "rainbow" higher. That would indicate the result obtained below the flange was not accurate.

Fig #35 shows a sudden, unexplained shift to the left in the middle of otherwise uniform assembly.

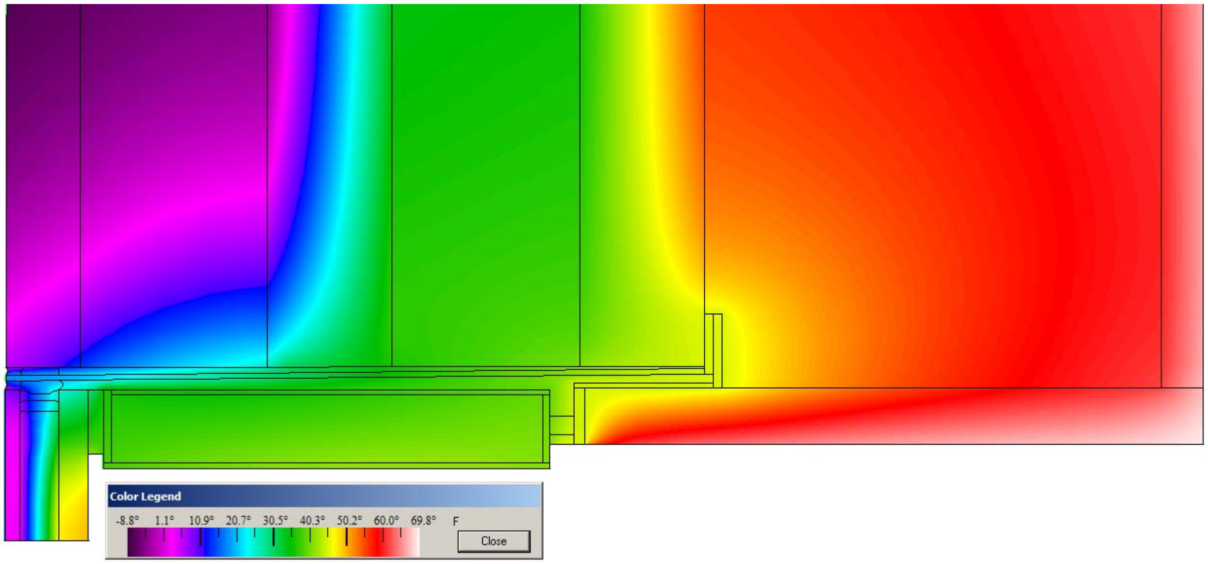


Fig. # 26. A head detail of a window punched in concrete precast wall. The opaque assembly consists of stone-faced concrete precast slab with mineral wool pinned behind it. One could easily identify thermally insulative materials: IGU and mineral wool, because they show the temperature "rainbow" The following two figures show alterations of material assignments.

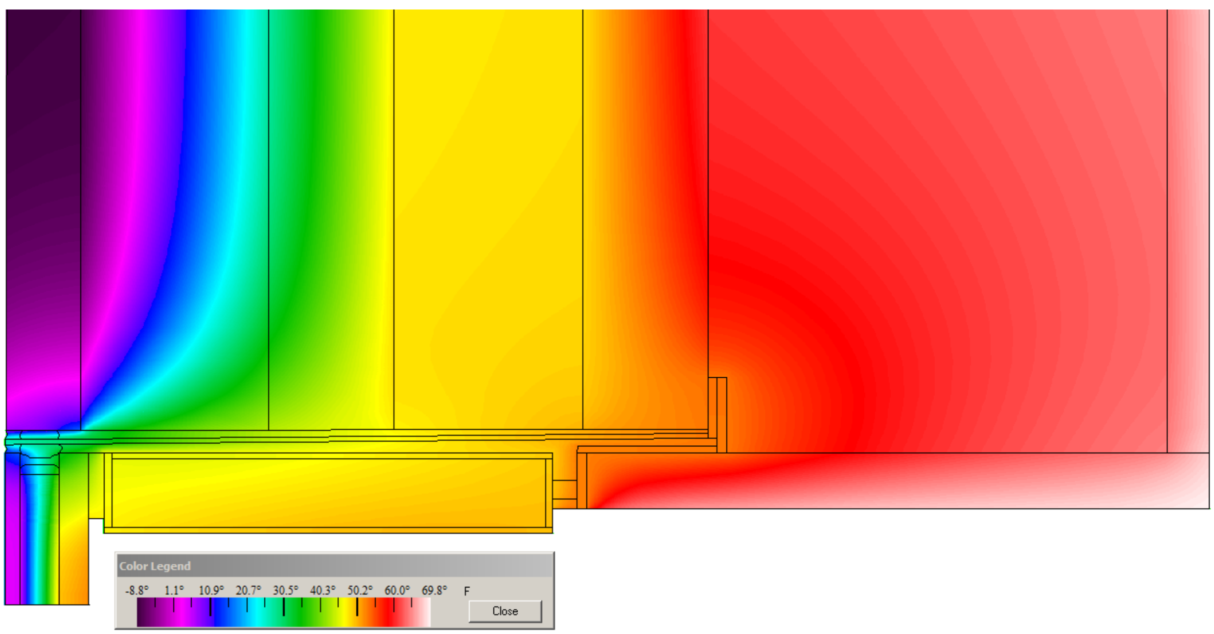


Fig. # 27. The same detail, except what was previously a concrete slab got assigned a different, more insulative material: styrofoam. The giveaway is the temperature "rainbow "showing in a wrong place: on a material that should be more conductive.

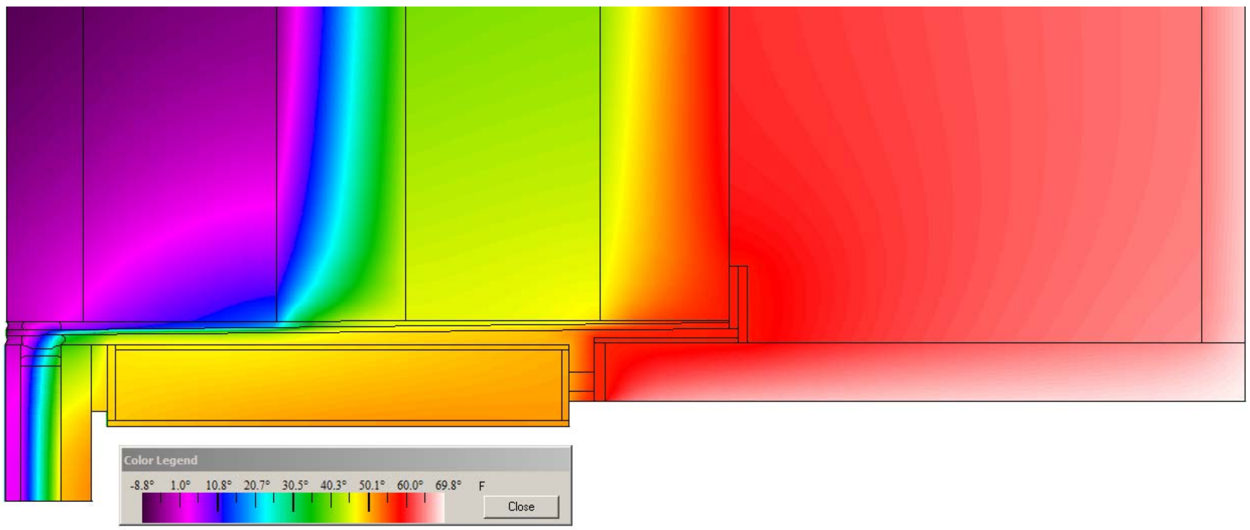


Fig. # 28.The same detail as in Fig #27, except for the temperature "rainbow "got conveniently squeezed into the steel through-wall flashing at the heat plane offset. What happened? A much less conductive material was assigned to the flashing and the secondary sealant, making a lot of difference.

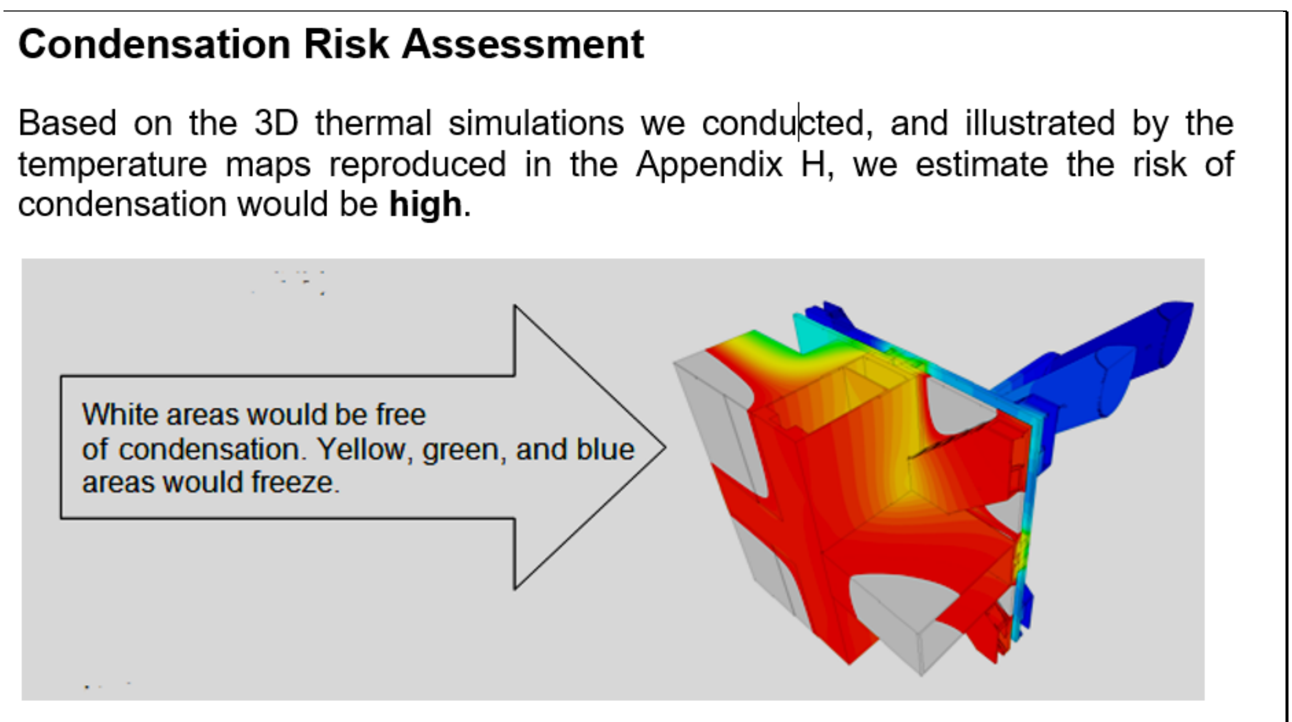


Fig. # 29 . The previous detail was shown in unusual way, with the full color scale. The more typical presentation is a color scale cut at the Dew Point, as shown on this and next examples. Courtesy of Building Enclosure Consulting Inc.

Skylight Ridge

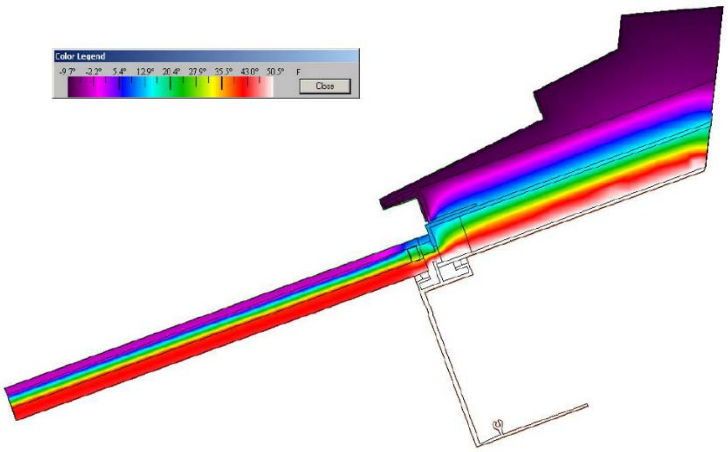


Fig. # 30 . The adjacent interior conditions are omitted in the skylight model here. Color scale is cut at the Dew Point: such a presentation simplifies determination of condensation risk: here it's indicated by red color red on the interior glass pane, while conditions adjacent to the spacer are shown warmer, unusually enough. Normally, joints tend to spoil field conditions. Why is it opposite on this picture? It's for three reasons, as follows: because the purlin extrusion is shown unrealistically exposed, picking heat on both sides, and acting as a heat sink. In reality, its upper side would not only be covered, but also subject to much less air movement, and therefore there would be less convective and radiation energy gain. The second reason is the larger heat sink on the exterior side made of metal cladding is shown unrealistically broken from the assembly, without the expected corresponding energy drain at its bottom attachment. The bridging is broken leaving a gap at it bottom edge and by use of intermittent "Z" clips, but such clips would require fasteners going deep into the purlin, which would need to be shown modeled here as a separate "spoiled" material, clearly missing here. The third reason is the square perimeter spacer of the upper insulation panel is assigned unrealistically insulating material, judging by the "rainbow" pushed outside within its boundary.

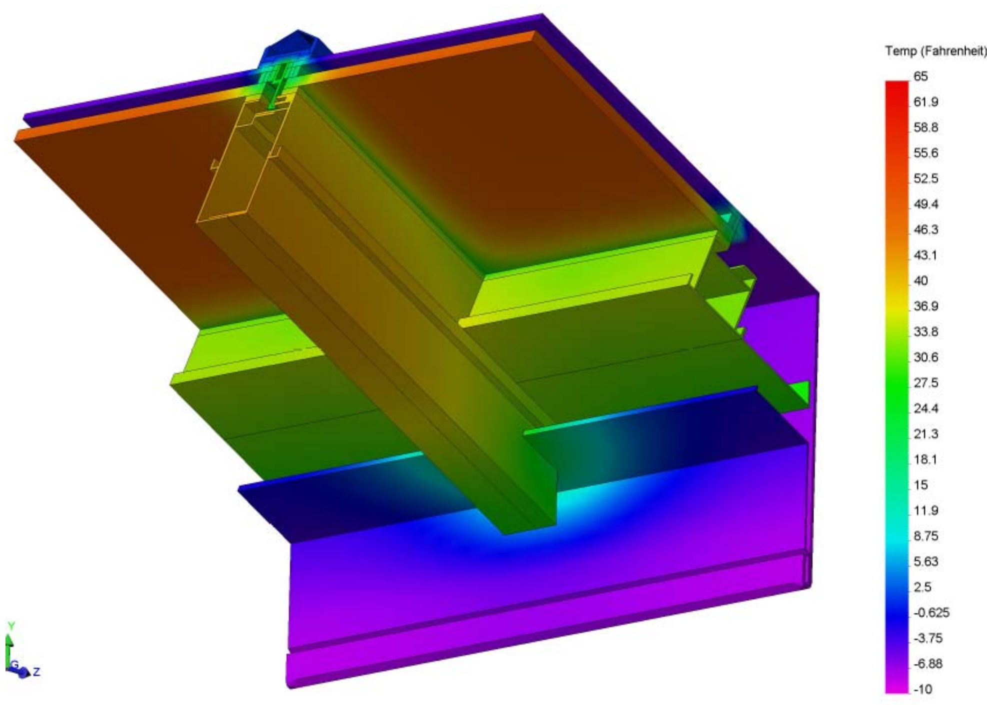


Fig. # 31. Here is an example of a skylight modeled in 3D, where interior conditions were modeled and simulated, but later switched to invisible for sake of clarity, as could be deduced by the temperature map. This simulation is much more convincing. The cold bridging is clearly visible around glass panes, opposite of the condition shown in Fig. #31. Also, the impact of 3D bridging is clearly visible at the intersection.

First Step – Goal

Specs and procedure could differ depending on the goal of the simulation, and so the goal needs to be clearly stated. A U value calculation needs a set of typical details, while a condensation analysis typically only needs the worst case scenario.

The best reports clearly reference specific requirements found in specifications, as well as how these could be modified by the subcontractor's contract's limitations, as in Fig. #33 below.

On the contrary, in Fig. #32 below, the typical example of confusion is presented. What followed was neither a U value simulation conducted on a typical sections, nor a condensation risk assessment on the worst case section, much less a calculation.

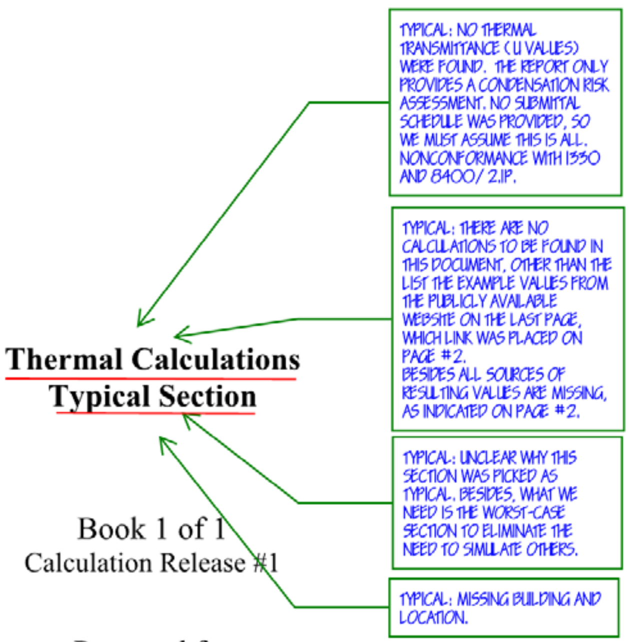


Fig. # 32. Here I an example of an ambiguous statement of the goal, yet contradicting the actual content of the report.

Final Remarks

This document has been prepared to assist you in determination of the overall thermal transmittance (U-value) of the curtain wall systems, and to verify whether the criteria of the specification section titled "Performance Requirements" 018100/1.12/ C/2b and 2c are met, and in accordance to the our accepted proposal dated 08/30/2012.

We reserve the right to alter or amend our comments regarding these items if new circumstances associated with the condition of the design, project site, or materials are brought to light by further investigations at a later date. If you have any questions regarding these observations or our general conclusions, please contact me at your

Fig. # 33. Here I an example of an unambiguous statement of the goal accompanied with a common-sense disclaimer. Courtesy of Building Enclosure Consulting Inc.

Second Step – Specs

When the simulator cannot even get the elementary data right, you may have reasonable doubt in their ability to model and simulate it.

It's such a frequent issue, that you need to verify it right away, and reject the report that shows incorrect values right away. See Fig. #13 or Fig #34 for example.

In the example below, the modeler twice assures the reader that the temperature came from the specs, while simultaneously showing incorrect outside temperature, 3 degrees warmer than the one specified, and therefore testing for less stringent requirements.

There is no indication what is this for (either U-value calcs, or condensation assessment, often utilizing two different sets of climate values), but the value didn't match either of the two.

TYPICAL: WRONG VALUE.
IT'S 8 DEGREES PER
SPECIFICATION
8400/ 2.1N3A

Summary

The thermal analysis of the detail provided via email on January 29th, 2018 is contained in the following report. The Analysis has been performed per NFRC standards as well as client specified environmental conditions

Boundary Conditions	
Outside Temp.	-5 Degree (F)
Inside Temp.	70 Degree (F)
Wind Speed	12.3 mph
Limiting Relative Humidity	30%

Dew Point Summary

The minimum surface temperature on the aluminum framing before condensation will form is 37.14 deg (F). See website below for dewpoint calculator

http://andrew.rsmas.miami.edu/bmcnoldy/Humidity.html

See Appendix A for example calculation.

Thermal Modeling Assumptions:

1. Client supplied ACAD drawings were precise and accurate to real conditions.
2. Temperatures used at boundary conditions are as specified by client.
3. Non-continuous elements are not modeled with the exceptions outlined in next section

Fig. # 34. Here, the modeler twice assures the reader that the temperature came from the specs, while simultaneously showing incorrect outside temperature, 3 degrees warmer than the one specified, and therefore testing for less stringent requirements.

Third Step – Modeling and Simulation

Assuming the reviewer is familiar with the project and its specs, certain differences would become immediately obvious, e.g. lack of interior enclosures such as suspended ceiling on the interior side of the example presented below. Other differences are perhaps less obvious, e.g. missing firestops, upper studwork, steel gussets, etc. See Fig. #35 below.

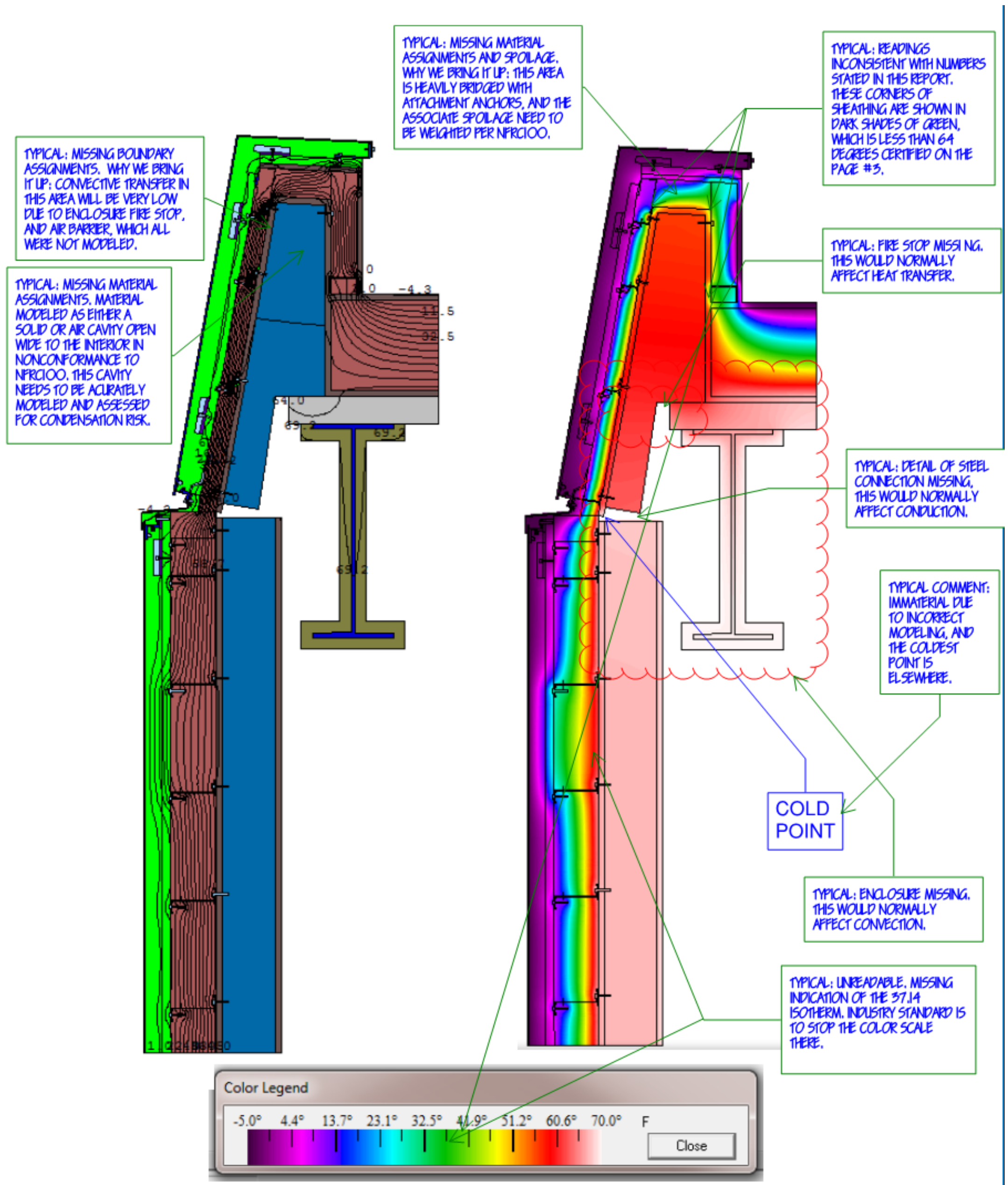


Fig. # 35. Certain differences are obvious, e.g. lack of interior enclosures such as suspended ceiling on the interior side, that even a person unfamiliar with a project would reasonably expect. Other differences include, e.g. missing firestops, upper studwork, steel gussets, etc. The modeler also assigned a large chunk of unknown material to the heavily bridged airspace inside the knee wall, which would be incorrect under any assumption. The Therm report was not attached, so not even the most elementary verification was allowed. Anonymous, unsigned report, the name of the company was covered to protect the guilty.

The Therm report was not attached, so not even the most elementary verification was allowed.

There are so many things wrong here, that the recitation would take too much space. E.g. sudden, unexplained “rainbow” shift to the left in the middle of otherwise uniform assembly.

The modeler also got confused and assigned a large chunk of unknown material to the heavily bridged airspace inside the knee wall, which would be incorrect under any assumption.

A strong and uniform red color inside the curb exposed to on three sides to the cold exterior compared with pinkish colors showed in materials closer to the warmer interior are also clear indications of this assembly modeled incorrectly.

The significant difference would result from HVAC modes (intermittent forced air supply from ceiling registers) and how the space above the suspended ceiling would be utilized (it wouldn’t, no air movement whatsoever, air return via the main space).

The “Cold Point” callout completely missed the actual coldest point which is correctly seen inside the vapor retarder’s boundary, even though the interior space was shown overly optimistic. This is why the industry standard is to cut the scale at Dew Point. However, it needs a modeler’s understanding where the vapor barrier is located, in other words which conditions could be exposed to the interior Dew Point.

Figures #36 and 37 on the next pages show the bottom detail of an exterior wall and a slab above exterior space.

It also bears little resemblance to what was actually built there, well-illustrated by some tell-tale signs of an inexperienced modeler: e.g. an over-hanging end of the horizontal mineral wool wrap at the bottom. Several other relevant differences, such as e.g. a missing firestop, were a result of poor architecturals: the Design Builder denied the firestop was necessary. Normally, it would form a continuous air barrier at the extension of the concrete slab. Eventually, these firestops were haphazardly installed in the field only after the sheathing was already in place, creating a patchwork: where access was challenging e.g. those steel studs’ cavities faced each other, there would be a gap left.

The tolerances of the construction, particularly the position of concrete slab edges in relationship to walls were not accommodated in the architecturals, resulting in several different modes of wall studs’ attachments observed in the field: some ballooning, some terminated in steel tracks nailed above and below the slab edge, and some slab edges actually sticking through the sheathing.

In either case, lack of clearance for the “ballooning” of vertical steel studs required significant bridging by steel tracks, missing in this model. There is not a single indication of any bridging modeled at the bottom mineral wool wrap, and the thin exterior soffit just magically hangs there held by the edge.

No perpendicular steel members were modeled either, and their influence could be seen in infrared photos (Fig.#38) taken after the building was heated.

Both these examples combine horizontal and vertical energy transfer, and therefore their data would need to be verified to make sure that they reflected the two. This data was omitted from this simulation report, so there was nothing to verify with.

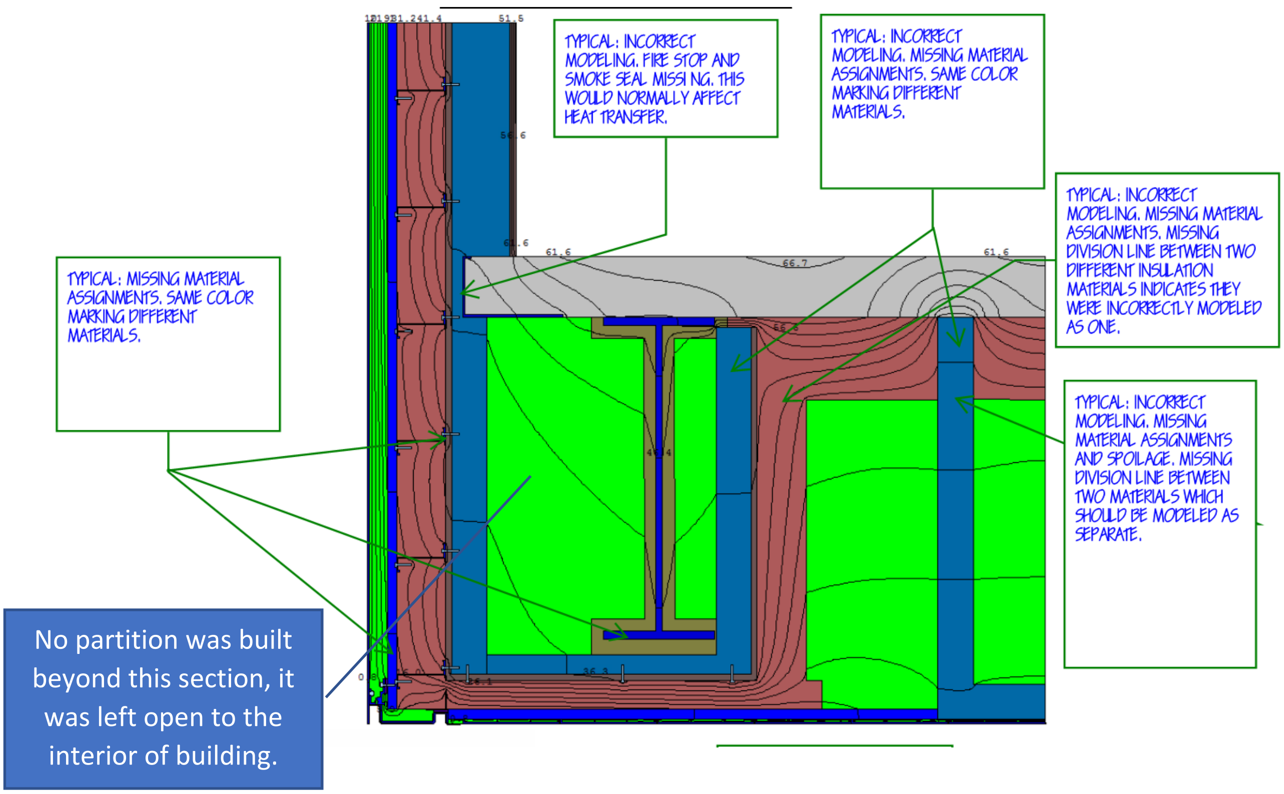


Fig. # 36. The bottom detail of a slab above exterior space, modeled without much resemblance to the actual conditions. Anonymous, unsigned report, the name of the company was covered to protect the guilty.

The next picture (Fig. #37) shows the "Cold Point" callout completely missed the actual coldest point, just as in the previous example.

There is often some confusion where is a vapor retarder in concrete slabs, I would refer an interesting reader to my other publications; however, the general rule of thumb is that the interior floor covering would create such a barrier. It was the case here as well, as the interior design featured such a carpet.

There was only so much that a reviewer could anticipate, but such a clear failure of the modeler and simulator to even recognize the coldest spot in the temperature maps they generated should serve as a warning sign. It's obviously incorrect on first sight.

At the time of the review, I did not anticipate this condition could be made even worse: interestingly enough, neither the drawings, nor the contractor closed the end of the cavity containing the "W" beam, effectively connecting it to the building's interior of the floor below. There was no architectural drawing nor any shop drawings showing such condition, and according to Murphy's law, it was interpreted by the Design-Builder in the worst possible way: they just left this space open to the interior.

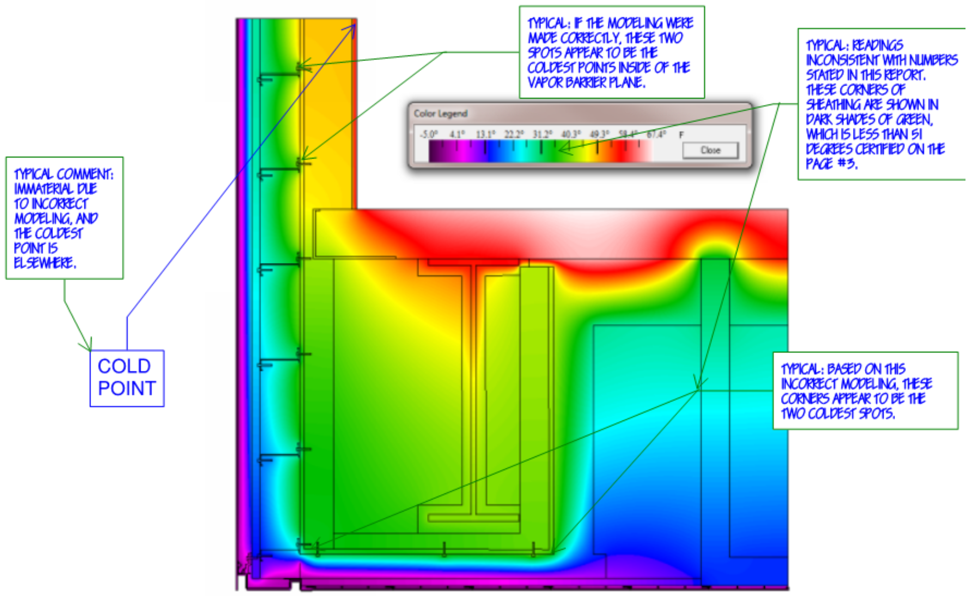


Fig. # 37. The temperature map of the bottom detail of a slab above exterior space seen in the previous example. Both coldest spots inland of the air and vapor barrier could be seen here somewhere in the lower 30-ties, creating an obvious condensation risk. Anonymous report, the name of the company covered to protect the guilty.

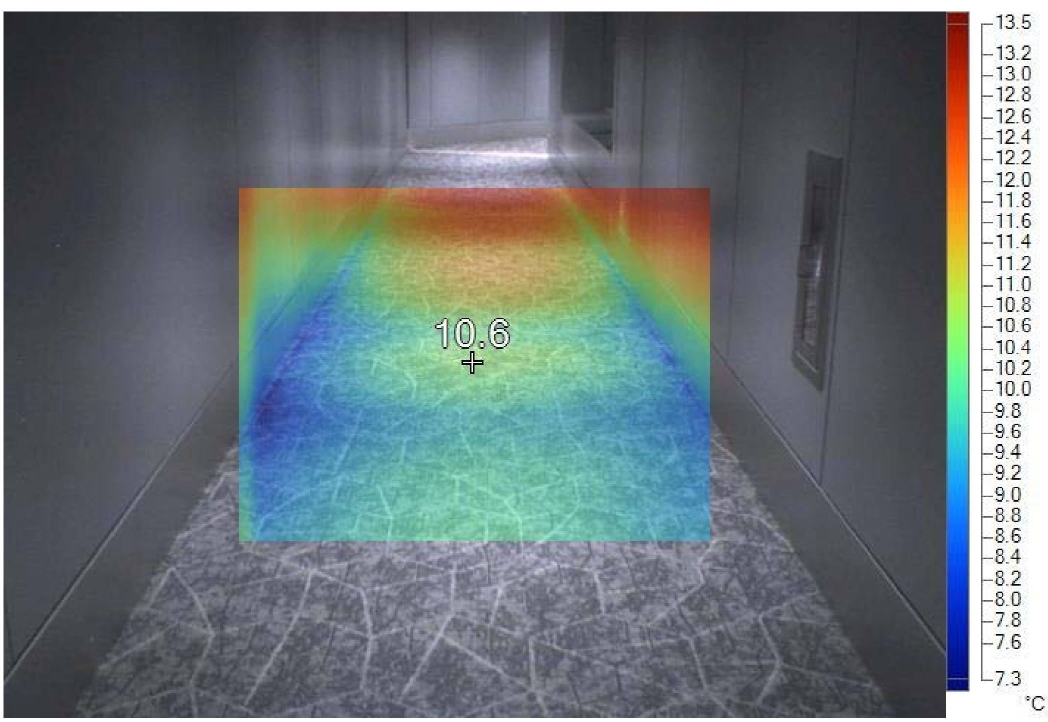


Fig. # 38. Verification of the simulation results during mild (approx. 36◦F) winter night. The coldest interior surface of the exterior floor slab reading at 7.3◦C (~45◦F), contrasting with 50-ties shown on the temperature map in Figure #37 above, simulated at a much lower exterior temperature. Similar reading seen on Fig #40. Visible pattern of perpendicular steel beams, illustrating the need for 3D modeling. Courtesy of Building Enclosure Consulting Inc.

Therefore, the actual, as-built condition resembled the model without a fire stop, with the cavity open to the interior. Therefore, the relevant coldest interior points are what I initially marked as “*Based on this incorrect modeling, these corners appear to be the two coldest spots.”* Both somewhere in the lower 30-ties. This sweating would occur within the gypsum sheathing, far away from sight. However, wet gypsum is a very corrosive environment for steel, that all cladding fasteners penetrated. Therefore, the condensation risk created risk of premature structural failure. Also, gypsum is a moisture sensitive material as well.

This was a case where such a faulty simulation could still inform and improve the construction. My suggestion was to replace these compromised areas of sheathing with e.g. a cement boards, that were both moisture insensitive and would not affect steel fasteners as much. Design-Builder ignored this suggestion. My thermal imaging (Figs. #38-40) proved these areas were actually worse than simulated.

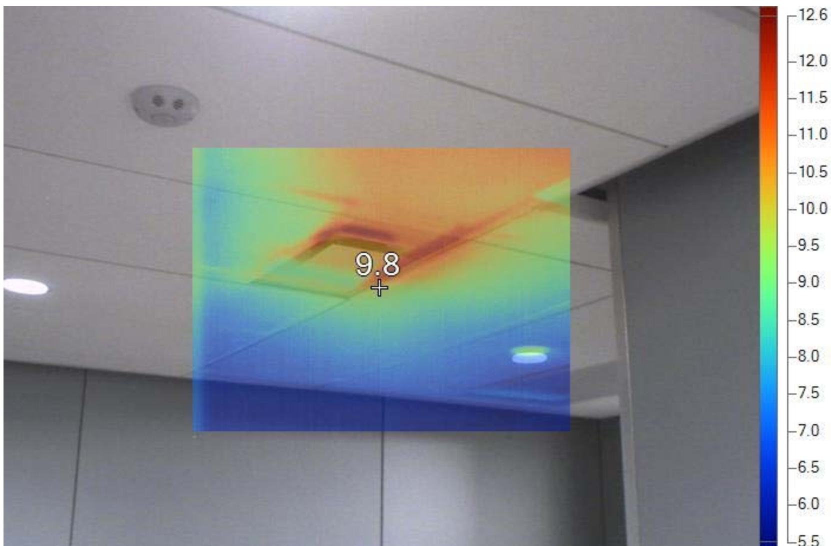


Fig. # 39. Verification of the simulation results shown in Fig.35 during mild winter. The interior surface of the exterior wall was 5.5◦C (~42◦F), which was enough to prove the above simulation (claiming it was in 60-ties) was inaccurate.

Courtesy of Building Enclosure Consulting Inc.

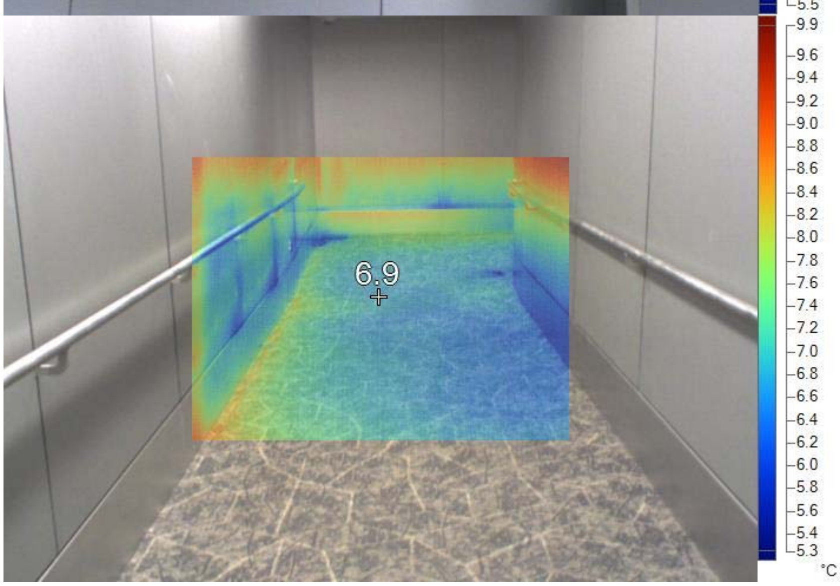


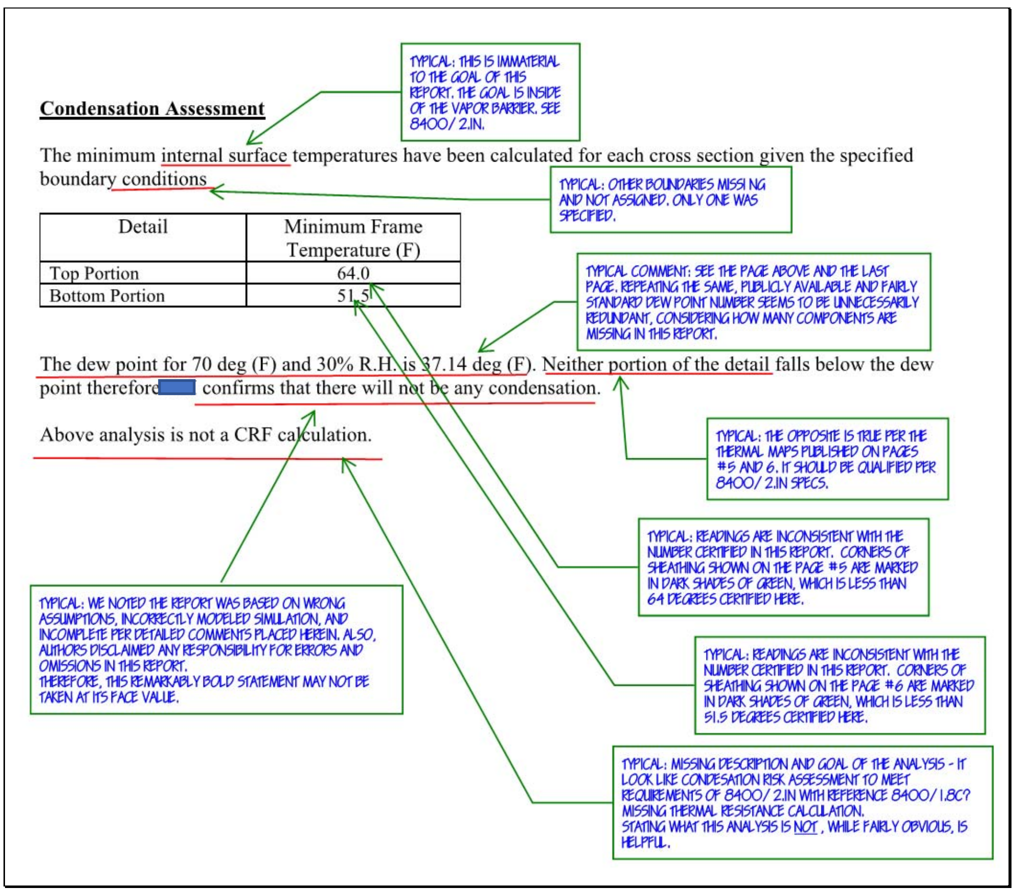
Fig. # 40. Verification of the simulation results (Figs. #36-37) during mild winter. The interior surface of the exterior wall was 5.3◦C (~42◦F), which is enough to prove the above simulation (claiming it was in 50-ties) was wrong.

Courtesy of Building Enclosure Consulting Inc.

HVAC Mismatch

The above three infrared photos were taken in the first months after the heat was turned on. Analyzing the thermograms, the top temperatures are nowhere near the 70◦F interior design temperature, even at the ceiling register. As explained in the introduction, the average building's life in the U.S. is characterized by the initial phase, in which HVAC turns out to be inadequately sized to provide thermal comfort to occupants (and, in some extreme cases, to even protect installations from freezing).

It illustrates the gap between the certification and the as-built conditions. The energy model was perhaps based on the inflated shell numbers certified by designers, or the model was inaccurate, or the construction differed too much from the design, or it was based on inaccurate thermal reports such as described in this paper. In some cases, HVAC suffers from its own infancy challenges. Whatever the case, heating at this early phase had not yet matched the actual load. It would need to be repaired, replaced, or supplemented. These interiors did not have winter moisture controls, and therefore, condensation risk was increased. Once enough heat would be provided inside the building, it would warm the cold bridges, and the condensation risk could be lowered respectively. The two act in opposite way: the more energy, the less condensation, as stated in the introduction.


Condensation Assessment

The minimum internal surface temperatures have been calculated for each cross section given the specified boundary conditions

Detail	Minimum Frame Temperature (F)
Top Portion	64.0
Bottom Portion	51.5

The dew point for 70 deg (F) and 30% R.H. is 37.14 deg (F). Neither portion of the detail falls below the dew point therefore [redacted] confirms that there will not be any condensation.

Above analysis is not a CRF calculation.

Fig. # 41. The internally-inconsistent, unsupported, and incorrect conclusion attached to the examples shown above in Figures #35-37. A reviewer anticipated a failure, later confirmed by thermograms shown in Figs #38-40. The report devoted disproportionately much space to Dew Point, copying the same website information thrice, while crucial data was inexplicably omitted. Anonymous, unsigned report, the name of the company and the project covered to protect the guilty.

Comparisons

The above example shown in Figures #35-37 showed a winter condensation analysis, which should be conducted at the worst spot (it wasn't), and should identify the coldest interior spots subject to interior Dew Point (it didn't). Both above simulations clearly showed the lowest points exposed to the interior air to be in 30-ties.

This was contrasted with the following bold statement: "*there will not be any condensation*,", and claiming lowest temperatures in 50-ties and 60-ties, in the conclusion shown in Fig. #41, which, considering so many errors and internal inconsistencies, was obviously inaccurate even based on the little information we were presented with at the time the report was submitted.

This example was an easy one, showing a clearly incomplete and incorrect testing report. It failed all possible checks, yet was accepted by the architect, so the next winter I could walk it with thermal imager, verifying its results in the real life. Although the exterior temperature and wind speed weren't as extreme as specified, nor was I allowed to pull the interior or exterior panels to verify the concealed conditions, the interior pictures told the story well enough.

The next pictures in Figs. #38-40 showed the lowest temperatures registered on the interior surfaces of the exterior partitions far below the reported numbers. Extrapolating these numbers based on actual readings of interior and exterior conditions at the time of the measurements was enough to prove this simulation completely inaccurate.

Not surprisingly, the report was anonymous, giving neither showing name of the author, nor any signature or stamp. The only identifying feature was name of the company.

The condensation was shown in the gypsum sheathing. A premature structural failure of steel fasteners sitting in the wetted gypsum sheathing, a phenomenon well described in literature, would be therefore anticipated. These fasteners are responsible for façade cladding attachment, so premature cladding loss would be an expected result.

U Value – First Glance

The above examples showed condensation assessment, which typically constitute only half of work. The other half is U-value calculations, which is often conducted based on a different set of data, and for a different purpose, moreover the goals of the two are often opposite: U-value is supposed to verify the energy is saved, while on the other hand, successfully mitigating the condensation risk often requires a huge waste of heat energy. Such a disparity of goals actually could assist a reviewer in his or her verification, given enough data were provided in the report.

The U-value determination is a straightforward calculation, that is simplified by using a simulation software that weights areas and provides a set of numbers. It could be done and presented in many different forms, e.g. an Excel worksheet (e.g. Fig.#42), or even a handwritten calculation.

The number is normally the COG (center of glass) spoiled by joints. COG numbers are typically fairly solid, the trouble hides in numbers representing the joints, because these come from the same often faulty simulations, examples of which we just presented in above chapters.

Looking at the example below, a reviewer could glean a fairly typical picture: an R-3.4 glass spoiled by aluminum yielded a total of approximately R-2.6. This is a simulation of unrealistic perimeter conditions as seen in a system's catalogue, because if the true numbers were plugged here, the ones actually simulated for project-specific perimeter details, the result would not meet the specs. Therefore, after numerous futile attempts of modification of inferior architectural transitions affecting those perimeter details, project-specific perimeter conditions were silently waived by the project architect, as showed in Fig.#24. This is an example illustrating another general rule: the real number on majority of projects would be much worse, were it ever revealed.

Just as structural calculation submittals are required to show the full record (or printout from FEA software) plus a certification by a state-licensed professional, thermal report would be expected to provide such two components: verifiability and certification.

However, very often (almost invariably) a reviewer would be given an unsubstantiated number and requested to believe it on faith, just as unsubstantiated, net conclusions were given in condensation risk assessment examples. Just as above, few authors would have civil courage to reveal their names, much less to seal and stamp their work, and broad disclaimers were posted instead (e.g. Fig #43).

What you should receive is a lengthy Therm reports listing U-values of details, and area-weighting calculations. Some of these are too complicated for LBNL suite, and are done by hand (or Excel sheet). This is how it looks:

AREA			**sill 3D3**	**2D head**	**3D head**	**2D transom**	**3D transom**	**mullion 10D8**
Frame in2			101.12	68.72	69.88	137.40	139.76	703.56
Edge in2			162.26	127.26	95.00	254.48	190.00	1366.00
COG in2	*9384.56*							
Total in2	*12800*							
U-Values								
Frame Btu/m^2 x F			*1.091*	*2.034*	2.331	*1.042*	1.820	*0.936*
Edge Btu/ m^2 x F			*0.316*	*0.323*	0.311	*0.310*	0.301	*0.289*
COG Btu/ m^2 x F	*0.289*							
Total U value	**0.38**		**Btu/m^2 x F**					

Figure 11. Elevations E4, E6, E8. The area-weighting U-value calculation.

Fig. # 42. An example of an Excel sheet congregating and area-weighting data for U-Value calculation. Courtesy of Building Enclosure Consulting Inc.

Needless to say, without them you are asked to believe in the final number on faith. This is where a subject of disclaimers looms large, and this is the next topic.

Disclaimers

Some disclaimers could be amusing, such as the overly broad disclaimer read under work shown in Figs. #36-37 above and presented in Fig. #43. Legal disclaimers are generally developed by companies, not software operators employed by them. Therefore, such a disclaimer as seen in Fig.#43, claiming full immunity from errors and omissions, reflects badly on the company, not necessarily on its employees. One more good reason for you to grab a phone and try to call their authors to find out the truth.

Disclaimers help realize limitations of work, and clarify the scope. Therefore, they are an important part, that should not be treated lightly. There are several typical types of disclaimers: legal, general common sense, and common-sense building physics.

Disclaimer:

TYPICAL: FULL IMMUNITY FROM ERRORS AND OMISSIONS CLAIMED BY THE AUTHORS MAY EXPLAIN THE ERRORS AND OMISSIONS FOUND AND LISTED IN THE REPORT ABOVE.

While all attempts have been made to verify information provided in this report, no one associated with [redacted], Inc. assumes any responsibility for errors, omissions or contrary interpretation of the subject matter herein. This report has been created using some and or all of NFRC 100, 200, 300, and 500 procedures and the information provided by the client. [redacted] is not a certified NFRC simulation lab, nor was the simulation(s) completed by an NFRC approved simulator. This report is not intended for use as a source of NFRC certification, legal, or accounting advice. All clients are advised to retain competent counsel to determine what state and/or local laws or regulations may apply to the user's particular business. The client of [redacted], Inc. assumes responsibility for the performance of these materials and information pertaining to the product simulated. [redacted] Inc. does not imply or claim that the product simulated in this report will perform as stated in actual use conditions. Adherence to all app… , governing professional licensing, business practices, adv… S or any other jurisdiction is the sole responsibility of the clie… Fenestration Rating Council) assumes no responsibility or liab… rials. Any perceived slights of specific people or organization are unintentional. Information contained within this report is provided solely for the user's information and, while thought to be accurate, is provided strictly "as is" and without warranty of any kind, either expressed or implied. We will not be liable to you for any damages, direct or indirect, or lost profits or data arising out of the use of the information provided in this report. Even if informed of the possibility thereof. Proceeding beyond this disclaimer constitutes acceptance of these terms and conditions. This report is the property of [redacted] Inc. and client. This report may not be reproduced or rewritten without the written approval of both [redacted] Inc. and the client. The report shall be kept for a period of four years, after which they may be destroyed.

TYPICAL: MISSING NAMES AND SIGNATURES OF AUTHOR(S) AND REVIEWER(S). SPECIFYING WHO DID NOT COMPLETE THE SIMULATION NARROWS THE NUMBER OF POTENTIAL AUTHORS TO APPROXIMATELY 7.6 BILLION PEOPLE.

Fig. # 43. Some overly broad disclaimers from a particularly bad submittals, seen in the examples above. In spite of this full immunity, the author(s) was not courageous enough to identify themselves, much less sign it. The simulation was rife of inaccuracies, void of the data and assignments, reflected few actual conditions, and there were tell-tale indications of incorrect material assignments. The statement "Using some and or all NFRC…procedures" in the example above further deprived the report of any value. Name of the guilty company was concealed to provide anonymity.

Legal disclaimers are typically buried in fine print in contracts, and these are seldom seen shared. When we post them prominently in our reports in order to clarify scope limitations, as seen in our report example referenced earlier, we are often asked to remove them by our clients. So, a reviewer would almost never become privy to them.

However, some are fairly standard: e.g. most insurance providers would require at least that the liability is limited to the cost of the service, and it should concern you a lot, as your multimillion project could rely on a reimbursement for e.g. an average fee ranging between $500-1,000 for such a certification.

Second category is the general common sense: "*We reserve the right to alter or amend our comments regarding these items if new circumstances associated with the condition and requirements of the primary and delegated designs, project site, or materials are brought to light by further investigations at a later date." (*This is an example from my own work.)

It's surprising how much difference this simple wording entails. It means that if it's built differently (and it almost always is), the joke is on you. However, it would be unreasonable to expect the simulator could do otherwise.

Real-life limitations are important, e.g., a vacuum insulation that was penetrated with a fastener would quite dramatically lose its thermal resistance, or a reflective insulation surface that is dusty, over-sprayed, or simply touching another material would also lose its nominal thermal resistance, etc.

The logical conclusion is that someone would need to watch over contractor's shoulder every step on the way (it's called "monitoring key events" in building enclosure commissioning lingo) to verify how far away they strayed. That's what the building enclosure commissioning is for. See " Building Enclosure Commissioning Kickoff Seminar" https://youtu.be/oQDQ2NdCOnE for reference.

Disclaimer Litmus Test

This mix of disclaimers presented in my report template, I developed over the years, copying good ones noticed in work of others, and polishing them in anticipation that I may need them if my results were challenged one day. I never hired a lawyer to verify them, and fortunately such a day never came.

I anticipated that they would be copied by my competitors in the thermal field, and I would eventually see them in reports I reviewed. That never happened either.

I was always surprised that some clients objected to such simple disclaimers, even though they functioned as a reminder of obvious truths, and would be probably easily legally enforceable even if they were not stated in writing.

I happily took them down whenever asked, because by then they already did their job- their intended recipient acknowledged reading them.

Absence of disclaimers in the vast majority of work observed in the wild may be taken as disturbing evidence of a general tendency of succumbing to such dumb clients.

The third category is the elementary building physics. You would see multiple titles such as "*Limitations of the Condensation Assessment*," "*Limitations of Location,"* "*Limitations of the Simulation Method."* of disclaimers in my report's template under the link: http://bec-miami.com/sample%203D%20report.pdf.

They tell you obvious but often forgotten truths: e.g. if the temperature or windspeed outside are more extreme than the climate conditions written in specs, than a simulation based on such specs should no longer be relied upon, or that the cheap steady-state conduction simulation is a poor approximation of the real life which is not only dynamic, but also features two more modes of energy transfer: convection and radiation.

The chart shown on Fig. # 52 indicates what's the right simulation type depending on the conditions. I made this chart and typically gave it to my clients at the outset of a project, to make sure they were given the choice, could not complain later they were not told that they chose a wrong type, and because I could provide all these types of simulations in house, something very few other shops could offer.

Unfortunately, majority of specifications got it wrong, while my clients were subcontractors or material providers, who were bond by these specs. My clients easily understood the limitations, but were unable to change them at this stage.

Interestingly enough, reviewing such projects as a commissioning agent working for owners (from the very top of the food chain as opposed to the very bottom), I neither had any success to improve these inferior specs. Later "post mortem" investigations revealed that architects and specification writers did not understand my comments, and preferred to bury their heads in the ground. Their formal explanations could form an interesting gallery of excuses, worth presenting separately. Therefore, these limitations could hurt your project very badly.

Meteorological conditions are not as precise as their format would suggest (listed to 1/10 of degree.), and certain relationships are only established as general rules of thumbs. E.g. precipitation may or may not form in the certain combination of temperature and humidity, depending on many other factors, etc. Reference the introduction, where I suggested to round all temperatures.

Last, but not least comes the standard error involved in simulations. I don't recall a single author who was courageous enough to mention it, but it's generally approx. 10% Once you combine it with other standard errors, you get a picture. You may recall the example given e.g. in Fig #12, where the lowest temperature was claimed to be 40.6 degrees F, while the actual Dew Point was 37 degrees F.

Even if this result were true, its lower range would be 40.6◦F x 90%= 36.5 degrees F, less than Dew Point, indicating potential for condensation, except that the report also mistakenly assumed a lower Dew Point.

Even given the permissive character of this industry association, NFRC set certain standards. In this case not even the author was revealed, much less felt confident enough to sign his work.

Procedures sometimes need to be modified, but unless the extent and nature of such a modification needs to be explained. The statement "*Using some and or all NFRC…procedures*" in the example shown in Fig #43 above deprived the report of any value. Below in Fig. #45 is an example where procedures were modified, because no 3D simulations are standardized, and accompanied with a precise description how they were modified.

U Value Confusion

You could see my seminar on the confusion regarding different measures and units if thermal energy transfer, one of its slides is presented below in Fig. #44.

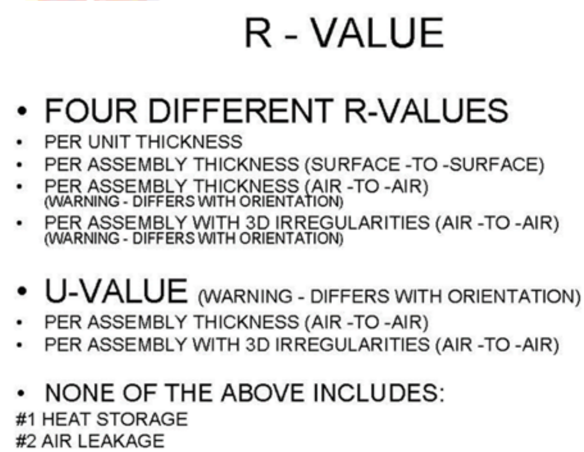


Fig. # 44. A slide from my thermal engineering seminar, just as a reminder of complexities that we do not intend to dwell here upon.

However, this paragraph is not about those technical aspect. It’s about specs and how they are met.

In a great abstract, there are two reasons why we need it in specs: 1) as a benchmark for substitutions, 2) to meet energy goals.

Those two are almost always confused in specs, or downright combined in one, causing a lot of headaches at this stage. Here is a short description of the two:

1) Thermal transmittance is measured under standard conditions on a representative sample, as a benchmark for substitutions. Product A could be compared with Product B, apples to apples.
2) Project-specific thermal transmittance was sometimes written in the specs in order to respond to a different question: would this particular-sized opening, shaped and divided in this particular way, in this particular climate, protecting this particular space, allow the project to meet its energy goals?

The latter is a completely different, and much more laborious task than the former one, and undertaken too late to make any difference.

Also, the expectations could be misaligned. Custom testing is normally procured to harvest efficiencies, e.g. cost of wind tunnel studies is justified by savings achieved by lower wind pressure numbers.

In theory, the thermal performance should be improved this way, because opaque assemblies are more economically and better thermally insulated than openings, because modern openings are exceedingly larger, allowing use of less joints (remember: joints tend to spoil results), and because site-specific climate conditions are less severe in most of U.S. is than the NFRC benchmark conditions (remember, U.S. latitude is generally south of Europe, and therefore warmer). Therefore, a reasonable expectation would be that the adiabatic perimeter conditions shown in standard testing could be improved by the project-specific conditions.

In other words, your wall packed with cheap mineral wool, should offer a much more favorable testing site, allowing certain efficiencies, e.g. allowing for purchase of a less expensive fenestration in order to meet the same overall U-value.

Nothing further from the truth. In practice, the opposite is true in the U.S. (with so very few exceptions that we could safely omit them here). Here, transitions to the adjacent opaque assemblies are designed so badly as a rule, that their typically spoil the openings far below their benchmark levels.

2.3 Fenestration Test Procedure

We based our procedure on the specified fenestration standard NFRC 100 "Procedure for Determining Fenestration Product U-factors " and the NFRC "Simulation Manual," which we modified for our purpose, in the following way: We modeled the assemblies per the NFRC 100, and used the 2D results for calibration and validation of the 3D models of the three-dimensional assemblies void of the analyzed thermal bridges.

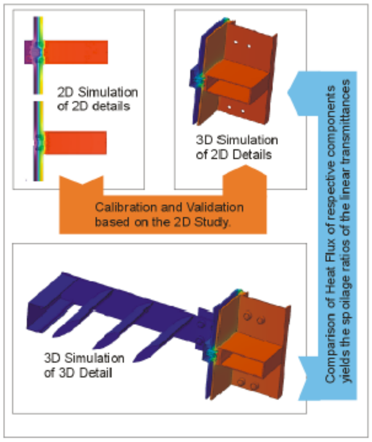
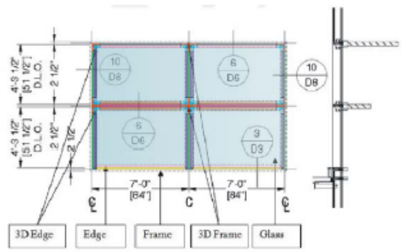


Fig. # 45. An example of description clearly explaining the procedure, including the modifications. Courtesy of Building Enclosure Consulting Inc.

Then, we modeled the three-dimensional details, featuring the same materials and boundary conditions, as the ones modeled previously, but this time including the 3D thermal bridges.

The subsequent comparison of the heat flows through relevant components of the three-dimensional models: with and without the 3D bridge, yielded the respective spoilage ratios for framing, glazing, and the glazing edge components.



Application of 13 different thermal transmittances to the respective curtain wall bay.

This process is graphically presented on the charts reproduced on this and the previous pages.

The transmittances obtained this way were subsequently used in area-weighting, where each component was multiplied by its aggregate area and the number was divided by the total curtain wall area, in order to arrive to the transmittance for the entire glazing, using the whole-product area weighted U-value calculation formula, as documented in Equation 4 in "NFRC 100: Procedures for Determining Fenestration Product U-factors" reproduced on

$$U_t = \frac{\left[\sum(U_f * A_f) + \sum(U_d * A_d) + \sum(U_e * A_e) + \sum(U_{de} * A_{de}) + \sum(U_c * A_c)\right]}{A_{pf}}$$

Where:

U_t = Total product U-factor, W/m²-°K, (Btu/hr-ft²-°F).
A_{pf} = Projected fenestration product area, m² (ft²).
U_f = Frame U-factor, W/m²-°K, (Btu/hr-ft²-°F).
A_f = Frame area, m² (ft²).
U_d = Divider U-factor, W/m²-°K, (Btu/hr-ft²-°F).
A_d = Divider area, m² (ft²).
U_e = Edge-of-glazing U-factor, W/m²-°K, (Btu/hr-ft²-°F).
A_e = Edge-of-glazing area, m² (ft²).
U_{de} = Edge-of-divider U-factor, W/m²-°K, (Btu/hr-ft²-°F).
A_{de} = Edge-of-divider Area, m² (ft²).
U_c = Center-of-glazing U-factor, W/m²-°K, (Btu/hr-ft²-°F).
A_c = Center-of-glazing area in ft² (m²).

the previous page.

2.4 Analysis Methods

The modeling, preprocessing, and post processing were carried out in several different programs. The conditions were simulated in steady-state. The conductive heat transfer was simulated, while convection and radiation were only estimated. The list of software along with version numbers is provided in the Appendix E.

At the time these thermal simulations are run and reviewed, it's too late to fix the design, explaining why these specs are almost always silently waived by owners and architects.

Therefore, if you are a reviewer reading it in the U.S. you can just skip this entire part, because it wouldn't make a difference: the entire subject of verification of project-specific U-value, is often mute due to circumstances mentioned earlier: ignorance is a bliss.

If you are a specification writer or an architect, don't. The reason why it generally works in other countries is simple: and composed of three factors: 1) architects have those simulations completed before the construction documentation is finished, resulting in at least an awareness of what constitutes a correct transition. 2) the awareness of other aspects of building physics, building codes, construction sequencing, etc. that allow to design not only a warm, but also doable transitions. 3) Contractors are familiar with them and therefore willing and able to build them.

I only know one such architectural company in the U.S. and it repetitively met such a resistance from U.S. contractors that it had to take over the delegated design and produce shop drawings on its own. There is simply not enough expertise in this country, as explained in the introductory chapters.

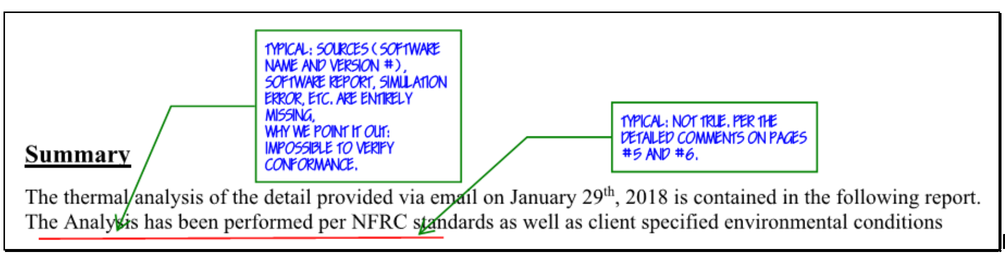
Scope Revisited

In roughly 95% of cases what you need is very simple, and is composed of two checks: a) the sweat won't damage anything, and b) the energy bills would be reasonable.

a) Condensation risk assessment must prove to you that the detail either would only sweat within reason, or that the condensate would be safely collected and drained away.
b) Heat transfer assessment must prove to you that the assembly would slow heat transfer down enough.

Time for some general remarks, as follows:

In both cases, the report must prove these points to you beyond any reasonable doubt. Otherwise, you are entitled to return it as unresponsive or for corrections. In the latter case, you would need to spend a lot of time typing, as you could see by the number of comments on the examples of my reviews, such as Fig. #50.



Summary

The thermal analysis of the detail provided via email on January 29th, 2018 is contained in the following report. The Analysis has been performed per NFRC standards as well as client specified environmental conditions

Fig. # 46. Awkward wording that we dwell on due to absence of data, trying to figure out the scope. Either case is generally true: it was either based on client-specified environmental conditions or NFRC standards. If it wasn't conducted per NFRC standards as proven by analysis of the content of the report, it still doesn't mean that client-specified conditions were actually modeled.

Psychological Aspects

The reports presented here are obviously incorrect on face of them, anonymous and unsigned, yet were approved by both review layers (look at their transmittals, most typically: the general contractor and the architect both certified their conformance before buildings got built based on them.

I could hardly imagine any other industry where such an outright scam could be possible and persist for such a long time. How do they accomplish such immunity? There are several reasons, e.g. the general indifference due to mild climate and low energy costs, described in the introduction.

However, some other reasons are easier to modify, as follows:

One of the important factors is that they count on you, the reviewer, feeling intimidated by math and physics, and therefore afraid to pose questions. And they almost always succeed beyond their wildest dreams. It reflects badly on you, the reviewer: It's their job, not yours. If in doubt, just return it.

We all met different judges in our life and work. There are two kinds of stereotypical reviewers: laid back individuals either oblivious or benevolent enough to let issues pass under their radar, and strict disciplinarians, draconian in their passion to dwell on other people's faults. There doesn't seem much room between these two extremes, and the two seems to be inextricably represented in different milieus and countries. Western societies generally tend to employ the former type, while eastern ones the former ones, for multiple reasons.

Aversion for confrontation planted in the western societies, combined with introvert upbringing makes it fundamentally difficult for many individuals here to question experts.

The interesting, opposite attitude is observed in foreign reviewers, otherwise outspoken: reverence for America and its technological achievements gags any criticism, as described below.

Apparent Authority

Every now and then you would stumble upon a report coming from a seemingly reputable source. E.g. there would be a PhD behind author's name, or an engineering company of international repute, that we could use as a standard of quality in the past. It's important to understand their limitations: in the U.S. the same company has to rely on local workforce, and the quality drops.

PhDs in this field typically come from material sciences, where sadly they generally have no relevant experience that would allow them to understand realities of the American construction field, and tend to be oblivious of building codes. Many PhDs in these fields are foreign immigrants, whose language barrier creates an additional challenge.

Another issue is the poor English and syntax. I typically give authors benefit of the doubt, assuming the author is probably an immigrant like myself. Some of them questioned about their assumptions and methods came with very good answers, in the process making me humbly realize how much I need to learn. However, it was in the past, and now they are just plainly incommunicative. Perhaps America no longer drains brains from the rest of the world?

Also, this guide is exclusively devoted to the U.S. market. If you are a foreign reviewer of such a report, your expectations could be severely mismatched. America abroad is seen as cradle of science and technology, first in research and development, home of many Nobel laureates, and therefore coming across an imbecilic report may prompt you to question your judgment. “It can’t be as bad as it seems, because it was made in USA,” is the typical attitude, as flattering as it may sound, actually reflects disappointingly on the eventual perception of quality.

Don’t. If you need to rationalize it, look at educational achievement statistics: it’s just a sad reflection of decades of neglect in math and physic departments.

CONCLUSION:

For summer, the temperature differential indicated on the previous thermal simulations show an exterior temperature of 100 degrees F exterior and an interior temperature of 72 degrees F – therefore a 28-degree temperature delta.

There is not a temperature delta greater than 3 degrees anywhere inside the wall cavity. That temperature delta does not provide a nucleation site with temperatures, pressures and humidity levels that are used for conditioned buildings. This is due to both the thermal efficiency of the [redacted] and the fact that no through-wall fasteners are used.

See the psychrometric chart on the following page for reference dew point/temperatures for 40%, 50% and 60% ranges. These ranges include 08400 – Exterior Enclosure System Requirements performance requirements (2.1L, M) in the specifications and cover the worst-case scenarios of summer. The temperatures in the wall cavity do not approach the dew point temperatures found in the highlighted portions of the psychrometric chart.

The submitted reports indicate successful performance of [redacted] system within the most stringent temperature/humidity range combinations.

TYPICAL: THIS ONLY CONDENSATION RISK ANALYSIS, WHICH IS NOT REQUIRED FOR SUMMER.
THE RATIONAL FOR THERMAL RESISTANCE VALUE IS MISSING.

Fig. # 47. Summer condensation assessment is something that is almost always absolutely unnecessary, particularly with respect to cold bridging in cold climates.

Big Picture - Procedure.

This work seemingly boils down to comparing two sets of respective numbers, e.g. the resulting U value with the required U value, etc. How difficult could that be?

First, good luck finding out what these numbers are. You could see an example in Fig. #48, where I missed the big picture: the result claimed by the subcontractor that missed the goal by 5%, wasn't the result of the simulation, and the actual result (presented on the right side) missed the goal by 225%. The subcontractor misidentified the required U value by the 5%.

It's easy to get lost in intricacies of thermal modeling and get distracted by many minor nonconformances. It takes some effort to focus on a big picture instead. We touched upon this subject in the introduction.

Fig. #50 shows an example of such a review. Almost nothing made sense there. Not also the key was missing that would allow to decipher any logic here, but author(s) seemed to suffer from severe dyscalculia. Half-way through this page, I could no longer see the big picture, and I still don't see. This was a flat roof cold-bridged in two ways: by continuous steel Z girts presented earlier in Figs. #11-13, and penetrated by a dense pattern of steel screws, with some areas thinned to create drainage, and multiple large and small penetrations. The roof's size could be compared to two football fields, divided in four phases, with multiple different conditions.

The big picture here was three-fold: 1) that a single page of calculations to represent all these complexities showed lack of seriousness, and 2) a report that claimed that a roof based on nominal insulation R value of approximately R-35 accomplished R-46 must better prove it, and 3) a thermal report issued months after the roof construction started without any submittals may need to be taken with a grain of salt.

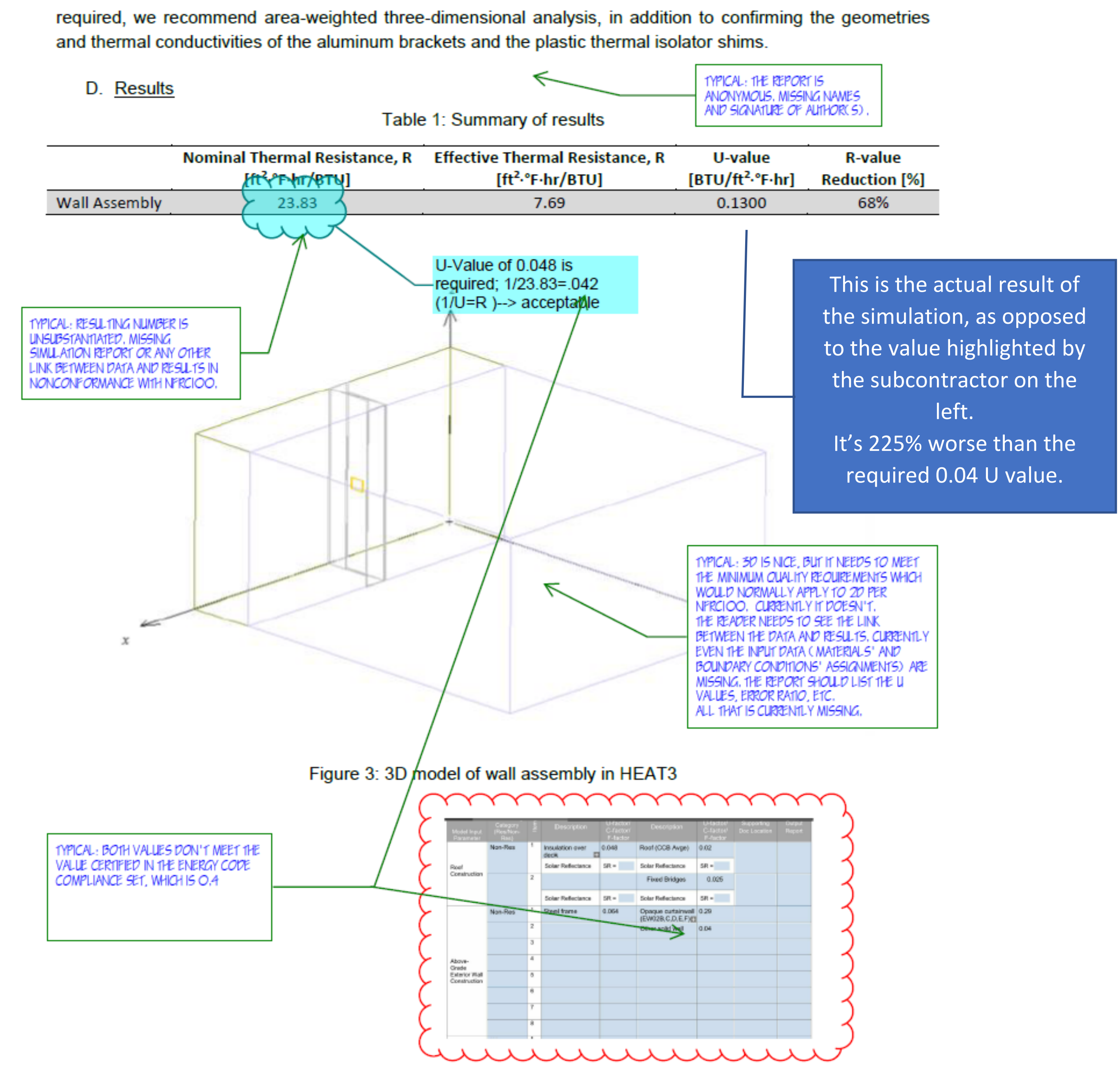
Another example is shown in Fig. #51. It presents a result without any evidence. We are asked to take it on faith that a nominal R-21 wall achieves R24.4 in spite of cold bridging by Z girts.

Another example is shown in Fig. #50. It seems to make things simple for you: the title says "Project Specifications," but what you see is the other side of the equation: it claims that 8 inches of R-4.17 (amounting to the nominal total R- 33.36) bridged by attachment pins achieved R-32, which claim, although completely unsupported by the report, seemed probably stretched considering it would be thinned to 3" on beams, but close enough.

The other side of this comparison, which is confusingly listed in the title "Project Specifications," is not shown here at all. The U value certified for this assembly by the architect was 0.018, which reciprocal is R-55, unrealistic enough, considering the depth of this insulation would need to be over 13 inches. (This is fairly typical on projects we saw: architects often drew spray foam insulation on large projects, and refused to acknowledge fire code nonconformance. Once the assembly was eventually redesigned to something incombustible, it wouldn't meet the same thermal resistance criteria.)

The big picture here is this assembly, in spite of making it as thick as possible only achieved only a little over half of the certified thermal resistance.

The submittal must prove the work is equal or better than the respective performance requirements. In all except very few rare cases, reports that I have seen in circulation did not meet this simple criterion, most often by omission of data, combined with internal contradictions, obvious inaccuracies, modeled conditions significantly different from the design, overly broad disclaimers, and lack of any certification, as in examples seen above.


required, we recommend area-weighted three-dimensional analysis, in addition to confirming the geometries and thermal conductivities of the aluminum brackets and the plastic thermal isolator shims.

D. Results

Table 1: Summary of results

	Nominal Thermal Resistance, R [ft²·°F·hr/BTU]	Effective Thermal Resistance, R [ft²·°F·hr/BTU]	U-value [BTU/ft²·°F·hr]	R-value Reduction [%]
Wall Assembly	23.83	7.69	0.1300	68%

Figure 3: 3D model of wall assembly in HEAT3

Model Input Parameter	Category (Res/Non-Res)	Item	Description	U-factor/ C-factor/ F-factor	Description	U-factor/ C-factor/ F-factor	Supporting Doc Location	Output Report
Roof Construction	Non-Res	1	Insulation over deck	0.048	Roof (OCB Avge)	0.02		
			Solar Reflectance	SR =	Solar Reflectance	SR =		
		2			Fixed Bridges	0.025		
			Solar Reflectance	SR =	Solar Reflectance	SR =		
Above-Grade Exterior Wall Construction	Non-Res	1	Steel frame	0.064	Opaque curtainwall (EW02B,C,D,E,F)	0.29		
		2			Other solid wall	0.04		
		3						
		4						
		5						
		6						
		7						
		8						

Fig. # 48. An example of confusion. The result claimed by the subcontractor that missed the goal by 5%, wasn't the result of the simulation, and the actual result (presented on the right side) missed the goal by 225%.

If you are an architect, you should reject submittals on the first sight of nonconformance. Your review means that the submittal was already certified by a GC., and it should be a good enough reason. E.g. imagine being presented with a submittal shown in the Fig. #50. It is marked already as a revision, meaning that there was at least one undisclosed version circulated prior to this submittal, and it could be presumed that it was even worse one. It's still a colossal waste of time to go over it and point out every issue.

In my entire career, I never saw any comments from a general contractor. That included submittals clearly stating that the product failed the testing. They also were invariably stamped as meeting the specifications and passed onto an architect. I can only hope that my experience was uncommon, and GCs don't just generally rubber stamp everything without even a cursory review. I always console myself that I only see the worst projects there are. But those weren't some backwater projects, to the contrary, it happened on largest and most expensive ones.

Architects also generally approved such rare reports that indicated assemblies never met the specified values. However, these submittals often bore tell-tale marks indicating that they actually reviewed them as opposed to rubber stamping: e.g. some formal comments referring to construction documentation procedures. Useful architectural comments were generally seen in only one category: complains about the report not reflecting the design. As a reviewer, you may be tempted to place such remarks. However, if you do, you would severely restrict your ability to demand conformance later in those areas that you've missed, particularly if the entire submittal missed the performance mark.

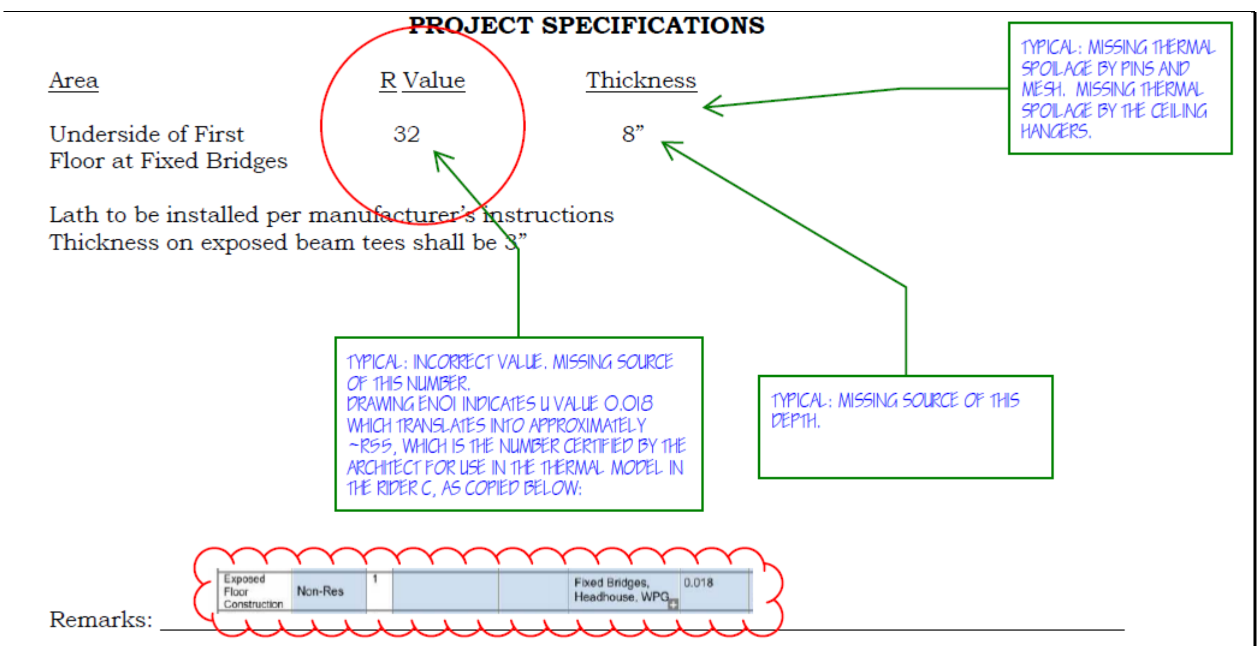
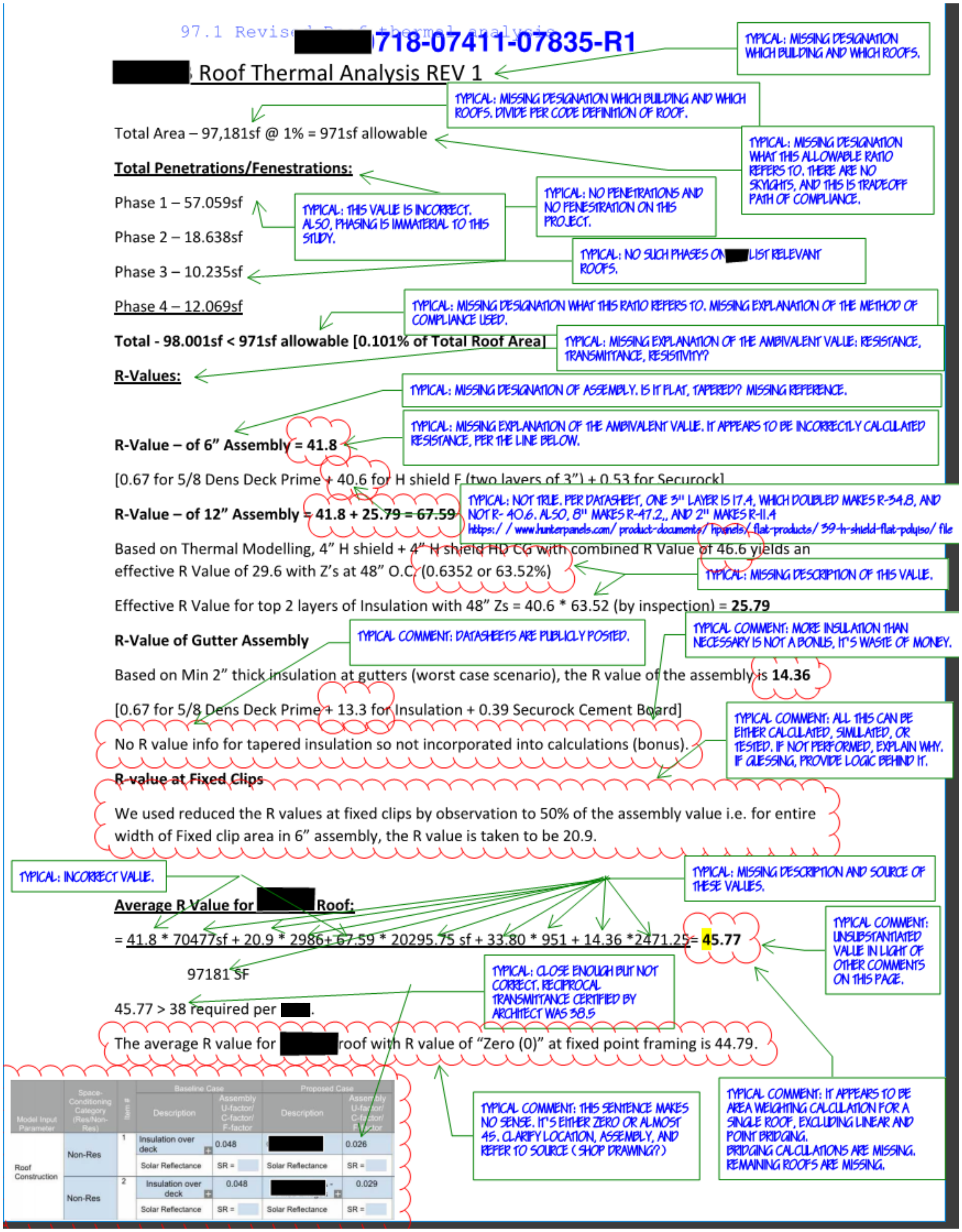


Fig. # 49. This is one of the simplest reports you would see as a reviewer. It says that 8 inches of R-4.17 (amounting to the nominal total R- 33.36) bridged by attachment pins achieved R-32, which claim, although completely unsupported by the report, seemed close enough, although probably stretched, considering it would be thinned to 3" on beams. The trouble is the other side of this comparison, which is confusingly listed in the title "Project Specifications," but not shown here at all. We pulled it from the set: the U value certified for this assembly by the architect was 0.018, which reciprocal was R-55, unrealistic enough, considering the depth of this insulation would need to be over 13 inches. The big picture here is this assembly, in spite of making it as thick as possible only achieved a little over half of the certified thermal resistance.



97.1 Revis[redacted] thermal analysis

[redacted]718-07411-07835-R1

TYPICAL: MISSING DESIGNATION WHICH BUILDING AND WHICH ROOFS.

[redacted] Roof Thermal Analysis REV 1

TYPICAL: MISSING DESIGNATION WHICH BUILDING AND WHICH ROOFS. DIVIDE PER CODE DEFINITION OF ROOF.

Total Area – 97,181sf @ 1% = 971sf allowable

TYPICAL: MISSING DESIGNATION WHAT THIS ALLOWABLE RATIO REFERS TO. THERE ARE NO SKYLIGHTS, AND THIS IS TRADEOFF PATH OF COMPLIANCE.

Total Penetrations/Fenestrations:

TYPICAL: NO PENETRATIONS AND NO FENESTRATION ON THIS PROJECT.

Phase 1 – 57.059sf

TYPICAL: THIS VALUE IS INCORRECT. ALSO, PHASING IS IMMATERIAL TO THIS STUDY.

Phase 2 – 18.638sf

Phase 3 – 10.235sf

TYPICAL: NO SUCH PHASES ON [redacted] LIST RELEVANT ROOFS.

Phase 4 – 12.069sf

TYPICAL: MISSING DESIGNATION WHAT THIS RATIO REFERS TO. MISSING EXPLANATION OF THE METHOD OF COMPLIANCE USED.

Total - 98.001sf < 971sf allowable [0.101% of Total Roof Area]

TYPICAL: MISSING EXPLANATION OF THE AMBIVALENT VALUE: RESISTANCE, TRANSMITTANCE, RESISTIVITY?

R-Values:

TYPICAL: MISSING DESIGNATION OF ASSEMBLY. IS IT FLAT, TAPERED? MISSING REFERENCE.

TYPICAL: MISSING EXPLANATION OF THE AMBIVALENT VALUE. IT APPEARS TO BE INCORRECTLY CALCULATED RESISTANCE, PER THE LINE BELOW.

R-Value – of 6" Assembly = 41.8

[0.67 for 5/8 Dens Deck Prime + 40.6 for H shield F (two layers of 3") + 0.53 for Securock]

R-Value – of 12" Assembly = 41.8 + 25.79 = 67.59

TYPICAL: NOT TRUE. PER DATASHEET, ONE 3" LAYER IS 17.4, WHICH DOUBLED MAKES R-34.8, AND NOT R- 40.6. ALSO, 8" MAKES R-47.2,, AND 2" MAKES R-11.4
https:/ / www.hunterpanels.com/ product-documents/ hpanels/ flat-products/ 39-h-shield-flat-polyiso/ file

Based on Thermal Modelling, 4" H shield + 4" H shield HD CG with combined R Value of 46.6 yields an effective R Value of 29.6 with Z's at 48" O.C (0.6352 or 63.52%)

TYPICAL: MISSING DESCRIPTION OF THIS VALUE.

Effective R Value for top 2 layers of Insulation with 48" Zs = 40.6 * 63.52 (by inspection) = **25.79**

R-Value of Gutter Assembly

TYPICAL COMMENT: DATASHEETS ARE PUBLICLY POSTED.

TYPICAL COMMENT: MORE INSULATION THAN NECESSARY IS NOT A BONUS, IT'S WASTE OF MONEY.

Based on Min 2" thick insulation at gutters (worst case scenario), the R value of the assembly is **14.36**

[0.67 for 5/8 Dens Deck Prime + 13.3 for Insulation + 0.39 Securock Cement Board]

TYPICAL COMMENT: ALL THIS CAN BE EITHER CALCULATED, SIMULATED, OR TESTED. IF NOT PERFORMED, EXPLAIN WHY. IF GUESSING, PROVIDE LOGIC BEHIND IT.

No R value info for tapered insulation so not incorporated into calculations (bonus).

R-value at Fixed Clips

We used reduced the R values at fixed clips by observation to 50% of the assembly value i.e. for entire width of Fixed clip area in 6" assembly, the R value is taken to be 20.9.

TYPICAL: INCORRECT VALUE.

TYPICAL: MISSING DESCRIPTION AND SOURCE OF THESE VALUES.

Average R Value for [redacted] Roof:

= 41.8 * 70477sf + 20.9 * 2986+ 67.59 * 20295.75 sf + 33.80 * 951 + 14.36 *2471.25= 45.77

97181 SF

TYPICAL COMMENT: UNSUBSTANTIATED VALUE IN LIGHT OF OTHER COMMENTS ON THIS PAGE.

TYPICAL: CLOSE ENOUGH BUT NOT CORRECT. RECIPROCAL TRANSMITTANCE CERTIFIED BY ARCHITECT WAS 38.5

45.77 > 38 required per [redacted].

The average R value for [redacted] roof with R value of "Zero (0)" at fixed point framing is 44.79.

Model Input Parameter	Space-Conditioning Category (Res/Non-Res)	Item #	Baseline Case: Description	Baseline Case: Assembly U-factor/ C-factor/ F-factor	Proposed Case: Description	Proposed Case: Assembly U-factor/ C-factor/ F-factor
Roof Construction	Non-Res	1	Insulation over deck	0.048	[redacted]	0.026
			Solar Reflectance	SR =	Solar Reflectance	SR =
	Non-Res	2	Insulation over deck	0.048	[redacted]	0.029
			Solar Reflectance	SR =	Solar Reflectance	SR =

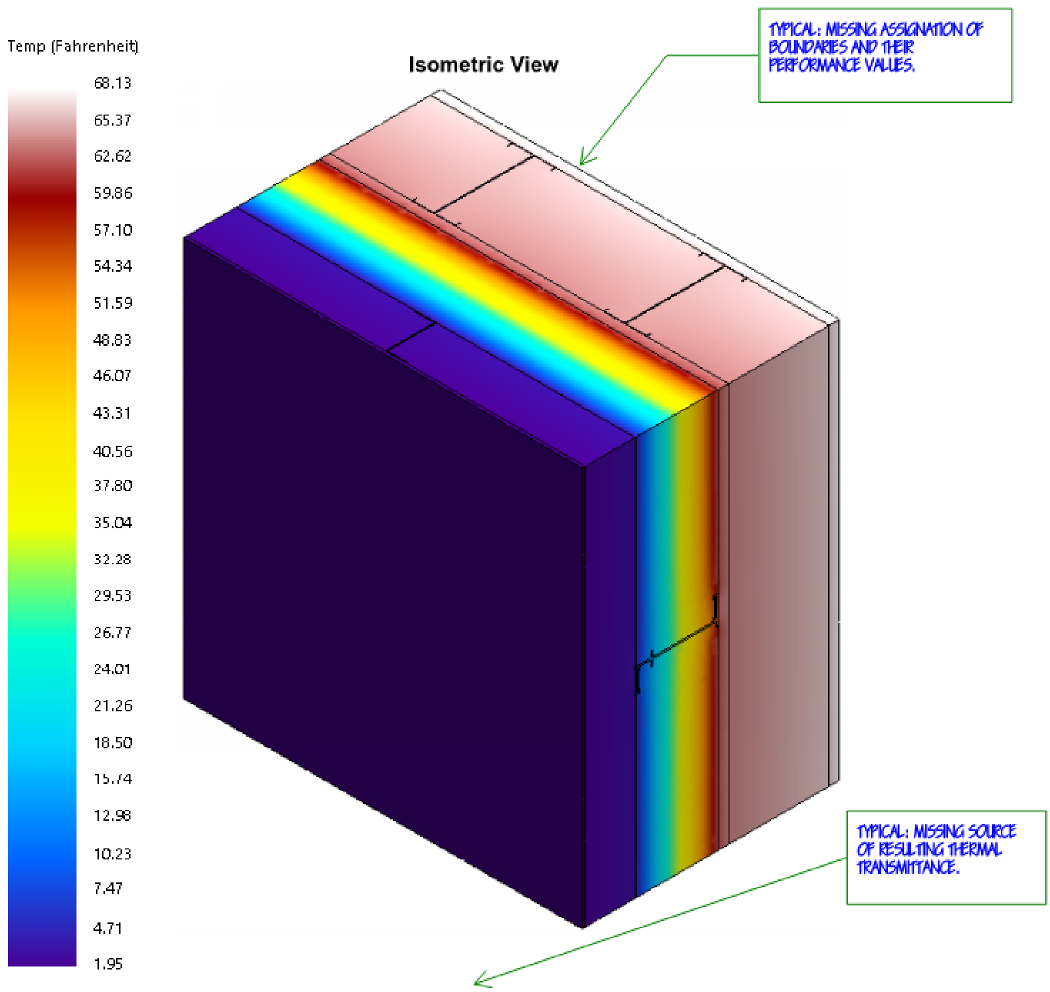
TYPICAL COMMENT: THIS SENTENCE MAKES NO SENSE. IT'S EITHER ZERO OR ALMOST 45. CLARIFY LOCATION, ASSEMBLY, AND REFER TO SOURCE (SHOP DRAWING?)

TYPICAL COMMENT: IT APPEARS TO BE AREA WEIGHTING CALCULATION FOR A SINGLE ROOF, EXCLUDING LINEAR AND POINT BRIDGING. BRIDGING CALCULATIONS ARE MISSING. REMAINING ROOFS ARE MISSING.

Fig. # 50. Sample report page with my comments, showing severe dyscalculia and confusion on part of its author, severely distracted the reviewer. Missing key that would allow to understand logic here, unsupported numbers. Either reject the report as unresponsive or prepare for a lot of typing.

WALL CONSTRUCTION #1:

Aluminum cladding attached to vertical 3” stainless steel “Z” girts 24” O.C., attached to 5” [redacted] oriented horizontally 24” O.C. with stainless steel inserts & fasteners, with 5” of mineral wool insulation @ R-4.2 per inch, on 5/8” gypsum board exterior grade sheathing, attached to double 6”- 16ga. galvanized steel stud at 11 ½” O.C. The perimeter of the wall in the simulation software applies adiabatic boundary conditions.



EFFECTIVE R-VALUE: 24.4 / PERCENT EFFECTIVE: 94.9%

Fig. # 51.. A link is missing between values and data, it presents a result without any evidence. We are asked to take it on faith that a nominal R-21 wall achieves R24.4 in spite of cold bridging by Z girts. Based on the list of components, and a pretty picture, we are asked to trust a number that someone typed under it. In this case, the limitation of the chosen software is that it doesn’t easily produce a report. However, as each software comes with its distinct pros and cons, and this one allows a modeler to show an “exploded view,” that would help to validate it. None was found, so this advantage was not taken. Instead, a plan view (shown below) was presented with some numbers, all fairly useless for a reviewer.

Tell-Tale Signs

A suspicious report is relatively easy to spot for someone familiar with the trade, because there are obvious signs all over it: e.g. incorrect units (e.g. squared conductivity), incorrect names of values (e.g. transmittance confused with transmissivity), confused scope (e.g. winter with summer), dyscalculia (e.g. 17.4+17.4=45), overly broad disclaimers, lack of certification, etc. All these issues suggest need for a deeper investigation at the first glimpse. In order to notice them, you would need to actually understand this business, and it's too much to expect. However, if you insist, I posted a thermal seminar on YouTube, which would be a good start: https://youtu.be/WySwQdcBZf4

The next issue is net conclusions presented at absence of any substantiating data. Physical testing report show net data, but they need to follow certain quality assurance standards, e.g. ISO 9001, so there would be two camcorders on tripods, one filming the testing, while the second would be filming the first one, equipment would be calibrated, and the lab would be accredited, all by independent third parties, and such measures would make a recipient of such a report trust their numbers. Unfortunately, the large players in this industry made such net result presentations also a standard for simulations and calculations.

However, in case of calculations and simulations, you, the reviewer are the only other pair of eyes to verify their veracity, and any attempt to omit this data should be a reason to immediate rejection. You must be allowed to verify these results by independently running the numbers and/or replicating the testing, if needed.

Summary

1) Verify whether the scope is stated correctly. Understand the minimum requirements of the work that you are reviewing. It needs to respond to the requirements of the specs and be reasonably complete. Don't worry too much about any dissonance between testing procedure (fenestration) and your opaque assembly.
2) Verify the result against the performance requirements stated in specifications. Obviously, you need to reject reports with failing score, but respect their authors for honesty and courage.
3) Verify the climate data against the specification, because it's almost always listed wrong.
4) Verify whether the report lists net conclusions only, or substantiates them with data. They need to give you at least the basic information related to their work, such as the numeric data of materials and boundaries, assignments, glazing, etc. Reject incomplete reports. The only exception is listed in #9 below: a benchmark U-value pre-testing report, subject to NFRC Certification Program.
5) Find out whether the report is signed. It needs to show at least one name and contact information of someone who took responsibility for it. Reject unsigned reports.
6) Compare the modeled glazing with the glazing schedule (typically attached to specifications) and with the glazing chosen for the project. This includes gazing spacers. Verify the glass is rotated for sloped glazing applications (U-value varies with orientation, and a common error is modeling sloped glazing as vertical assemblies). Reject significant differences.
7) Compare models with current shop drawings. Reject significant differences.

8) Majority of work needs only two scopes, winter only: a) Condensation assessment and b) U-Value. Focus on the former. Majority of specs should request condensation is contained within certain climate range. If it returns some odd language like e.g. CRF, it's not comparable with any other metrics.
9) The latter is normally a benchmark U- Value. It should be best specified as an actual physical laboratory test, like AAMA 1503, but if you are unlucky, you would get an old simulation, like AAMA 507, and good luck getting the complete report. However, the reports used for labeling, are subjected to NFRC oversight, so you don't need to verify their accuracy. Compare with the numbers certified by architect for the whole energy modeling. If they are different than what you found in #2 above, make a note of it, and flag it.
10) If the latter scope includes a project-specific U-Value, don't bother with it, because it's too late at this stage to make any use of it anyway.
11) If it doesn't look right, don't be afraid to ask. It's their job to prove their point, and if you learn in the process, it's your gain, nothing to be ashamed about.
12) If the report looks ridiculous, or is unsigned, or both, there may be a good reason for it. Find out the cellular number of its author, and listen to what they may have to say. Record this conversation.

Remaining 5%

You may remember my saying that roughly 95% of reports deal with either winter condensation or winter U-value. The remaining 5% is composed of odd cases that you may not need to worry about, but its' worth to know what they are out there, so you can spot them. The most common such item is a summer analysis, completely unnecessary in all cases in which I have seen it so far (e.g. cold bridging see Fig. #47), but most clients demand them anyway. Some analyses add SHGC, and these are actually very useful if done correctly, but we skipped this subject entirely here. Some analysis would add thermal stress and differential movement to the picture, which could also be useful. Some analyses add actual simulations of the two remaining modes of heat transfer: radiation and convection. The latter needs air movement analysis, called computational fluid dynamics (CFD). There are many different needs and ways to satisfy these different needs, and I touched upon them in the next chapter.

Applications of Simulation Software.

I attached two slides below, illustrating the decision tree. The chart below explains the choice of a particular type of simulation depending on the kind of the analyzed assembly, on example of condensation risk analysis.

Generally speaking:

- 1D simulations are suitable for uniformly-layered make-ups of partitions (i.e. adhered "sandwich" roofing assembly),
- 2D simulations are suitable for one-directional variations of assemblies (i.e. studwork),
- steady-state simulations are suitable for low heat storage assemblies (i.e. fenestration),
- transient simulations are necessary for high heat storage assemblies, (i.e. masonry)
- moisture transport analysis are necessary for permeable and water storage assemblies (i.e. solar transport in brick-veneered wall),
- CFD analysis are necessary for convection-sensitive assemblies (i.e. double skin walls), radiation analysis is necessary for radiation-sensitive assemblies.

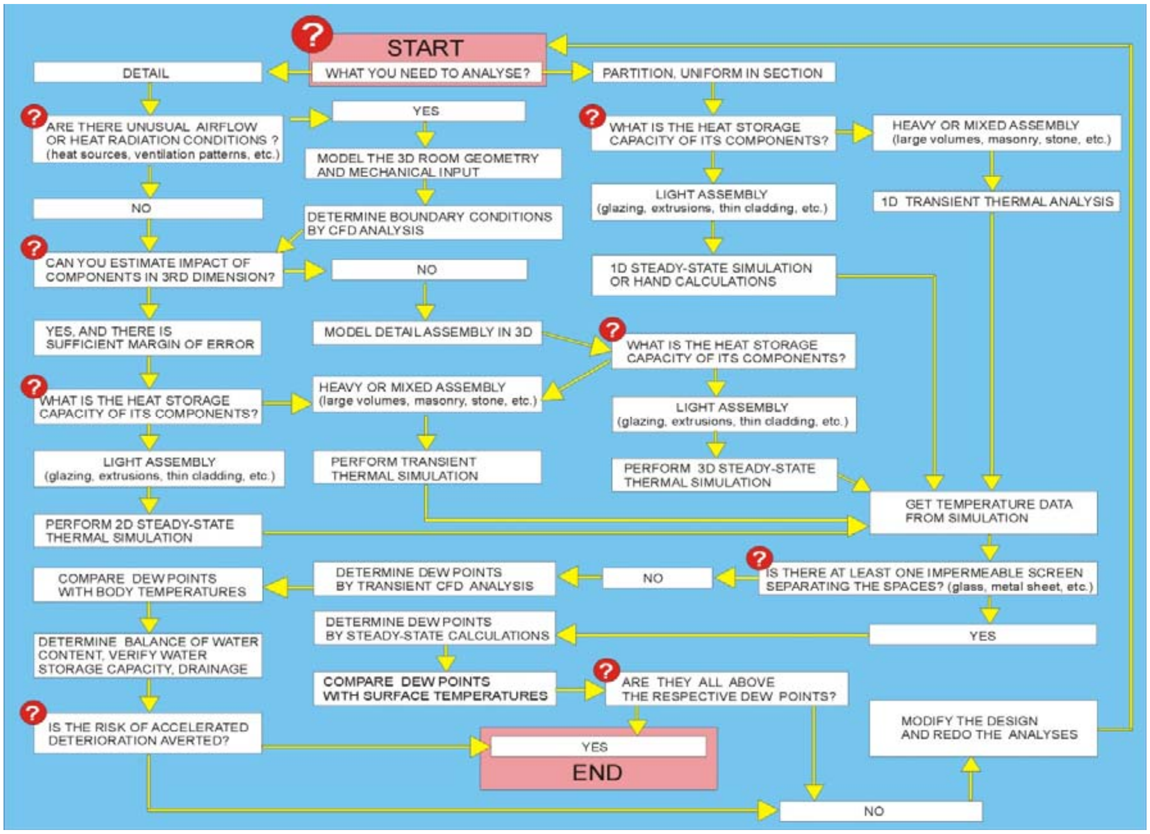


Fig. # 52. What simulation do I need for my project? Here is the decision-making chart.

Although free, the LBNL suite of software is not the only one there**,** but often used for its comprehensive glass library**,** in combination with other software. You could see examples in the reports shown in this paper: HEAT3, Physibel, Catia, Solidworks, to name a few. Each comes with its pros and cons, their cost range is stunning, and the operator's learning curve is even more challenging. You, as a reviewer don't need to be concerned about that, but it's an interesting conundrum to solve when a company decides to acquire such a software, and could severely limit its abilities later. (I started with LBNL, tried HEAT and several parametric FEA titles including Catia, moved to Solidworks for its CFD capabilities combined with relatively low cost, and ended up with Physibel.) A company that acquired such an illiquid asset and became a hostage of its operator becomes limited in their ability to assist its clients following the chart above, and may be overly eager for repetitive business to pay the investment back, and that may affect its policies.

At the very least, a reviewer needs to know what software and which version of it were used for the modeling, preprocessing, and simulation. Software is a link between the data and results. Keep in mind that there could be several different pieces of software that were needed for each step, and a good report would explain the choice. See Fig. #53 and #54 for example.

Software

The modeling was performed on basis of an image in JPG format, and an AutoCAD DWG file showing framing components and configuration, both provided by the Client.

The pre-processing and simulations were carried out in THERM Version 7.4, a state-of-the-art, Microsoft Windows™-based computer program developed at Lawrence Berkeley National Laboratory (LBNL) and approved by the National Fenestration Rating Council (NFRC). The THERM program is based on the finite-element method and can simulate two-dimensional steady-state heat conduction in building components such as windows, walls, foundations, roofs, and doors; appliances; and other products where thermal bridges are of concern. THERM's heat-transfer analysis allows to evaluate a product's energy efficiency and local temperature patterns, which may relate directly to problems with condensation, moisture damage, and structural integrity. THERM can also estimate two-dimensional heat-transfer effects of radiation and convection. THERM is based on the finite-element analysis (FEA), which can model the complicated geometries of building products.

The glazing and area-weighting calculations were carried out in the Window 7.4 program developed by LBNL, and featuring a state-of-the-art Microsoft Windows™-interface, and updated algorithms for the calculation of total fenestration product U-values and Solar Heat Gain Coefficient consistent with ASHRAE SPC142, ISO15099, and the National Fenestration Rating Council. WINDOW 7.4 provides a versatile heat transfer analysis method consistent with the updated rating procedure developed by the National Fenestration Rating Council (NFRC) that is consistent with the ISO 15099 standard. THERM's results were used with WINDOW's center-of-glass optical and thermal models to determine total fenestration U-factors.

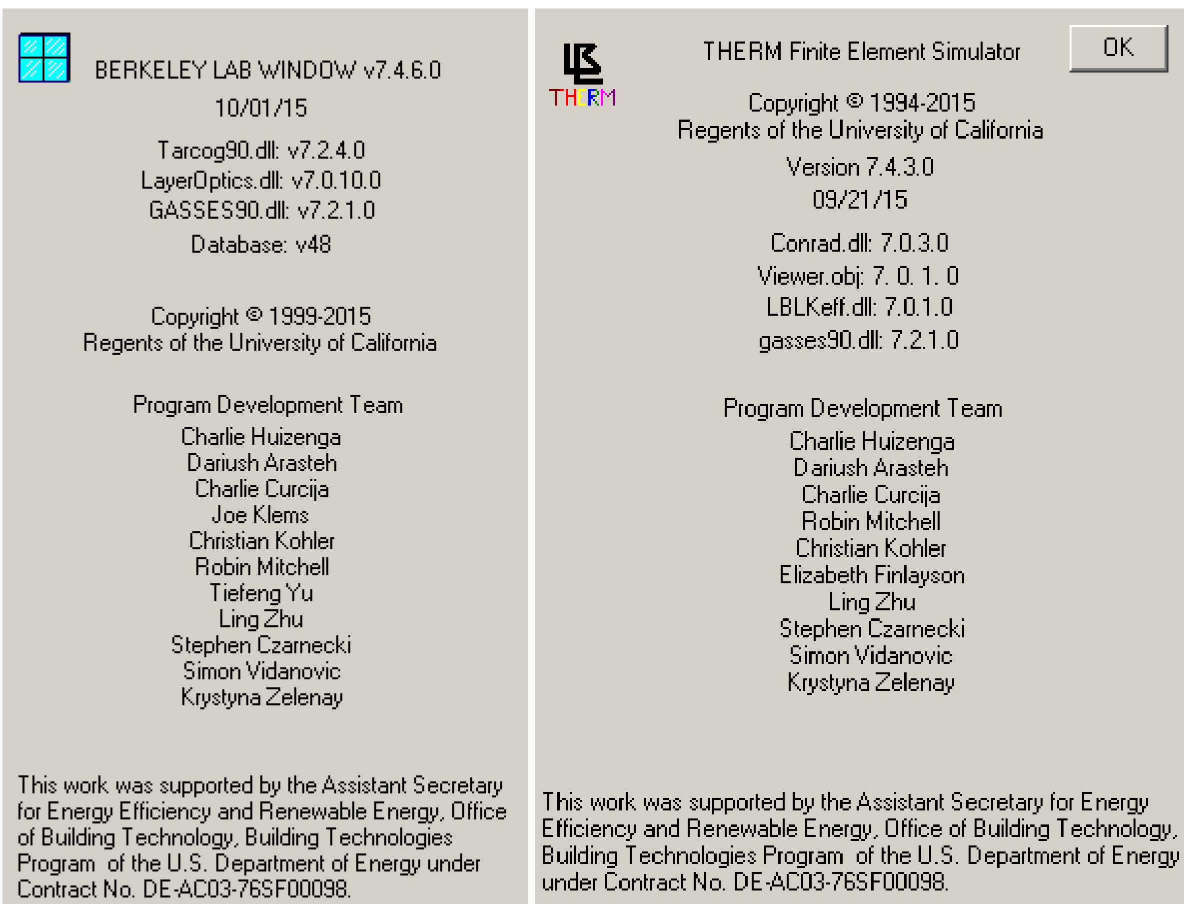
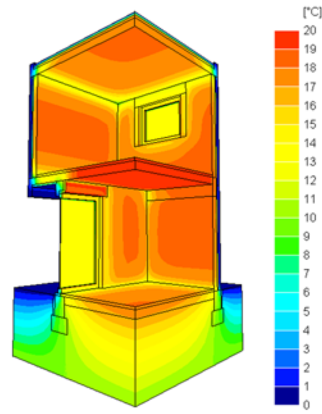


Fig. # 53. Above is the typical software description page attached to the report, the simplest one including only the LBNL suite. This page would normally be followed by a page of explanations, focusing on limitations of certain software titles. Courtesy Building Enclosure Consulting Inc

Software

The modeling was performed on basis of the Adobe PDF, AutoCAD DWG and Therm THM files showing framing components and configuration, and provided by [redacted], the fabricator, by [redacted] Inc, the manufacturer of the curtain wall system, and [redacted] North America, Inc, the manufacturer of the warm spacer system. The modeling was carried out in various CAD programs, such as: GStarCAD ver. 2011, and Google SketchUp, and auxiliary file converters.



The pre-processing and simulations were carried out in several FEA programs, including THERM Version 6.3, a state-of-the-art, Microsoft Windows™-based computer program developed at Lawrence Berkeley National Laboratory (LBNL) and approved by the National Fenestration Rating Council (NFRC). The THERM program is based on the finite-element method and can simulate two-dimensional steady-state heat conduction in building components such as windows, walls, foundations, roofs, and doors; appliances; and other products where thermal bridges are of concern. THERM's heat-transfer analysis allows to evaluate a product's energy efficiency and local temperature patterns, which may relate directly to problems with condensation, moisture damage, and structural integrity. THERM can also estimate two-dimensional heat-transfer effects of radiation and convection. THERM is based on the finite-element analysis (FEA), which can model the complicated geometries of building products.

The glazing and area-weighting calculations were carried out in the Window 6.3 program developed by LBNL, and featuring a state of the art Microsoft Windows™-interface, and updated algorithms for the calculation of total fenestration product U-values and Solar Heat Gain Coefficient consistent with ASHRAE SPC142, ISO15099, and the National Fenestration Rating Council. WINDOW 6.3 provides a versatile heat transfer analysis method consistent with the updated rating procedure developed by the National Fenestration Rating Council (NFRC) that is consistent with the ISO 15099 standard. THERM's results were used with WINDOW's center-of-glass optical and thermal models to determine total fenestration U-factors. For a user-defined fenestration system and user-defined environmental conditions, WINDOW calculates:

3D thermal simulations were carried out in Solido Version 3.1w, and Trisco Version 12.0w, a state-of-the-art, Microsoft Windows™-based computer program suite developed by Physibel c.v., to calculate three-dimensional steady-state heat transfer in architectural assemblies, consisting of different materials and submitted to different boundary conditions. These finite element analysis (FEA) programs were developed and validated based on the doctoral thesis on the 2D and 3D heat transport in building physics by Piet Standaert in year 1984. They comply with the following standards: EN ISO 6946 " Building components and building elements -- Thermal resistance and thermal transmittance -- Calculation method," ISO/FDIS 10211 "Thermal bridges in building construction - Heat flows and surface temperatures - Detailed calculations," EN ISO 10077-2 " Thermal performance of windows, doors and shutters -- Calculation of thermal transmittance -- Part 2: Numerical method for frames," EN12524 " Building Materials and Products - Hygrothermal Properties - tabulated Design Values."

Fig. # 54. Above is also the typical software description page attached to a 3D report. Courtesy Building Enclosure Consulting Inc

Literature:

Simulations should follow certain standards, such as e.g.:

- AAMA 507 , "Standard Practice for Determining the Thermal Performance Characteristics of Fenestration Systems in Commercial Buildings,
- NFRC 100 Procedure for Determining Fenestration Product U-Factors
- NFRC 200 Determining Fenestration Product Solar Heat Gain Coefficient
- NFRC technical Interpretation TI-2003-12, Curtain Wall Simulation
- NFRC Simulation Manual. National Fenestration Rating Council: Greenbelt, MD. www.nfrc.org.
- Teaching Students About Two-Dimensional Heat Transfer Effects in Buildings, Building Components, Equipment, and Appliances Using THERM 2.0. ASHRAE 1999

Condensation risk assessment sources:

- Sean O.Brien "Finding a Better Measure of Fenestration Performance: An Analysis of the AAMA Condensation Resistance Factor" Interface May 2005 https://iibec.org/wp-content/uploads/2016/04/2005-05-obrien.pdf
- Karol Kazmierczak "Condensation Risk Assessment in Glazing Design," The Construction Specifier, October 2007.
- Karol Kazmierczak "3D Thermal Modeling to Improve Performance Requirements." Journal of Building Enclosure Design, 02/2010.
- Karol Kazmierczak "Thermal Engineering in Building Enclosure Design." 2.5hr seminar on video: https://youtu.be/WySwQdcBZf4
- Karol Kazmierczak "Typical South Florida Wall." http://www.b-e-i.org/pemeability.pdf

Having simulations internally validated with infrared thermography and actual testing is invaluable. Common industry procedures are utilized, as follows:

- Thermal imaging of building envelope assemblies, by ASTM C 1060 "Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings,"
- Thermal imaging for wet materials, insufficient or wet insulation, and air leaks, following the ASTM standard C1153, titled "Standard Practice for Location of Wet Insulation in Roofing Systems Using Infrared Imaging,"
- Practices listed in RESNET National Home Energy Rating Standards,
- ASTM Test Method D 1864 "Standard Test Method for Moisture in Mineral Aggregate Used on Built-Up Roofs."
- NFRC 102: Test Procedure for Measuring the Steady-State Thermal Transmittance of Fenestration Systems

Commissioning procedures:

- Karol Kazmierczak " Building Enclosure Commissioning Kickoff Seminar" https://youtu.be/oQDQ2NdCOnE

Similarly, one cannot avoid the subject of bad or merely confusing sources and textbooks. I made fun of some of them in the past, but there is so many of them, that I eventually gave up.

Here is a confusing example coming from a reputable source:

http://www.aamanet.org/upload/file/Why_R_Is_Not_Simply_The_Inverse_of_U_September.pdf

Recently I still copied some outrageous examples from CEU seminars that I attended, showing how the low is the quality of continuing education of architects.

1. What is U-factor a measure of?
- A. Admittance of visible light
- B. Resistance to heat flow (selected)
- C. Absorption of UV light
- D. Air leakage

Fig. # 55.. CEU Seminar of a company, which name is not mentioned to protect the guilty. The final test with the response considered correct by author(s) of the seminar marked with a dark dot. U factor could be a measure of heat transmittance or thermal conductance. An architect must mark an obviously wrong answer in order to pass a test. Three more such examples are shown below.

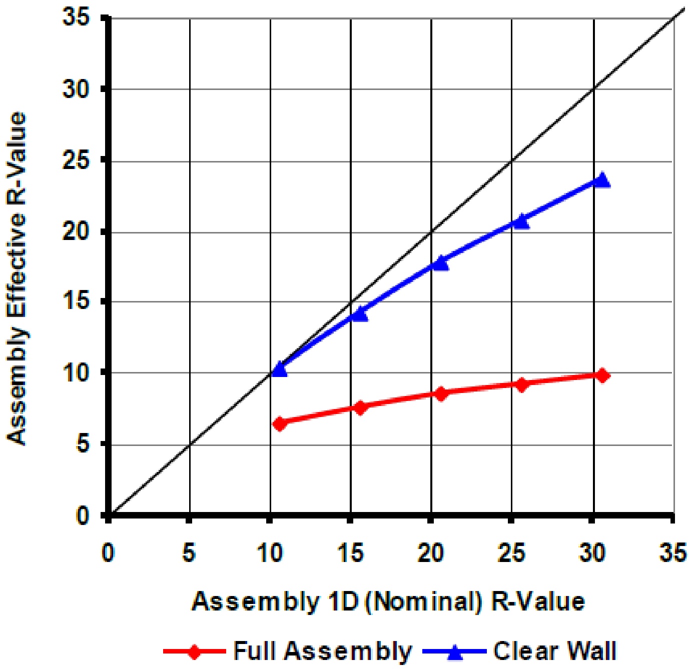
8. Thermal expansion of insulated panels is accommodated by ______.
- A. thermal bow
- B. linear expansion
- C. both thermal bow and linear expansion (selected)
- D. None of the above

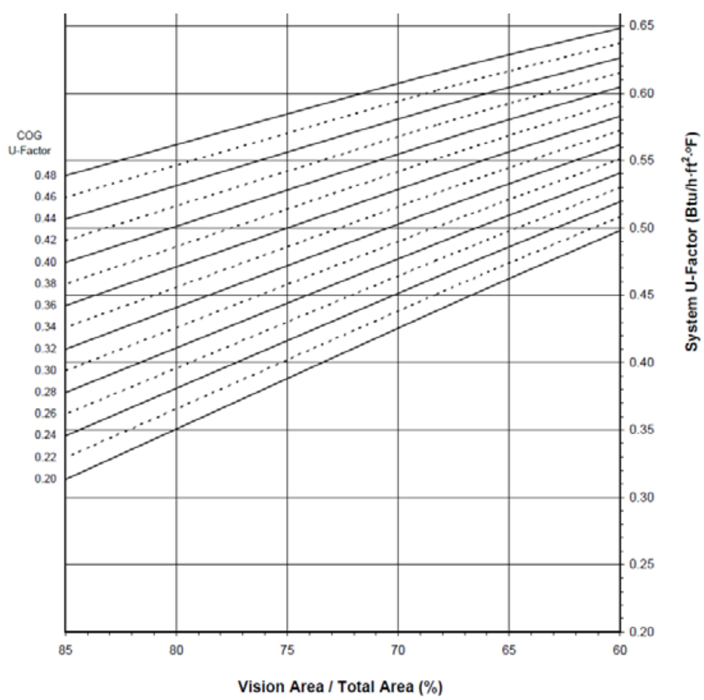
5. Which of these does not affect the significance of thermal short circuits?
- A. The amount of material penetrating the insulation
- B. The conductivity of the material penetrating the insulation
- C. The type of material used in the secondary framing (selected)
- D. The thermal resistance of the insulation

1. The purpose of insulation can be defined as __________.
- A. providing comfortable, healthy interior environments
- B. preventing air leakage and infiltration
- C. reducing annual heating and air conditioning costs
- D. All of the above (selected)
- E. A and B only

Other Figures

Below are some figures that I collected, but haven't have time to use yet.





Figs. # 56 and # 57.. The typical benchmark report would present relationships on charts. In the above examples, one could glean that the thermal transmittance is influenced by cold bridging logarithmically, and on glazing area linearly.

Courtesy of ATI (now Intertek) and Morrison Hershfield Corp.

These companies have their reports signed and sealed, which is generally so unusual in this industry, that it deserves to be mentioned.

1) In some cases, the aluminum extrusions can be re-designed in order to expand the interior surface within the same bounding geometry as shown below.

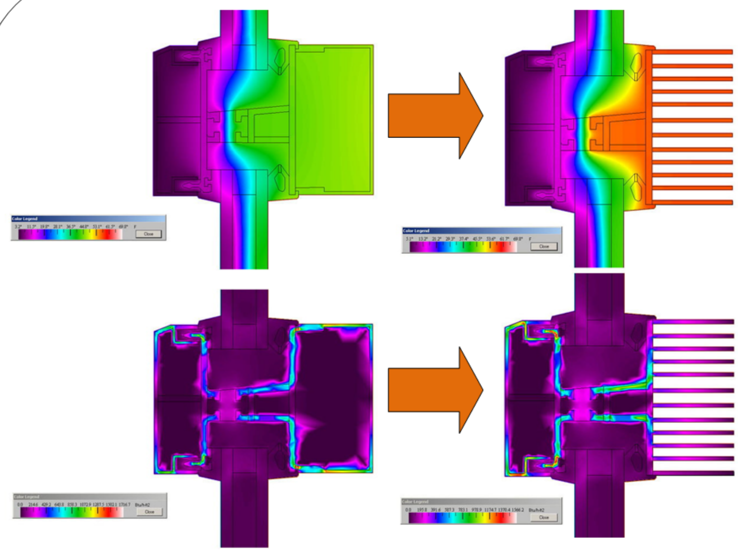


Figure 5. Examples of thermal improvement by introducing a heat sink, which would be hardly distinguishable.
Left: The introduction of a pour-and-debridge break proved insufficient for condensation control.
Right: Addition of a comb-shaped heat sink warmed up the area, reducing the condensation risk.

Fig. # 58. The bottom row shows heat flux maps. Thermal flux map is a useful simulation result that allows for a quick verification and improvements. It is seldom presented in the average report.

However, this slides' original purpose was to show the influence of heat sinks. Courtesy of Building Enclosure Consulting Inc.

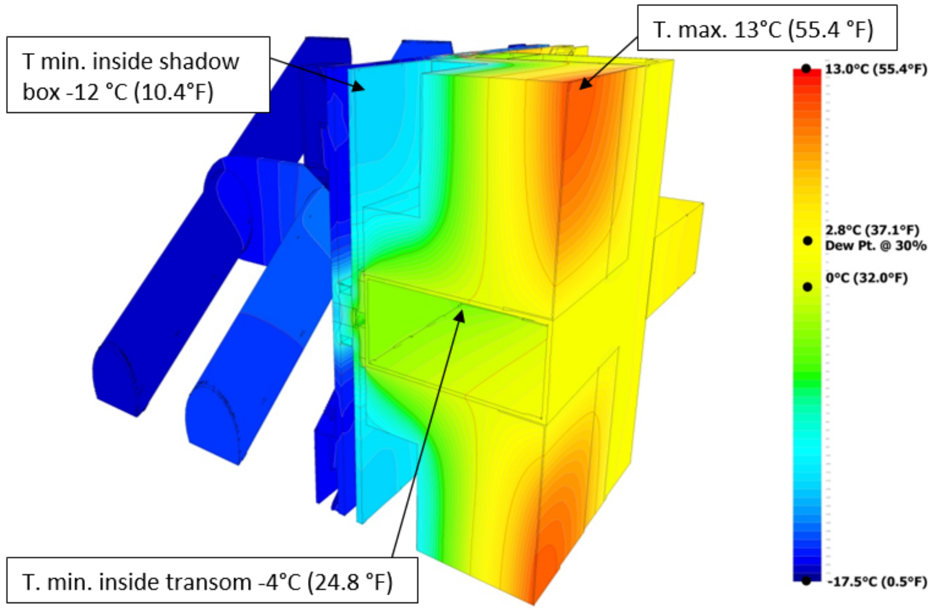


Figure 3. The temperature map of the 3D detail. Interior view at the shadow box.

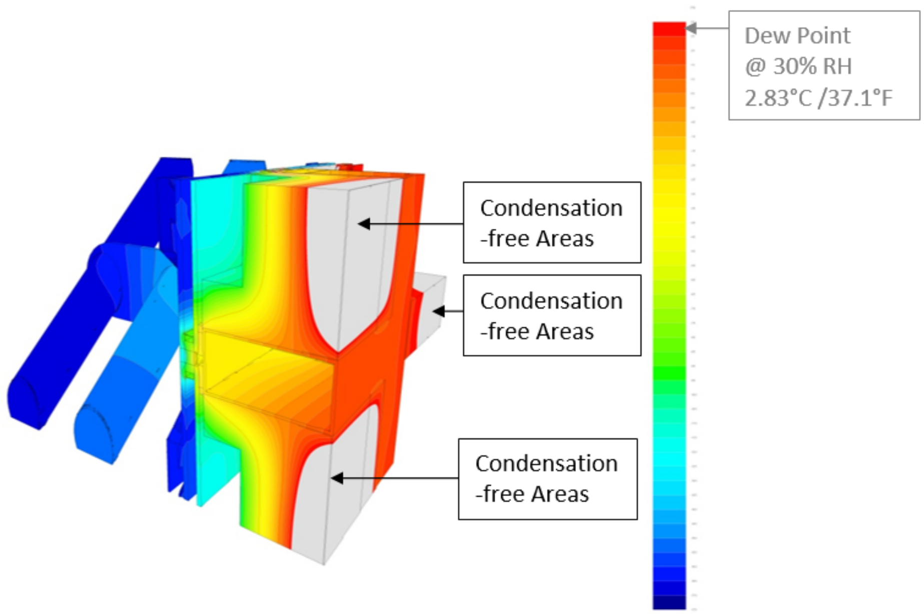


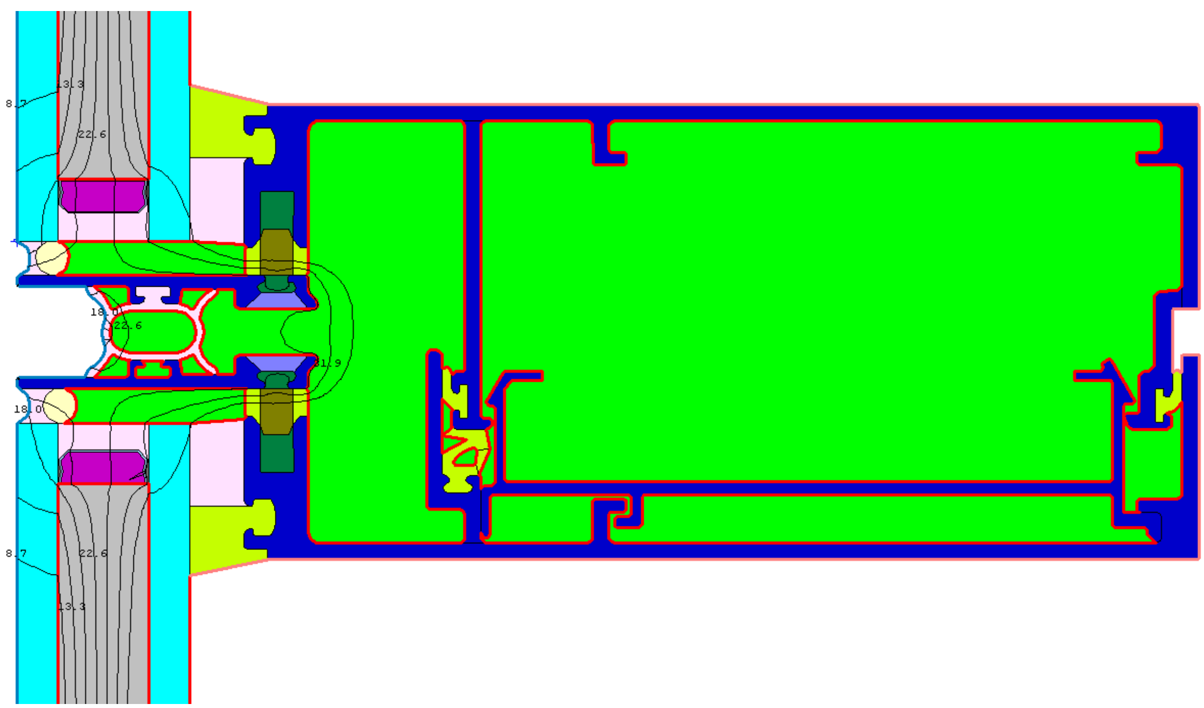
Figure 4. Same picture, with the different temperature scale. White areas indicate condensation-free surfaces.

Fig. # 59. Two different ways to present the temperature map: either the full scale or cut at Dew Point. This is alos the correct way to show the lowest temperature points inland of air and vapor barrier. Courtesy of Building Enclosure Consulting Inc.

Solid Materials

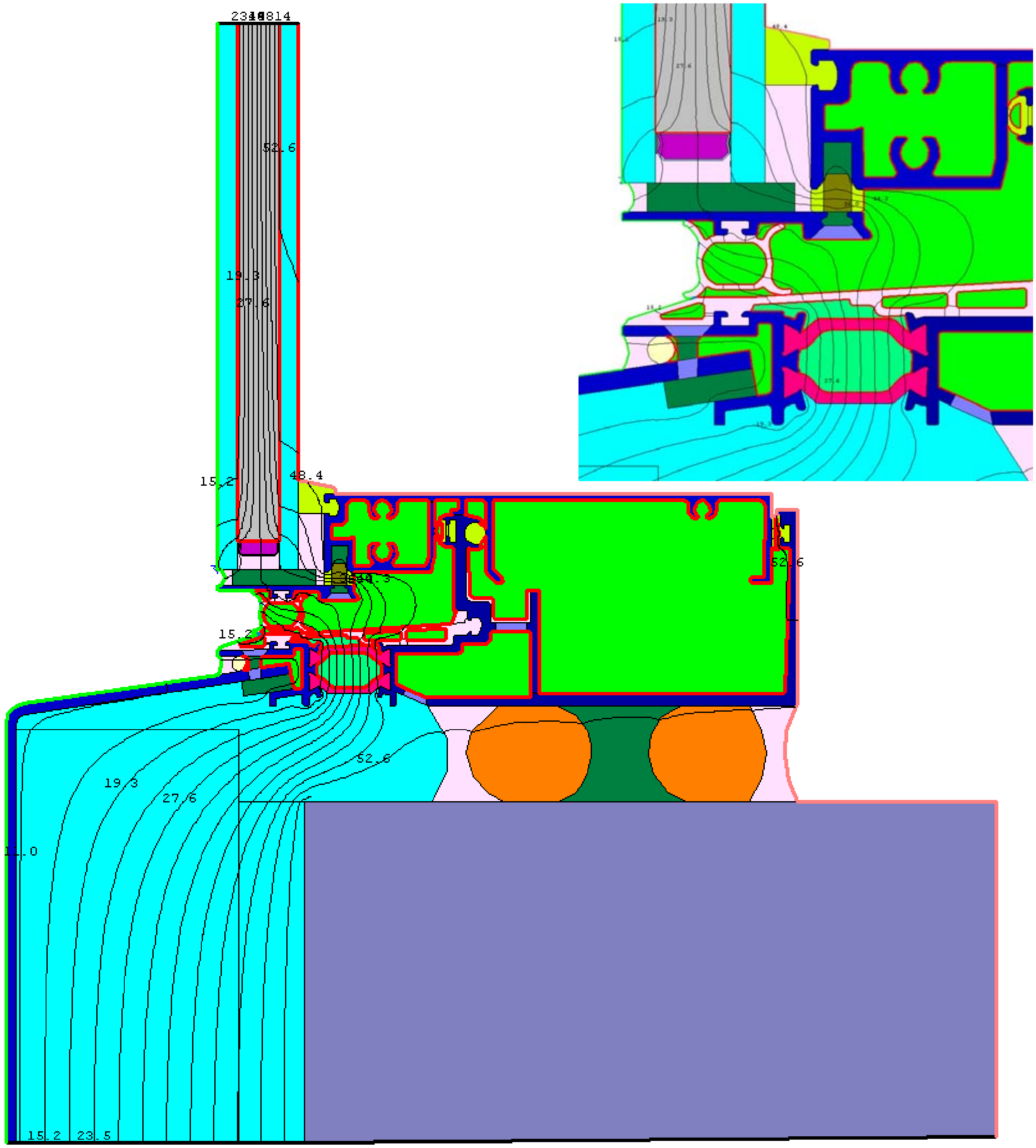
Name	Conductivity Btu/h-ft-F	Emissivity	Color
Butyl Rubber	0.139	0.90	grey
Concrete	3.85	0.90	colonial blue
Silica Gel (Desiccant) - Loose Fill	0.02	0.90	violet
Silicone Filled	0.20	0.90	light pink
Steel - Stainless (Oxidized)	9.22	0.80	cloud blue
Mineral Wool Batt FireSpan40	0.02	0.90	turquoise
Aluminum (Painted)	136.94	0.90	blue
Aluminum (Anodized)	136.94	0.80	navy blue
Ethylene Propylene Diene Monomer (EPDM)	0.14	0.90	yellow
Spoiled Aluminum	125.37	0.90	Dutch blue
Spoiled EPDM	0.17	0.90	khaki
Polyurethane Foam	0.029	0.90	orange
Polyamide (Nylon)	0.144	0.90	dark pink
Frame Cavity NFRC 100	calculated by software		vivid green
Spoiled Air Cavity	0.132	0.90	dark green

(Material assignments are shown on the following pages accompanied with isotherms for convenient verification of the modeling.)



Material assignment

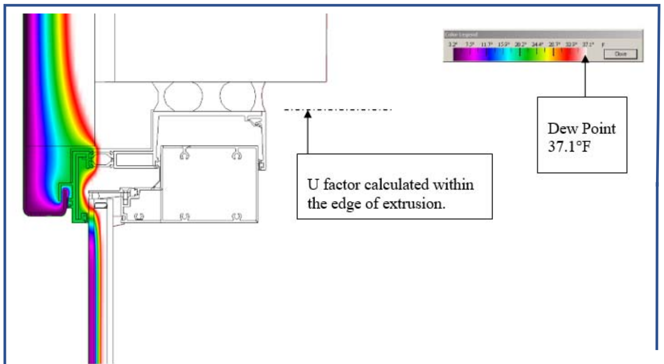
Fig. # 60. An example of a page explaining material assignment in Therm model. Easy to follow and verify for a reviewer, and comes with an additional benefit of a plot showing resulting isotherms. Courtesy of Building Enclosure Consulting Inc.



Material assignment - sill

Magnified critical area shown on the right

Fig. # 61. An example of a page explaining material assignment in Therm model with a magnified dense "Swiss watch" area . Easy to follow and verify for a reviewer, and comes with an additional benefit of a plot showing resulting isotherms. Courtesy of Building Enclosure Consulting Inc.



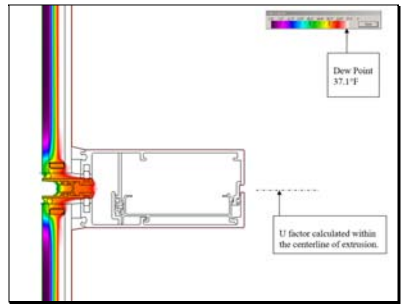
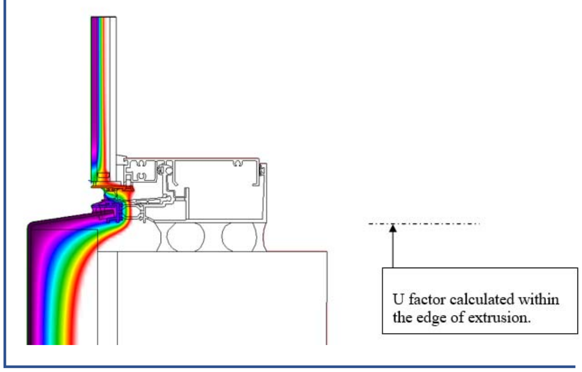


Figure 2. The 2D temperature map of head detail- stainless steel spacer



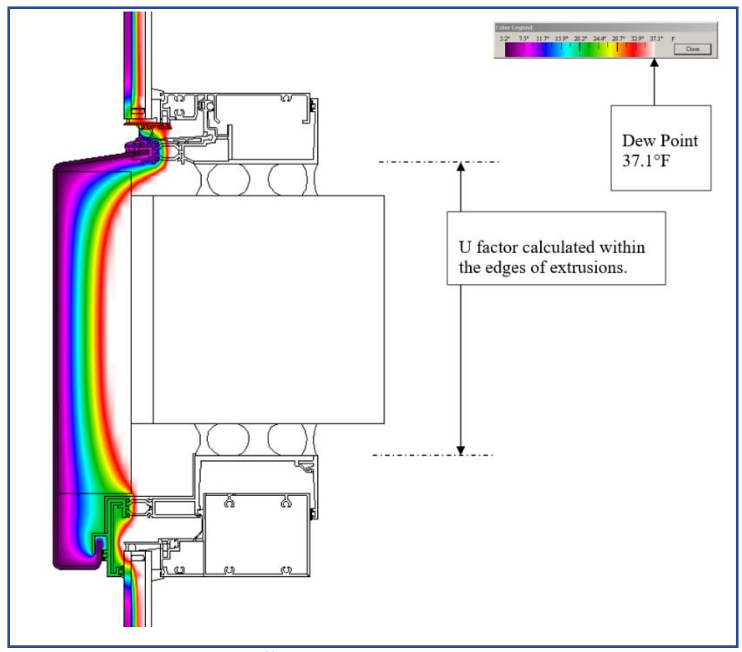


Fig. # 62. An example of a temperature maps with additional explanation how U-value was calculated. It's a simple boilerplate, that makes presentation and description of scope much clearer. It was developed to save time that would otherwise be lost in communication necessary to educate parties of the process about the elementary procedures.

Although the U value is calculated within these perimeters, the adjacent conditions could greatly affect it, as illustrated on numerous examples in my seminars. In the U.S., they would normally spoil the U value badly and caused interior condensation, leading to replacement of such details with generic details from the system's catalogue. However, a well-designed transition could actually improve the U-value of fenestration.

Courtesy of Building Enclosure Consulting Inc.