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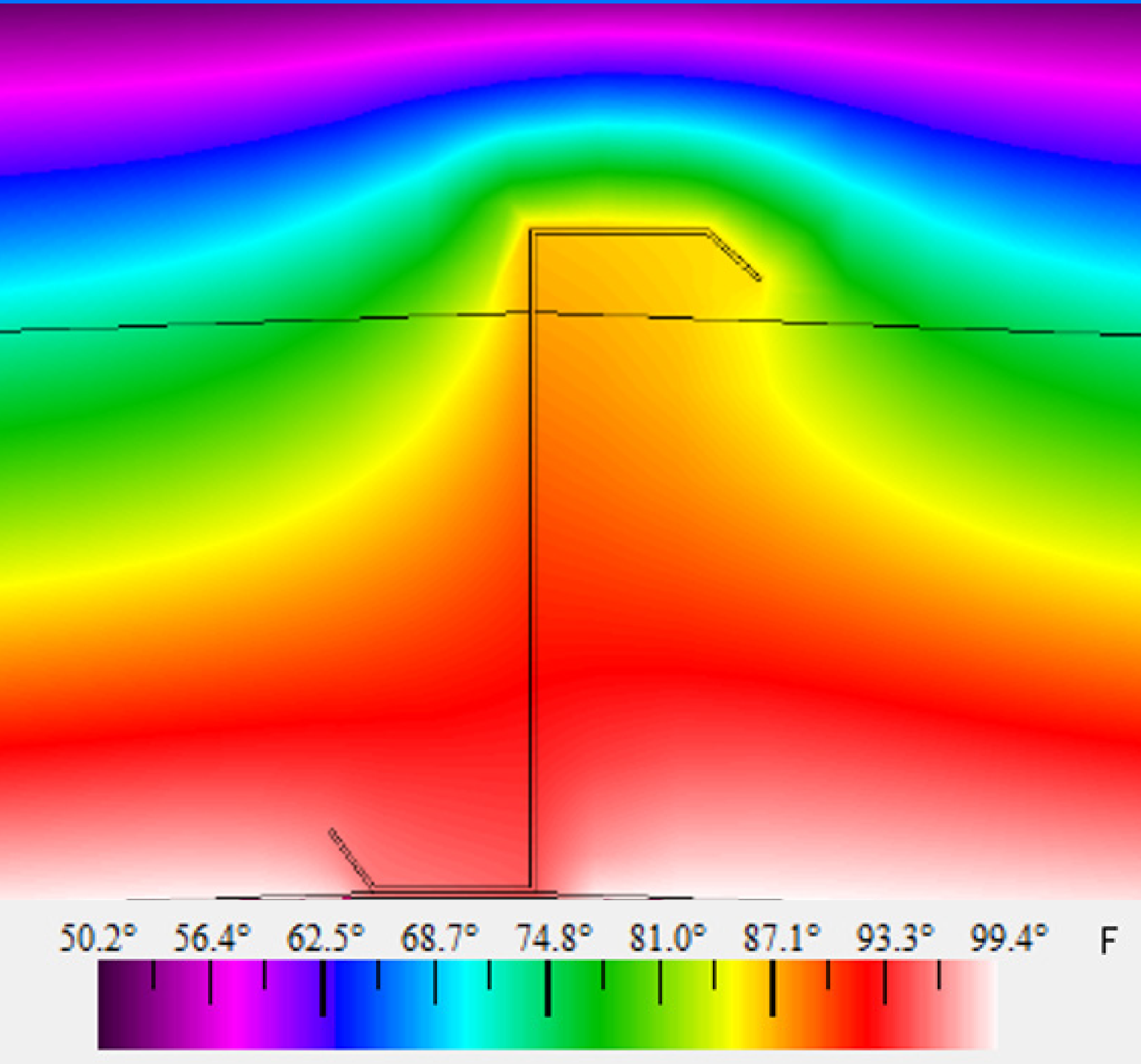
HYGROTHERMAL ANALYSIS GUIDE

FOR METAL BUILDING SYSTEMS



HYGROTHERMAL ANALYSIS GUIDE FOR METAL BUILDING SYSTEMS

September 2026

Modeling Progression Summary

Material Creation

Most of the materials in metal buildings are not defined in the material database, so the user will need to create each non-defined material prior to modeling the assembly. This may include, but is not limited to, metal siding, metal liners, fabric liners, polymetric lines, etc.

Build the Model

With the materials defined, build the metal building assembly. Be sure to place monitor positions at critical interfaces to provide more comprehensive post processing analysis.

Model Boundary Conditions and Moisture Sources

Set the climate conditions and place moisture sources (e.g., rain penetration, air flows, ventilation). The interior relative humidity (RH) and moisture sources can significantly impact the behavior of the modeled assembly. Adjust these inputs to closely align with project conditions.

Analyze the Results

Check to ensure that no convergence failures occurred and the moisture balances are aligned. Once the model is validated, evaluate the moisture content, surface temperatures, and surface RHs are monitor positions against the criteria set forth in ASHRAE 160 or industry standards.

DISCLAIMER

Although a diligent effort has been made to provide accurate and factual information based on the present state of research and technical knowledge, the Metal Building Manufacturers Association ("MBMA") does not guarantee the accuracy or completeness of the information contained in this Hygrothermal Analysis Guide for Metal Building Systems (the "Guide"), and does not undertake any obligation to update any information contained in the Guide.

This Guide is intended to be a voluntary informational reference for competent design professionals who assume all responsibility for their own design and commercial practices, including but not limited to their use of the Guide and its application to the design, specification, or construction of any Metal Building System. *MBMA is not responsible for, and expressly disclaims all liabilities for, damages of any sort, whether direct, indirect or consequential, arising out of the use of, reference to, errors or omissions in, or reliance on this Guide or any of its content. Use of the information contained in this Guide should not be considered by the user as a substitute for the advice of a registered professional engineer, attorney, or other professional.*

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ABBREVIATIONS/ACRONYMS

ABAA – Air Barrier Association of America

ACH - air change per hour

ASHRAE – American Society of Heating Refrigeration and Air Conditioning Engineers

Fraunhofer IBP - Fraunhofer Institute for Building Physics

I-P – Inch - Pound

MGI - Mold Growth Index

PE - Polyethylene

Q/A – flow rate (cubic feet per minute per square foot (CFM/ft^2)

RH – Relative Humidity

SI – International System of Units

SLC - Status of Last Calculation

SSR – standing seam roof

VTT - VTT Technical Research Centre of Finland

WRB – weather-resistive barrier

WUFI - *Wärme- und Feuchetransport Instationär,* which translates from German to Transient Heat and Moisture Transport

GLOSSARY

Capillary Conduction is the movement of water through porous materials due to capillary action. This phenomenon is driven by the forces of adhesion, cohesion, and surface tension, allowing water to move against gravity within porous materials.

Conduction is the transfer of heat by direct molecular contact. This contact can be within a material or between two materials in contact.

Convection is the transfer of heat and moisture by movement of a gas or liquid.

Effusion is the process where vaporized molecules escape from a container through a small opening or hole, usually into a vacuum.

Enthalpy is a number that characterizes certain properties of a thermodynamic system and that simplifies certain statements about the system. Although enthalpy is measured in Joules, it is not a distinct form of energy, such as kinetic or potential energy. (In particular, it must not be included if the total energy of a system is to be computed.)

Perm is the unit of measure for permeance (grain per hour per inch of mercury per square foot)

Radiation is the process of heat transfer from one body to another by electromagnetic radiation. No transfer medium (i.e., solid, liquid, or gas) is required.

Relative Humidity (RH) is the ratio of the amount of water vapor in the air to the amount of water vapor in saturated air at the same temperature.

Solution Diffusion is the process where water molecules dissolve into a material, then diffuse across the material due to a concentration gradient, and subsequently desorb from the other side of the material.

Surface Diffusion is the process involving the motion of water molecules at solid material surfaces.

Vapor Permeance is the quantity of vapor flow through a material for a given thickness.

Water Vapor Diffusion is the movement, under a vapor pressure gradient, of water vapor.

INTRODUCTION

Metal Building Systems (MBS) have long been recognized as a material-efficient construction solution, especially for enclosing large volumes of conditioned space. They are engineered with consideration of many environmental effects. The most well-known of these are loading due to snow, wind and earthquakes. However, there are other less well-known environmental effects at work as well. An example is heat transmission combined with air and water migration through the external building envelope due to entropy. Together, these impacts are commonly referred to as hygrothermal effects.

Hygrothermal effects are certainly not the threat to a building, its occupants and contents that environmental loadings are. However, long-term performance of a building can be heavily influenced by hygrothermal effects, and they need to be addressed for a building to perform its intended function over its life.

Hygrothermal Analysis

Every building is subjected to hygrothermal effects, including metal buildings. However, the impacts these effects have, and more importantly if and how they need to be mitigated, vary depending heavily upon the climate, occupancy and operation of the building. Tools such as WUFI provide the ability to model building enclosures so that building designers can consider hygrothermal effects and improve long-term building performance for any type of construction. Knowing this and that MBS solutions employ specialized details quite different from other types of construction, the Metal Building Manufacturers Association (MBMA) has produced this guide for building science practitioners who may not be familiar with MBS construction details and to help them more accurately and dependably model metal buildings for hygrothermal analysis.

Intended Audience

This guide is a reference for competent design professionals who are able to operate WUFI or similar tools to an expert level but who may not have a commensurate level of expertise of MBS methods and details. It presumes this user has a very strong technical understanding of WUFI and the underlying building science.

While it purports to provide guidance in modeling these systems, it is strictly incumbent upon the user to read and interpret this guidance, as well as the WUFI output obtained in the proper context. As with any other digital tool, ultimate responsibility for the conclusion and recommendations made lies with the user.

CHAPTER 1: INTRODUCTION

Section 1.1: Overview

WUFI Pro is a Windows-based software program developed in Germany by the Fraunhofer Institute of Building Physics (Fraunhofer). WUFI is an acronym for *Wärme- und Feuchetransport Instationär,* which translates from German to Transient Heat and Moisture Transport.

The calculation of one-dimensional simultaneous heat and moisture transport in a wall or roofing assembly was developed by Hartwig M. Künzel[1] in his doctoral thesis and is the basis for the WUFI software. The calculation uses a numerical calculation and considers eight (highlighted in orange) of the fourteen heat and moisture transport mechanisms (Table 1). While not a precise prediction of moisture affects due to air leakage, WUFI presents a method[2] to incorporate a one-dimensional approximation for a three-dimensional phenomenon. As such, air flow is also highlighted. More information on this strategy is provided in Section 2.2.1b.

Table 1: Heat and Moisture Transport Mechanisms

Transport Mechanism		Potential of Transport
Heat Transport	Heat Conduction	Temperature
	Heat Radiation	Temperature in 4th power
	Convection (Air Flow)	Total Pressure and Density Differentials
	Enthalpy Flows	Vapor Diffusion with Phase Change and Liquid Transport flows in Temperature Field
Vapor Transport	Vapor Diffusion	Vapor Pressure
	Molecular Transport (Effusion)	Vapor Pressure
	Solution Diffusion	Vapor Pressure
	Convection	Total Pressure Gradient
Liquid Transport	Capillary Conduction	Capillary Suction
	Surface Diffusion	Relative Humidity
	Seepage Flow	Gravitation
	Hydraulic Flow	Total Pressure Differential
	Electrokinesis	Electrical Fields
	Osmosis	Ion Concentration

This guide discusses the use of WUFI and its limitations within the context of metal building assemblies and outlines strategies for using the software program to take advantage of its

[1] Künzel, Hartwig M., Simultaneous Heat and Moisture Transport in Building Components: One- and two-dimensional calculation using simple parameters, Fraunhofer IRB 1995.

[2] Künzel, Hartwig M., et. al., Modelling the Effect of Air Leakage in Hygrothermal Envelope Simulation

strengths and avoid issues due to its weaknesses. Subsequent sections will provide general information to assist with selecting inputs and interpreting outputs along with commentary that further explains the building science and physics behind the recommended approaches.

Section 1.2: WUFI and Metal Buildings

WUFI is a user-friendly program for a very complex analysis that requires strong, if not expert, knowledge of the building science and physics behind the hygrothermal behavior of materials and the mechanisms that influence heat and moisture transport. Knowledge of these concepts not only helps the user make educated selections within the program but is also needed for the interpretation of the results and to avoid overreaching the software's capabilities.

This guide will help users model metal building assemblies and make informed decisions and selections based on each project's needs. It is suggested that all modeling should attempt to provide a relative comparison of assemblies via single variations (e.g., rigid versus fibrous (e.g., mineral or fiberglass in batts or rolls) or sprayed insulations, include or remove a vapor retarder).

In addition to these variations, sensitivity analyses are also recommended. Sensitivity analyses include the effects of orientation and order of magnitude changes to material properties and moisture loads and removals (i.e. sinks and sources). Performing sensitivity analyses enables the user to better understand the effect certain changes make to the simulated distribution of heat and moisture within the assembly. The results of these analyses can facilitate better input assumptions for each individual project.

If a hygrothermal performance design is the main purpose of the work and the main interest of the client, then modeling results should be analyzed and conveyed in terms of ANSI/ASHRAE 160-2016 - *Criteria for Moisture-Control Design Analysis in Buildings* (ASHRAE 160). However, some projects may need opinions on the potential for corrosion, which is not fully quantified and outlined in ASHRAE 160. This is a topic being researched within the ASHRAE 160 committee.

All results should be presented in terms of relative risk, or meeting or not meeting the criteria of a standard such as ASHRAE 160. Guaranteeing future acceptable hygrothermal performance of a metal building assembly cannot be done with a WUFI (or any other) simulation. Client expectations should be set appropriately, and your interpretation of the simulation results should be properly characterized in your report.

Commentary: WUFI was created in Europe, so there are some inputs that do not change units when I-P units are selected. Most notably are the air layers which are titled with the thickness in millimeters (mm) and air pressures utilize Pascals (Pa). Generally, this guide follows the units provided by the software for clarity. Where unit conversion is needed, the converted value and unit is provided parenthetically.

CHAPTER 2: MODELING INPUTS

This guide assumes that the user has working knowledge of the WUFI software to construct and run models. The general purpose of the following sections is to guide and educate the user on their selection of materials, moisture and heat sources, coefficients and orientations, numerics, and climatic data. To accomplish this, two common metal building assemblies will be discussed: standing seam roofing (SSR) and corrugated metal wall panel assemblies (Figures 1 and 2).

Figure 1: Example of a liner system roof assembly with two layers of insulation. *Graphic courtesy of Silvercote.*

Figure 2: Example of a liner system wall assembly with two layers of insulation. *Graphic courtesy of Silvercote.*

It should be recognized that WUFI is a powerful tool for the relative comparison of various envelope assemblies by analyzing moisture and heat transfer through the assemblies. However, WUFI only analyzes a one-dimensional "cut" through an assembly without any consideration for thermal bridging. As such, where the user models the "cut" through the assembly should be taken where interstitial condensation is mostly likely to occur. For metal building assemblies, this is typically at the midpoint between purlins and girts for both roofs and walls, respectively (Figures 3 and 4). Here the thermal bridging associated with clips, fasteners, and purlins do not warm the metal panel or SSR, which would reduce the likelihood of condensation development; whereas, the furthest point away from these bridging elements maintains the coldest surface temperatures that can allow for condensation. As such, it is at these locations that the user should create the one-dimensional section cut to model.

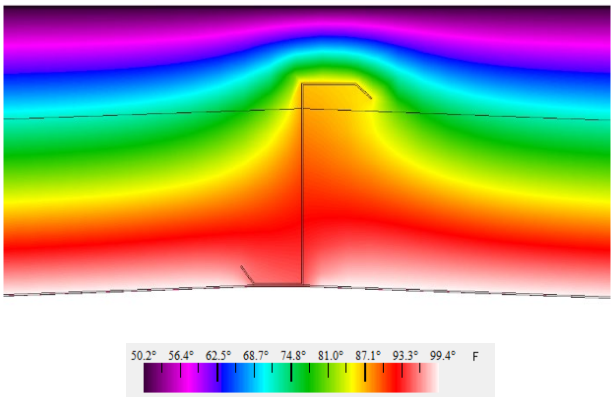

Figure 3: Thermal analysis of a standing seam metal roofing assembly illustrating the thermal bridging effects of the clip. Note the colder surface temperatures away from the thermal bridge. *Graphic courtesy of Finley Consulting Group (FCG).*

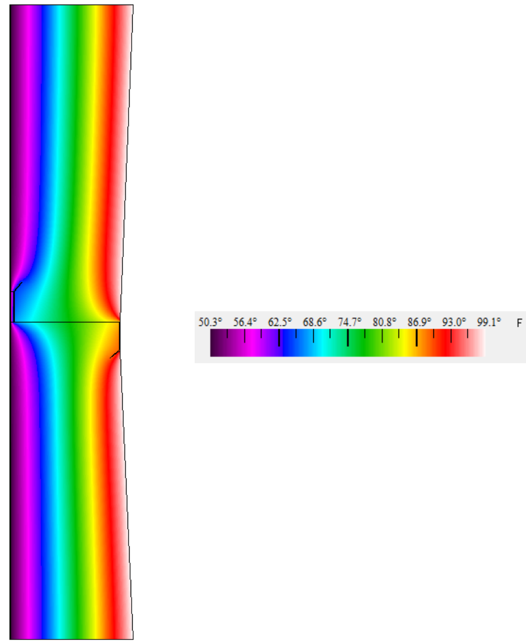

Figure 4: Thermal analysis of a metal wall panel assembly illustrating the thermal bridging effects of the girt. Note the colder surface temperatures away from the thermal bridge. *Graphic courtesy of FCG.*

Section 2.1 Components

This section follows each tab and entry of the "Component" segment. The following commentary for suggested inputs is provided based on known building science and physics applicable to metal buildings.

Section 2.1.1 Material Creation

If data for a specific material within your assembly is known (i.e. material testing or manufacturer's product literature), or if the specific material is not available in the database, a new material can be defined. To define a new material, right click on the material that most closely matches the new material definition and select "New Material" from the dialog box. This will open a new dialog box where the basic material data can be manually input. Additionally, the hygric extensions can be approximated, manually input, or uploaded from a file.

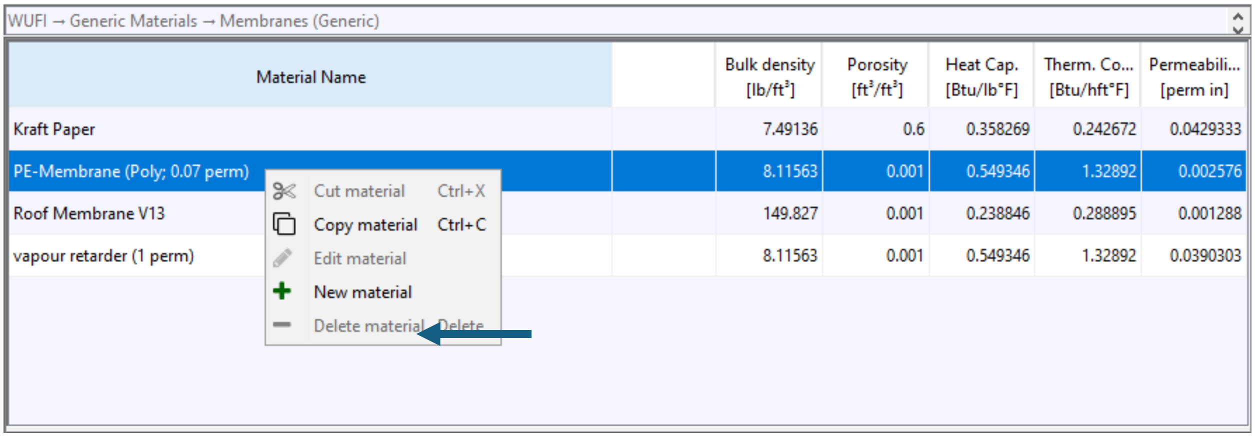

Figure 5: Create a new material by right clicking on a similar material and select new material from the dialog box.

Section 2.1.1a Manufacturer's Product Literature

Many times, a material's conductivity or permeability is published, but the other basic material data are not (e.g. insulations and vapor retarders). Most metal building insulation and vapor retarder types are listed within the database; however, if the conductivity and permeability of a specific material is known, you should create a new material (see above) and manually change the known values for that material and leave the remaining values unchanged.

Example 1: Polymeric Vapor Retarder

The generic material definition from the WUFI database has the following properties with a permeability of 0.002576 for a thickness of 0.03937 inch:

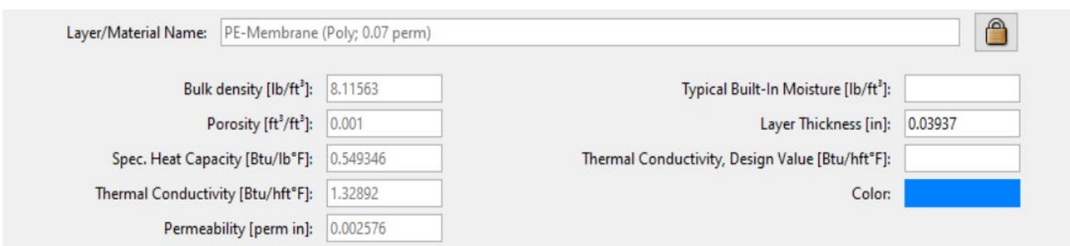

Figure 6: Material properties excerpt from WUFI for PE-Membrane (Poly; 0.07 perm) under the Generic Database.

A manufacturer's product literature indicates that their product has perm rating of 0.01 perms. Now, perms and perm-in (the value used for WUFI) are different. And the calculations within WUFI require the thickness of membranes to be set at 1mm or 0.03937 inches. Therefore, the published perm rating needs to be multiplied by the 0.03937 inch thickness to get the perm-in. value required for the analysis. Consequently, the permeability should be changed to 0.0003937 perm-in.

Section 2.1.1b Unavailable Materials

Most materials in the database are porous materials, as the program was originally created to assess the heat and moisture transport within porous media. As such, materials such as metal panels are not provided and must be created as described above.

This guide uses the following material properties for the creation of metal wall panels, through-fastened roofing, and standing seam roofing components:

Bulk density [lb/ft³]:	486.938	Typical Built-In Moisture [lb/ft³]:	0.00011237
Porosity [ft³/ft³]:	0.001	Layer Thickness [in]:	0.0315
Spec. Heat Capacity [Btu/lb°F]:	0.107481	Thermal Conductivity, Design Value [Btu/hft°F]:	
Thermal Conductivity [Btu/hft°F]:	26.5783	Color:	
Permeability [perm in]:	0.020125		

Figure 7: Material properties excerpt from WUFI for a user definition for "Metal Panel." These properties are representative of typical installed panels. If the thickness or installation method is atypical, one or both values will need to be modified to more closely represent a project specific condition.

Section 2.1.2 Recommended Components for Modeling

After all the required materials missing from the database are created, users can add each material layer for a metal building assembly. Below are the recommended material layer definitions for a SSR and metal wall panel assembly shown in Figures 1 and 2 above.

Section 2.1.2a SSR Assembly Material Definitions

Below outlines the materials definitions (from exterior to interior) for a typical SSR assembly used on metal buildings. Figure 8 illustrates the assembly as shown within the WUFI Component Assembly tab.

- Standing seam metal roofing panel (as defined in Figure 7 above),
- Low Density Glass Fiber Batt Insulation,
  - North America Database/Insulation Materials
  - Thickness: 3.28 inches (R-11)
- Low Density Glass Fiber Batt Insulation,
  - North America Database/Insulation Materials
  - Thickness: 5.665 inches (R-19)
- PE-Membrane (poly; 0.07 perm)
  - Generic Materials Database/Membranes (Generic)
  - Modify as needed for different manufacturers (see Section 2.1.1a)

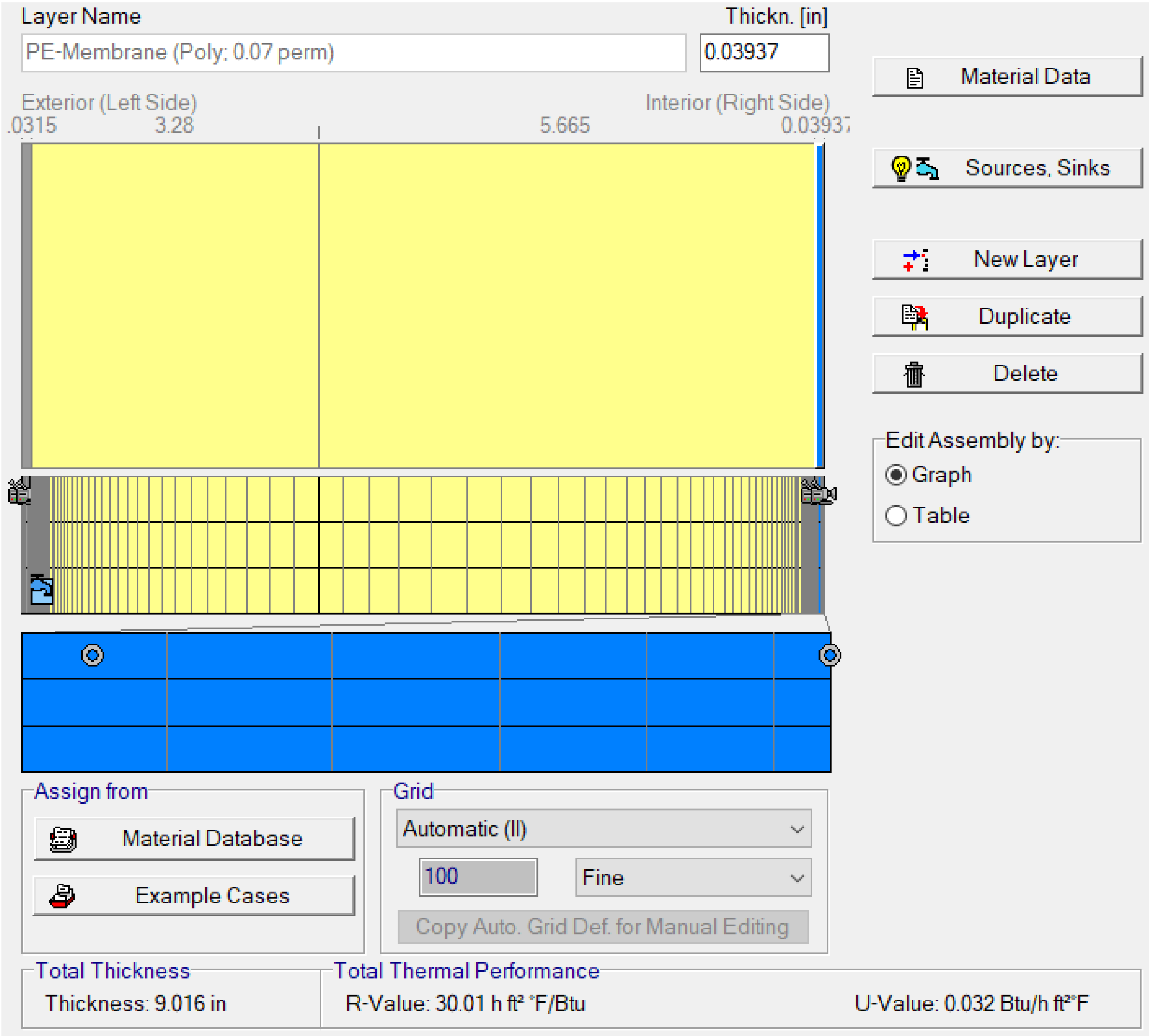

Figure 8: SSR Assembly definition under the Component Assembly tab in WUFI.

Section 2.1.2b Metal Wall Panel Assembly Material Definitions

Below outlines the materials definitions (from exterior to interior) for a typical metal wall panel assembly used on metal buildings. Figure 9 illustrates the assembly as shown within the WUFI Component Assembly tab.

- Metal Panel (as defined in Figure 7 above),
- Air Layer 25 mm; without additional moisture capacity,
  - Generic Materials Database/Air Layers
- Low Density Glass Fiber Batt Insulation,
  - North America Database/Insulation Materials
  - Thickness: 2.98 inches (R-10)
- Low Density Glass Fiber Batt Insulation,
  - North America Database/Insulation Materials

    - Thickness: 7.452 inches (R-25)
- PE-Membrane (poly; 0.07 perm)
    - Generic Materials Database/Membranes (Generic)
    - Modify as needed for different manufacturers (see Section 2.1.1a)

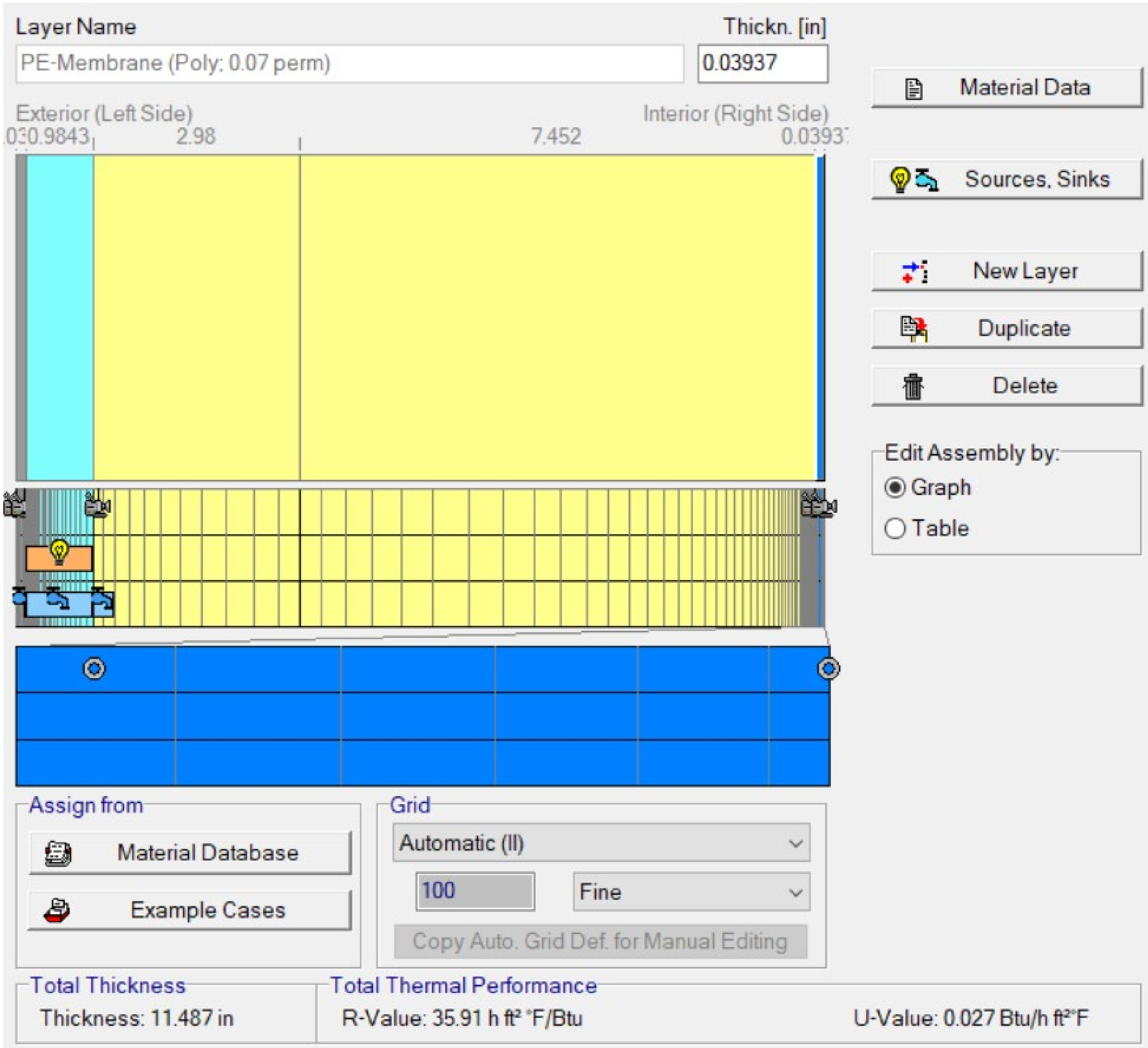

Figure 9: Metal Wall Panel Assembly definition under the Component Assembly tab in WUFI.

Section 2.2 Heat and Moisture Sources and Sinks

Heat and moisture sources and sinks are available in WUFI Pro Version 5.1 and all versions thereafter. These sources or sinks (sources) can be added to any material within the modeled assembly at a specific point, area, or throughout the entire material. The specified source strength can be input via an uploaded file or derived from climate data. A heat and a moisture source can be added simultaneously in the same material; however, two heat or two moisture sources cannot overlap in the same location. For metal building assemblies, only moisture and air change sources are typically used.

Section 2.2.1 Moisture Source Types

There are two moisture source types to generate moisture in or at a material surface applicable to metal buildings: "Fraction of Driving Rain" and "Infiltration Model IBP" (i.e., convective condensation).

Section 2.2.1a Fraction of Driving Rain

ASHRAE Standard 160 includes a calculation for the rain load. Luckily, WUFI will do this for you if you check the box under the Building Height/Driving Rain Coefficients; however, you still need to choose from the drop-down menus to make this calculation project-specific. The Building Height choices are less than 33 feet, between 33 and 66 feet, and greater than 66 feet which is the same as the graphical representation with the box unchecked. The exposure category includes severe, medium, and sheltered. Severe exposure includes hilltops, coastal areas and funneled wind from tall buildings nearby. Sheltered exposure includes protection by nearby buildings or other permanent obstructions to wind. Most of the time, users will select medium exposure. The last selection affects the rain deposition factor. The choices are walls below a low-slope roof, walls below a steep slope roof, walls subject to rain runoff, and user defined. For a steep slope roof, driving rain is reduced due to the likely use of an overhang. Walls subject to rain runoff may occur from a roof or impermeable surfaces above (i.e., metal panels, windows/glass).

In addition to the rain load, ASHRAE Standard 160 also requires the deposition of this rain on the weather resistive barrier (WRB). The standard indicates that 1 percent of the rain load for walls will be placed on the WRB. Now, for metal buildings, the WRB is usually the metal panels. The design of these structures is meant to act as a barrier system such that no water penetration occurs, and all rainwater is shed at the surface. If rain penetration occurred, it would manifest at fastener penetrations or lap seals between metal panels. As such, water that enters the wall assembly will predominately occur on the inboard face of the metal panel, which due to the corrugation profile, will either drain down the air space or wet the insulation in contact with the metal panel.

With this in mind, a 1 percent moisture source is excessive. Based on actual performance as well as laboratory testing, this guide reduces the percentage down to 0.1 percent and places the rain load on the outboard face on the insulation layer.

Section 2.2.1b Infiltration Model IBP

Recent adaptations of the software have added a simplified approach to at least account for a significant variable in the hygrothermal performance of enclosure assemblies. The air leakage model still has limitations as it is simplifying a 3D phenomenon into a 1D application, but it does get us closer to reality. However, WUFI looks at this as a worst case. Therefore, conditions where convective condensation does not occur, it does not remove moisture from the layer at warm periods of the year.

To add this source, an air leakage rate, floor-to-floor height, and mechanical pressurization is needed. Without project-specific testing, it is difficult to determine the leakage rate of the whole building; therefore, the International Energy Conservation Code's, maximum rate is a reasonable and defendable user defined input.

The "Stack Height" is generally easy to obtain from the drawings. For most wall assemblies, it would be approximately the girt spacing as the nature of the installation would limit air flow to the interstitial space between girts. The mechanical ventilation overpressure (i.e. positive air pressure with relation to atmospheric pressure) can be obtained from building measurements or the mechanical engineer. If unknown, use 0 Pa.

Commentary: For moisture sources, the materials in the model all have a limit to the amount of water that can be physically stored within their pore structure. Therefore, three choices are provided to have WUFI account for potential over-wetting: cut-off at maximum water saturation, cut-off at free water saturation, and user defined. For maximum water saturation to occur in capillary active materials, an external pressure must be exerted as normal suction forces cannot fill all pores. As such, cut-off at maximum water saturation will not be used in metal building applications. Conversely, cut-off at free water saturation stops adding moisture to a material when the normal suction forces have naturally saturated the material (95 to 99% RH). Since this is more realistic, cut-off at free water saturation should be utilized when adding a moisture source.

Section 2.2.1c Air Change Sources

In addition to a moisture source, an air change rate can be introduced to add a heat and moisture source or sink. The equations for each need only an air change per hour (ACH) rate. The most difficult part is determining a reasonable ACH. ASHRAE RP-1091 has researched ACH rates for various assemblies. Based on this research, introducing an air change source with an ACH of 20 to the air space created by the corrugated profile of the metal panel for wall assemblies is recommended.

Commentary: Air changes should be placed in air spaces. Similar flow rates have different ACH, because the thickness of the air space has an effect on the ACH and should be adjusted accordingly. To determine the ACH for the air space thickness, use the following equation:

$$ACH = \frac{Q}{A \cdot d}$$

where, Q/A is the flow rate ($m^3/h/m^2$) and d is the air space thickness (meters) for imperial units multiply the result using CFM/ft^2 and inches, respectively by 720.

Section 2.2.2 Recommended Moisture Sources for Modeling

After all the materials are defined, users can add moisture sources within particular materials for each metal building assembly. Below are the recommended moisture sources for a roof and wall assembly as shown in Figures 1 and 2.

Section 2.2.2a SSR Assembly Moisture Source Definitions

Below outlines the moisture source definition for a typical SSR assembly used on metal buildings. Figure 10 illustrates the source inputs as shown within the WUFI; its component illustration can be seen in Figure 8.

- Air Exfiltration is the only moisture source expected for a SSR (especially for colder climates)
  - Place moisture source in the first 1/4 inch of the top layer of the fibrous insulation.
  - Air Leakage Rate: 0.04 CFM/ft^2.
  - Stack Height: highest dimension from floor to underside of the roofing assembly.
  - Overpressure: If mechanically pressurized, input value.

Commentary: The source type is labeled "Air Infiltration model IBP," but that is a misnomer because it models exfiltration. It does not model infiltration which is expected in warmer climates. To model, infiltration, modelers can create a moisture source to mimic the exfiltration model; however, this technique is not validated by Fraunhofer Institute of Building Physics (Fraunhofer).

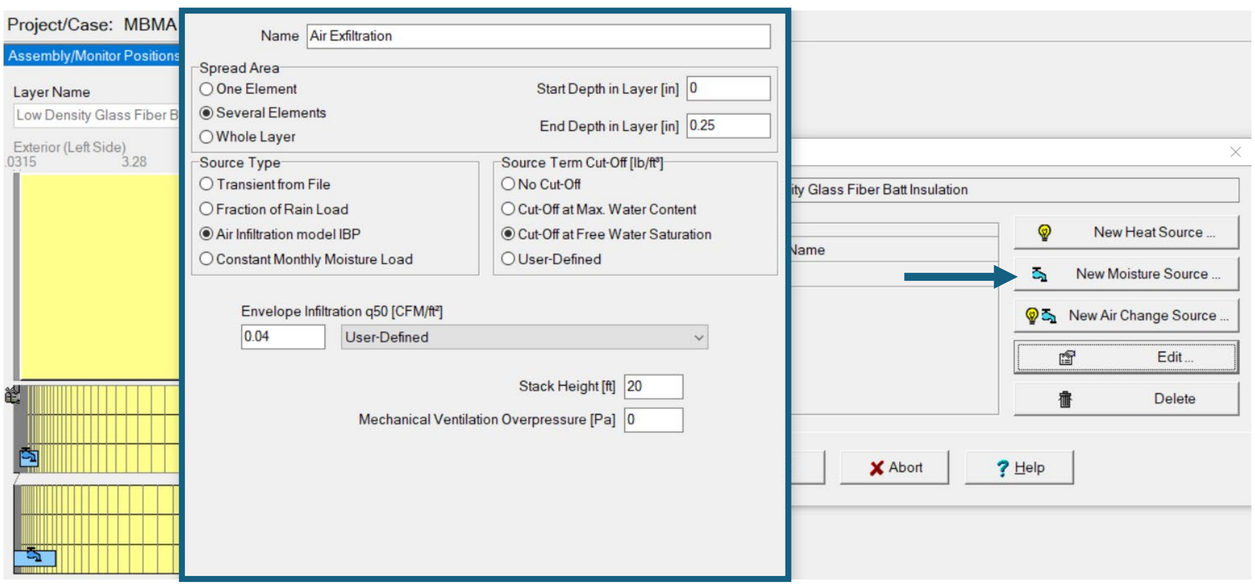

Figure 10: For this example, the above inputs were used after creating a new moisture source in the top layer of insulation.

Section 2.2.2b Metal Wall Panel Assembly Moisture Source Definitions

Below outlines the moisture source definitions for a typical metal wall panel assembly used on metal buildings. Their component illustrations can be seen in Figure 9.

- Rain Penetration (Figure 11)
  - Place moisture source in the first 1/4 inch of the outboard layer of the fibrous insulation.
  - Fraction of Rain Load: 0.1 percent.

Commentary: Ideally, this moisture source would be placed in the air layer created by the corrugation; however, you cannot have two moisture sources in the same material. Since we need to add an air change course in the air space (see Section 2.2.1c), we must shift the rain penetration source to the insulation layer.

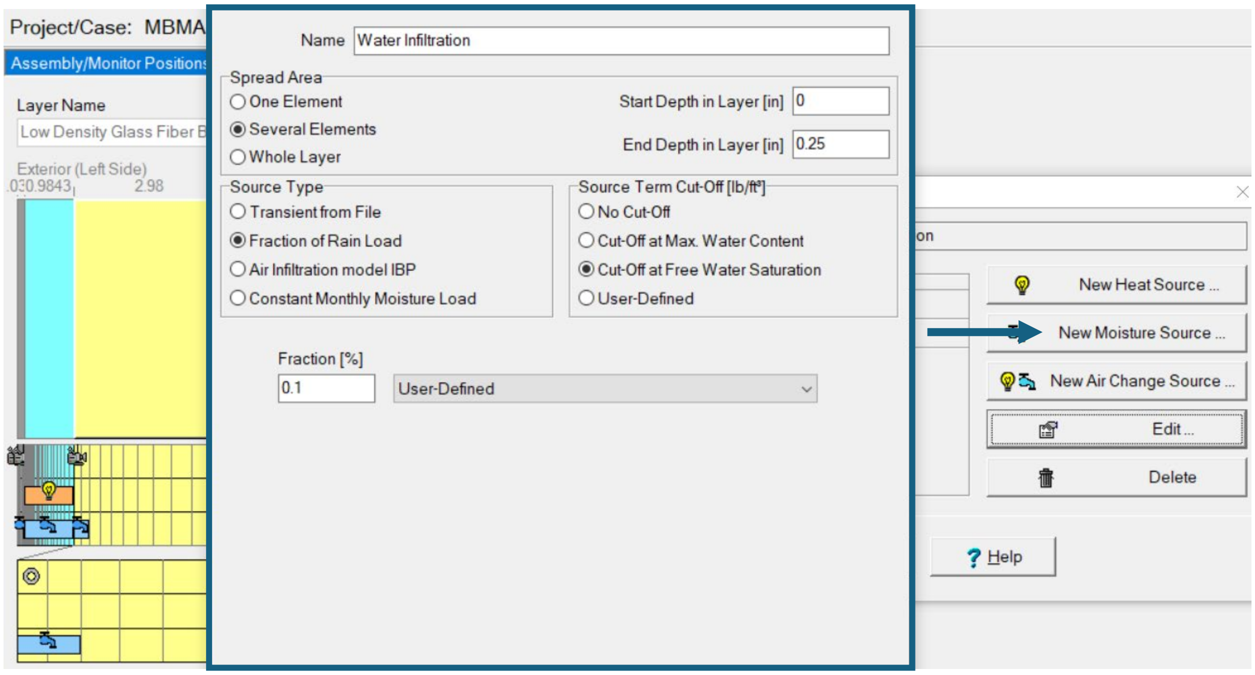

Figure 11*:* For this example, the above inputs were used after creating a new moisture source in the outboard layer of insulation.

- Air Exfiltration (Figure 12)
  - Place moisture source on the backside of the metal panel.
  - Air Leakage Rate: 0.04 CFM/ft^2.
  - Stack Height: highest dimension from floor to underside of the roofing assembly.
  - Overpressure: If mechanically pressurized, input value.

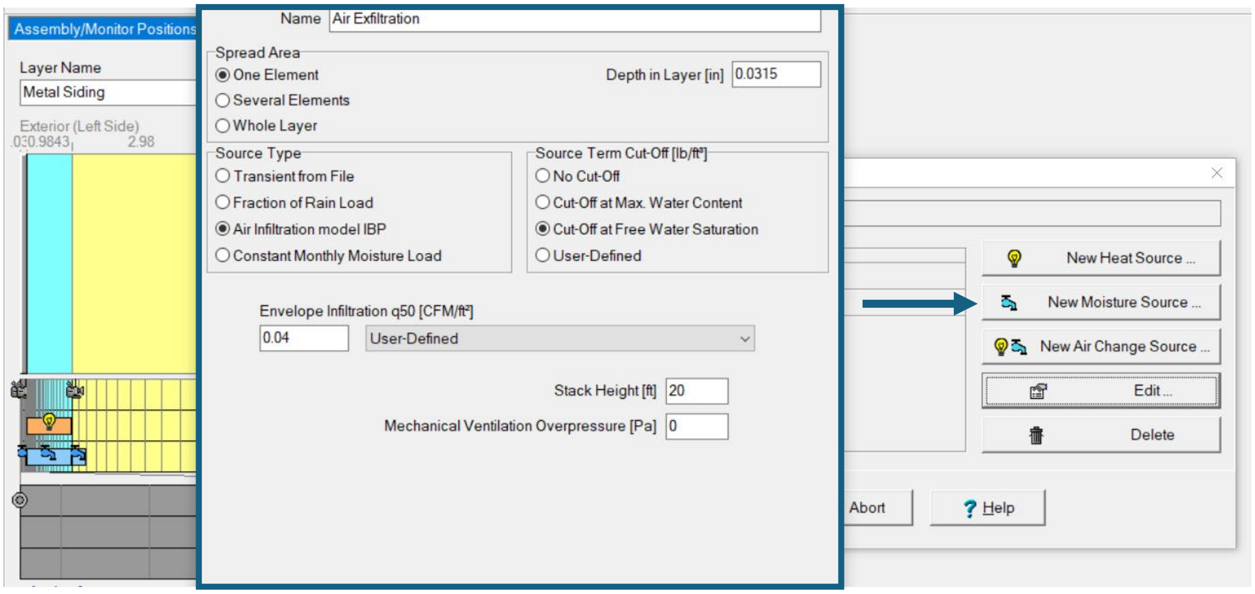

Figure 12: For this example, the above inputs were used after creating a new moisture source in the top layer of insulation.

- Cavity Ventilation (Figure 13)
  - Place air change source in the entire air layer ("Whole Layer").
  - "Constant" Air Change Rate: 20.
  - Link changes to the exterior side (left side).

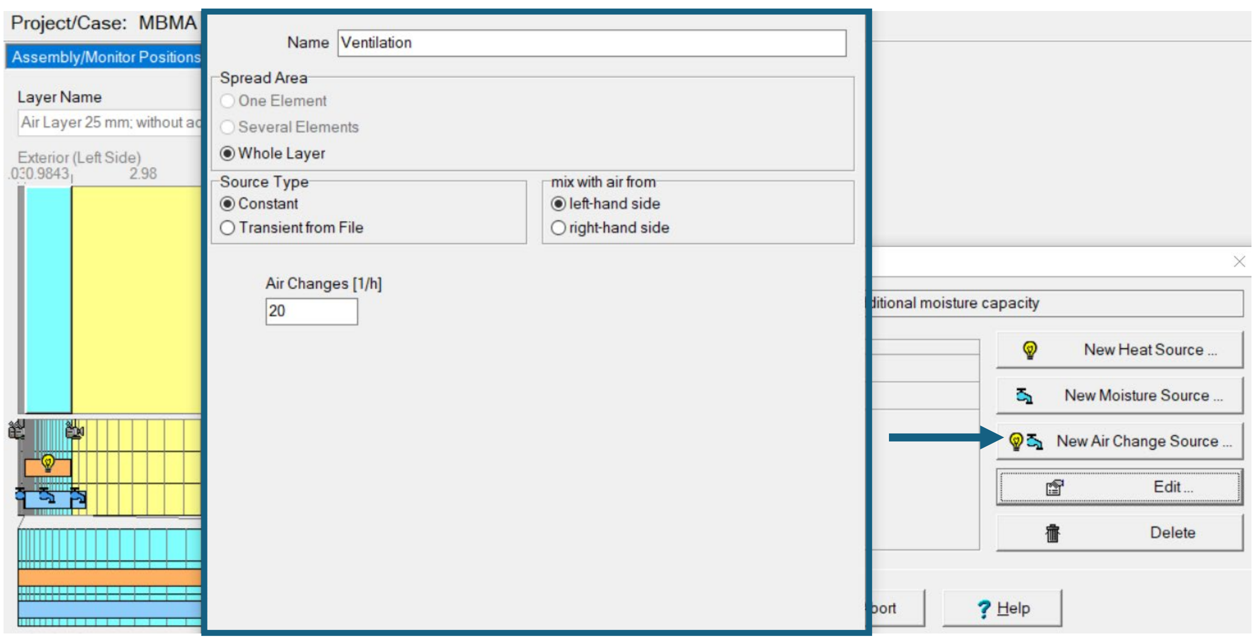

Figure 13: For this example, the above inputs were used after creating a new air change source in the air space of the corrugations.

Section 2.3 Monitor Positions

Typically, the user is interested in the temperature, relative humidity (RH), and/or water content of a particular material or materials within the model. In order to aid the analysis of the data (Refer to Chapter 3), the user can insert a monitor position that will record the data specific to that location.

WUFI defaults to two monitor positions: the exterior surface and the interior surface. To add or remove a monitor position, simply click on the location of interest within the grid of the material.

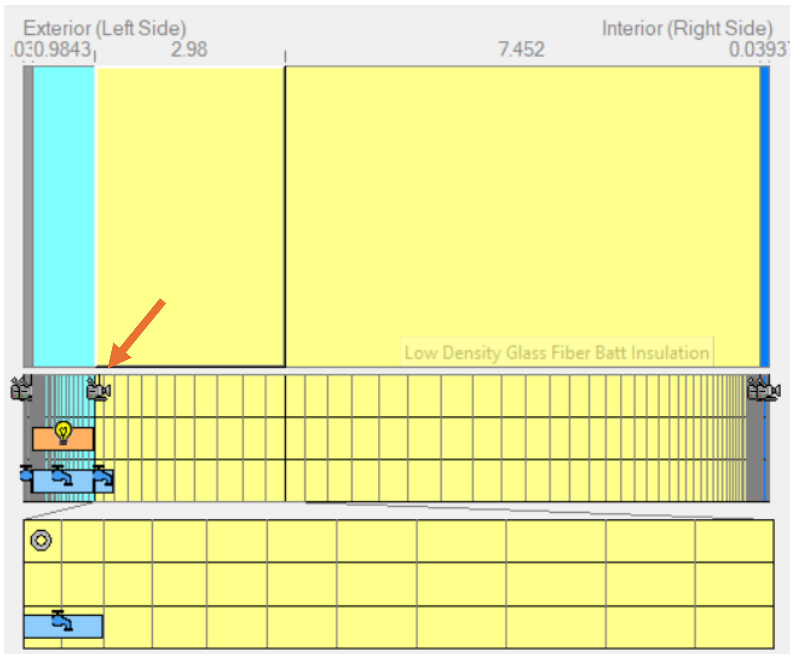

Figure 14: For this example, a monitor position was placed at the outboard face of the wall insulation layer where most of the moisture sources are.

Section 2.4 Orientation, Inclination, and Building Height

After inputting materials and hygrothermal sources, the next tab takes the user to set the orientation, inclination, and building height for the determination of driving rain and solar radiation loads.

Section 2.4.1 Orientation

The orientation for the model should be chosen either based on the known orientation for existing assemblies for forensic studies or the worst-case scenario for wind-driven rain loading and/or solar radiation effects for new construction.

In order to determine the worst-case scenario for wind-driven rain, the user can migrate to the Climate section under the Outdoor Climate (Left Side) tab. Once a climate file has been selected from the Map, click on the Climate Analysis tab to review the Driving Rain Summary. The orientation with the most wind-driven rain events should be used for one of your models.

Example 2: Wind-Driven Rain Orientation

Figure 15 shows the Climate Analysis of Chicago, IL. The orientation for the ASHRAE Year 2 weather file indicates that the east orientation should be chosen for one of your models.

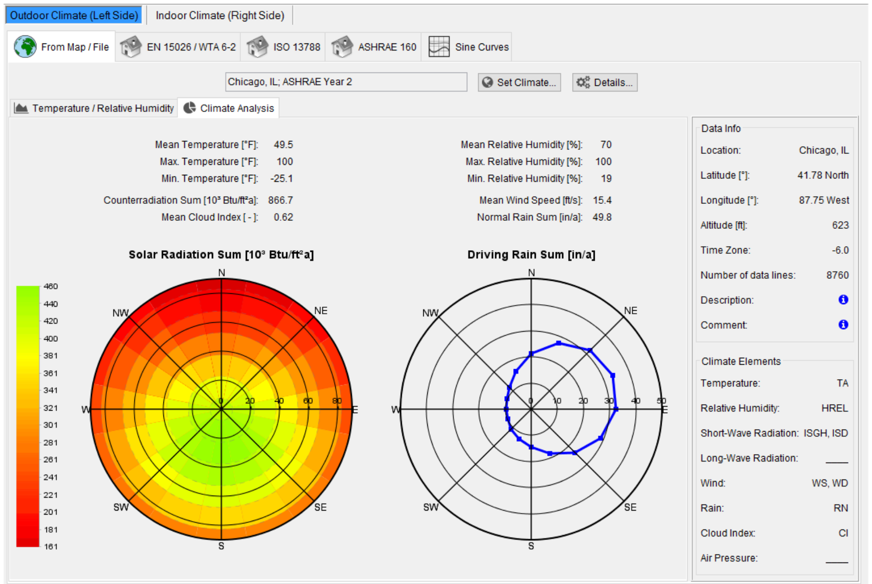

Figure 15: Climate Analysis for Chicago, IL: ASHRAE Year 2.

In addition to the wind-driven rain orientation, the orientation with the most solar radiation (i.e. south for the northern hemisphere and north for the southern hemisphere) should be modeled to assess the effects of solar-driven vapor diffusion.

For cold climates, running a north orientation is also recommended to assess the coldest orientation for vapor diffusion and air exfiltration drying capacity.

Once the user has determined the worst-case orientation, the remaining models should utilize that orientation for comparative results.

Section 2.4.2 Inclination

WUFI allows users to set the inclination of the modeled assembly from a range of 0 to 90 degrees. This information is used in the calculation of solar and heat radiation and rain loading because this data from the climate file is provided vertically incident to the exterior surface.

Section 2.4.3 Building Height/Driving Rain Coefficients

WUFI users are encouraged to use ASHRAE Standard 160 to determine the driving rain load on the exterior of the assembly. Luckily, WUFI will do this for you if you check the box under the Building Height/Driving Rain Coefficients; however, you still need to choose from the drop-down menus to make this calculation project specific. The Building Height choices are less than 33 feet, between 33 and 66 feet, and greater than 66 feet which is the same as the graphical representation with the box unchecked. The exposure category includes severe, medium, and sheltered. Severe exposure includes hilltops, coastal areas and funneled wind from tall buildings nearby. Sheltered exposure includes protection by nearby buildings or other permanent obstructions to wind. Most of the time, users will select medium exposure. The last selection effects the rain deposition factor. The choices are "walls below a low-slope roof," "walls below a steep slope roof," "walls subject to rain runoff," and "user defined." For a steep slope roof driving rain is reduced due to the likely use of an overhang. Walls subject to rain runoff may occur from a roof or impermeable surfaces above (i.e., metal panels, windows/glass).

Commentary: As mentioned previously, the rain penetration moisture source is 0.1% of this rain load calculation.

Section 2.4.4 Surface Transfer Coefficients

The third tab within the Component section allows the user to select surface transfer coefficients related to surface films, radiation, coatings, and rain absorption. Figures 16 and 17 show the inputs within WUFI for the SSR and Metal Wall Panel Assemblies, respectively.

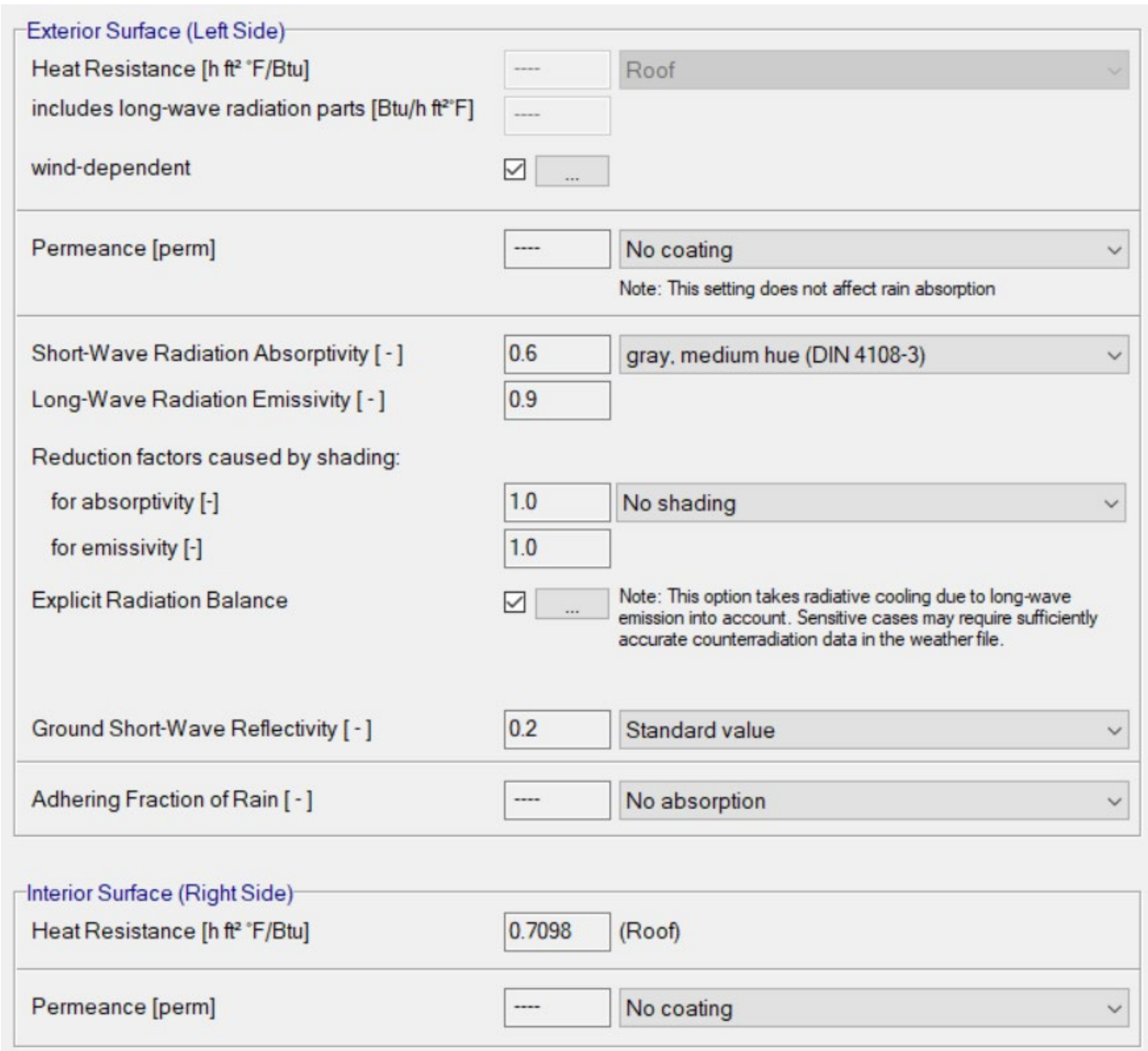

Figure 16: Above are the recommended Surface Transfer Coefficients for the SSR model.

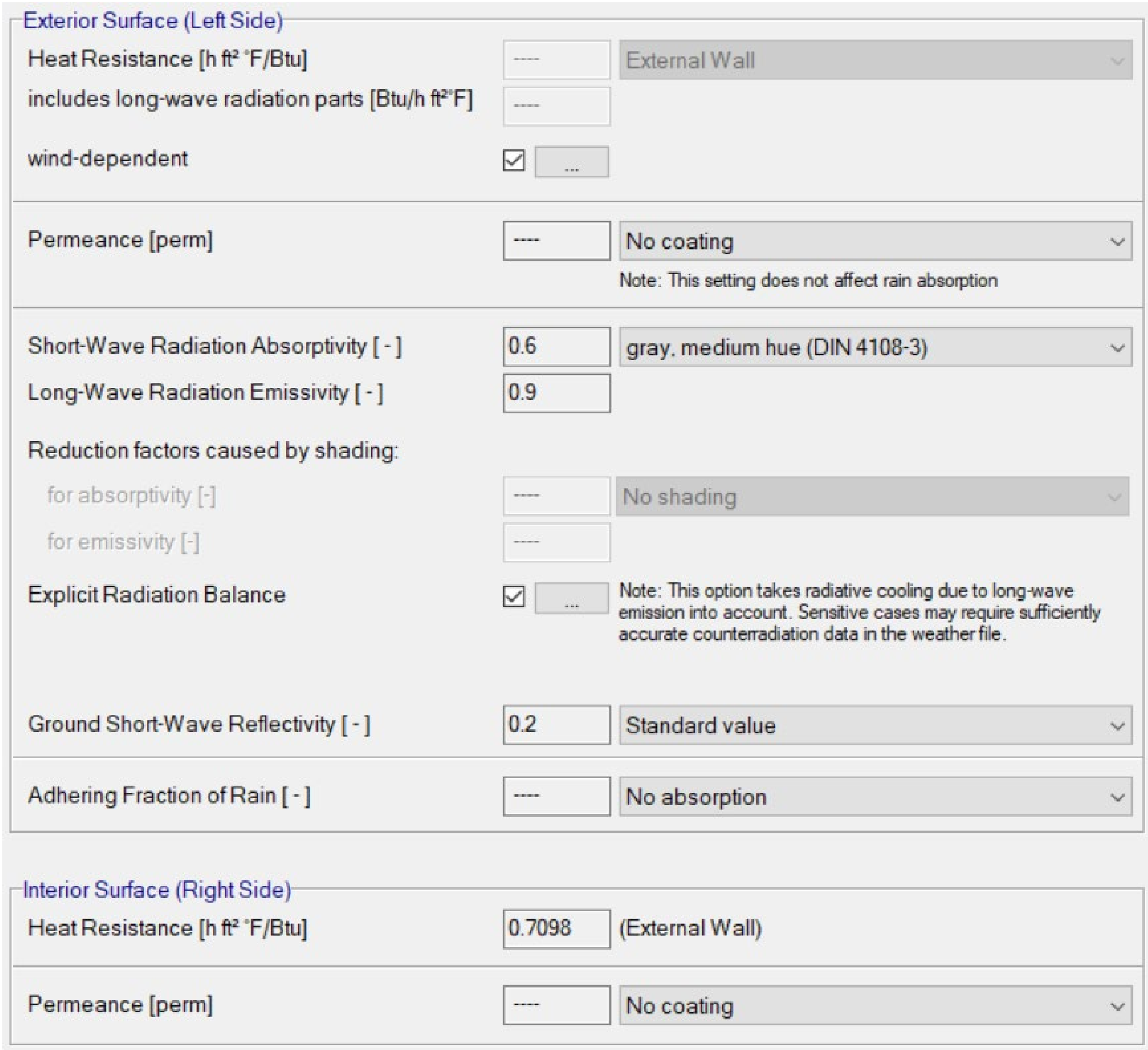

Figure 17: Above are the recommended Surface Transfer Coefficients for the metal wall panel model.

Commentary: For this example, a neutral gray color was modeled. The color of the SSR and wall panel for a given project should be used as darker colors will absorb more heat than lighter colors which will impact the hygrothermal response of the assembly.

Section 2.4.4a Exterior Surface

Heat Resistance

Most users will recognize this input as the exterior surface film resistance as defined in the ASHRAE *Handbook of Fundamentals,* Chapter 26 (refer to Figure 18 below). WUFI provides the user with predefined values of this coefficient for “External Wall, Roof, Basement, and Partition Wall (Inner)” in a dropdown menu. These coefficients include a convective (windless conditions) and radiative heat exchange. The radiative component is shown but greyed out. This value can be edited by the user if "User-Defined" is selected from the dropdown menu and the Explicit Radiation Balance is selected (see Radiation section below).

Table 10 Surface Film Coefficients/Resistances

		Surface Emittance, ε					
		Nonreflective ε = 0.90		Reflective ε = 0.20		Reflective ε = 0.05	
Position of Surface	Direction of Heat Flow	h_i	R_i	h_i	R_i	h_i	R_i
Indoor							
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32
Sloping at 45°	Upward	1.60	0.62	0.88	1.14	0.73	1.37
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70
Sloping at 45°	Downward	1.32	0.76	0.60	1.67	0.45	2.22
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55
Outdoor (any position)		h_o	R_o				
15 mph wind (for winter)	Any	6.00	0.17	—	—	—	—
7.5 mph wind (for summer)	Any	4.00	0.25	—	—	—	—

Notes:
1. Surface conductance h_i and h_o measured in Btu/h·ft²·°F; resistance R_i and R_o in h·ft²·°F/Btu.

Figure 18: Excerpt of Table 10 from Chapter 26 of the 2017 ASHRAE Handbook of Fundamentals.

The table in Figure 18 lists two options for exterior surface film resistances and both are related to wind speed. As such, it is recommended to use the "wind dependent" option. When "wind-dependent" is checked, the heat resistance values will be disabled as the coefficient will now be calculated using the wind speed from the climate file.

Commentary: The predefined values for "Roof" are for sloped roofs; flat roofs may not be accurate. Further the "wind-dependent" values will assume windward conditions for walls and roofs (surfaces less than 10 degrees) and should be used as long as the selected climate file includes wind data, which is the case for all climate files selected from the map under the Climate section. It is recommended not to use the exterior values in Figure 18, as these assume specific boundary conditions that may not match those equated in WUFI.

Permeance

Similar to the heat resistance associated with a surface film, a vapor permeance of the surface film also needs to be defined. WUFI automatically takes vapor diffusion resistance at the near surface into account; therefore, the user does not have to account for this. However, if a coating or surface deterioration that affects vapor diffusion but does not have significant influence on thermal or absorption properties, then an additional permeance or vapor diffusion resistance can be used. The user may choose from predefined values in the dropdown menu or define the permeance as needed.

Commentary: Using this transfer coefficient only changes the surface vapor diffusion resistance; it does not alter or influence rain absorption or solar radiation. These other factors must be addressed separately elsewhere. The user may also use a material layer to address surface permeance in lieu of this surface transfer coefficient as well.

Radiation

There are two means of heat transfer with regards to solar radiation: long wave and short wave.

Long wave radiation is absorbed and emitted from building materials; whereas, short wave radiation is only absorbed. Long wave radiation is only absorbed at the exterior surface and predominately from surrounding materials with negligible amounts coming from the sun. As such, long wave radiation is predominately coupled with the convective heat transfer associated with the exterior surface air film (See Heat Resistance above). The effects of overcooling due to long wave radiation (i.e., clear night sky) are not considered in a standard model. You need to uncouple the convective and radiation transfer and use an explicit radiation balance, which then adds a heat source or sink to the exterior surface and should be the default option to address long-wave radiation.

Short wave radiation adds a heat source to the exterior surface. The equation multiplies the absorptivity coefficient that the user can choose from the dropdown menu or manually defined by the solar radiation associated with the inclination provided in the previous tab (Section 2.4.2).

Adhering Fraction of Rain

"Adhering Fraction of Rain" is the ratio of wind-driven rain available for capillary suction for the surface. The wind-driven rain is calculated based on the selected weather file. The dropdown menu provides three choices: "Depending on inclination of component," "No absorption," and "User-Defined." For metal buildings, users will predominantly select "No absorption" because sheet metal is typically the exterior facing material.

Commentary: Turning the Adhering Fraction of Rain to zero or "No absorption" has no effect on moisture sources placed in material layers inboard of the exterior face. The moisture source is calculated using the rain load as calculated from the weather file. This factor only affects the amount of water available for porous exterior layer materials to absorb via capillary suction.

Section 2.4.4b Interior Surface

Heat Resistance

This section is similar to the exterior surface. WUFI will automatically provide a resistance factor associated with the assembly chosen in the exterior heat resistance dropdown menu. This can only be manually defined if "User-Defined" is selected in the exterior heat resistance dropdown menu.

Permeance

Also similar to the exterior permeance, is the interior permeance. Generally, users will select "User-Defined" from the dropdown menu and provide the permeance for the interior finish (e.g., paint).

For metal buildings, a polymeric vapor retarder or sheet metal liner is provided, which is modeled as a material. As such, "No Coating" should be selected in most cases.

Section 2.4.5 Initial Conditions

In order for the calculation of the heat and moisture transport to occur, an initial set of temperatures and moisture contents for the materials being modeled is needed. WUFI provides the user with the ability to define both these initial conditions in a variety of ways:

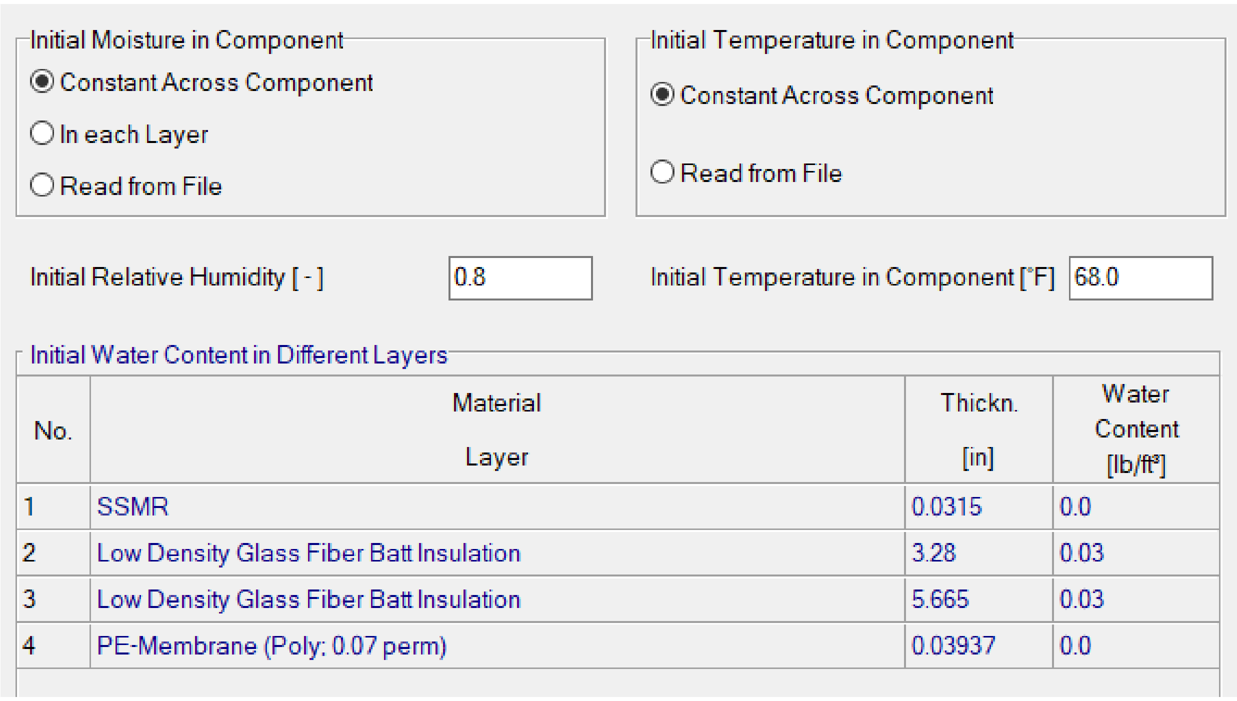

Figure 19: Initial Condition Tab allowing for the definition of initial moisture content and temperature within the materials.

Section 2.4.5a Initial Moisture in Component

Three choices are provided for inputting the initial moisture content: "Constant Across Component," "In each Layer," and "Read from File." The default provided in WUFI assumes the moisture content of each material at equilibrium with 80% relative humidity (RH). The default is the recommended input for modeling metal building assemblies for new construction.

Constant Across Component

This is the default option in WUFI and provides an initial moisture content associated to the equilibrium moisture content (EMC) for each material at 80% RH. While the initial RH can be defined by the user, users are encouraged to use ASHRAE 160 for modeling new or proposed enclosure assemblies. ASHRAE 160 requires defining the initial RH at the default value of 0.8 (80% RH); therefore, this option should be used if the model does not include concrete.

In each Layer

Selecting this option is similar to a "User-Defined" selection in other sections of the process. With this radio button clicked, the moisture content can be defined by the user. When this is selected, a new button appears to enable the user to "Assign Typical Built-In Moisture."

Read from File

If data has been logged for the materials within the modeled assembly, this data can be uploaded as an ASCII file to provide WUFI with the initial moisture content for the materials within the model. Typically, this information is not known, especially for new construction.

For changes to existing construction, this information may have been recorded; however, it is recommended that users run a model with the existing construction starting at the ASHRAE 160 default and saving the final moisture content result of the materials for use as the initial moisture content for the model with the changes to the existing construction.

Section 2.4.5b Initial Temperature in Component

Two choices are provided for inputting the initial temperature content: "Constant Across Component" and "Read from File."

Constant Across Component

This is the default option in WUFI and provides an initial temperature associated to a typical interior operating temperature of 68^{o}F. While the initial temperature can be defined by the user, users are encouraged to use ASHRAE 160 for modeling new or proposed enclosure assemblies. ASHRAE 160 requires defining the initial temperature at the default value of 68^{o}F.

Commentary: Generally, the temperatures of the materials will reach equilibrium in the first hour of calculation. Therefore, this initial input is not significantly important to the overall results of the analysis.

Read from File

If data has been logged for the materials within the modeled assembly, this data can be uploaded as an ASCII file to provide WUFI with the initial temperature for the materials within the model. Typically, this information is not known, especially for new construction.

Section 2.5 CONTROL

Section 2.5.1 Calculation Period

WUFI defaults to October of the current year and will run for 3 years. The time step also defaults to 1-hour increments. ASHRAE 160 requires a 5-year calculation period with 1 hour time steps.

Commentary: For investigative or explanatory modeling, the model should start and end with known dates of interest. Further, profiles are WUFI outputs for certain attributes at a particular point in time. If you are interested in the model profile at a certain time stamp during the calculation, add a profile and indicate the subject time of interest.

Beyond the recommended calculation periods, some modeling requires increased calculation periods to determine if and when equilibrium in the temperature and RH of a material of interest is reached. This is particularly valid if the ASHRAE 160 Mold Growth Index (Refer to Section 3.3.1.1b) is progressively increasing but has not exceeded the threshold within the 5-year calculation period. In these cases, it is recommended to increase the calculation period by 5 years for subsequent analyses.

Section 2.5.2 Numerics

Standard models have the necessary functions checked by default. By mathematical definition, numerical calculation is the iterative approach to converging on a solution to complex equations by reducing the problem into smaller increments or problems. Due to this "simplification," numerical analyses are only valid if the solution is validated with actual data. WUFI has been validated with data by Fraunhofer and other organizations worldwide; however, the fact that a very complex and transient problem, like hygrothermal behavior, relies on validation with actual data, some inputs can result in solutions that may not converge with reality. Therefore, changing the numerics is highly discouraged.

Section 2.6 CLIMATE

Section 2.6.1 Exterior Climate

WUFI provides many exterior climate files around the world. These files have all of the required inputs and should be used. These files also provide the option to select ASHRAE Year 2, which will be required for use in future publications of ASHRAE 160. For examples used in this guide, Chicago's Year 2 climate was used (see Figure 15).

Section 2.6.2 Interior Climate

Section 2.6.2a ASHRAE 160 Interior Climate

If the indoor temperature is not specified by the client, then the temperature is calculated based on the Simplified Method as specified in ASHRAE 160.

Commentary: WUFI's implementation of EN15026, used with a "Medium Moisture Load + 5%" (Figure 20), reflects the ASHRAE 160 simplified model and is a conservative approach. In case the evaluation fails the criterion, using the normal moisture load is an option to pass.

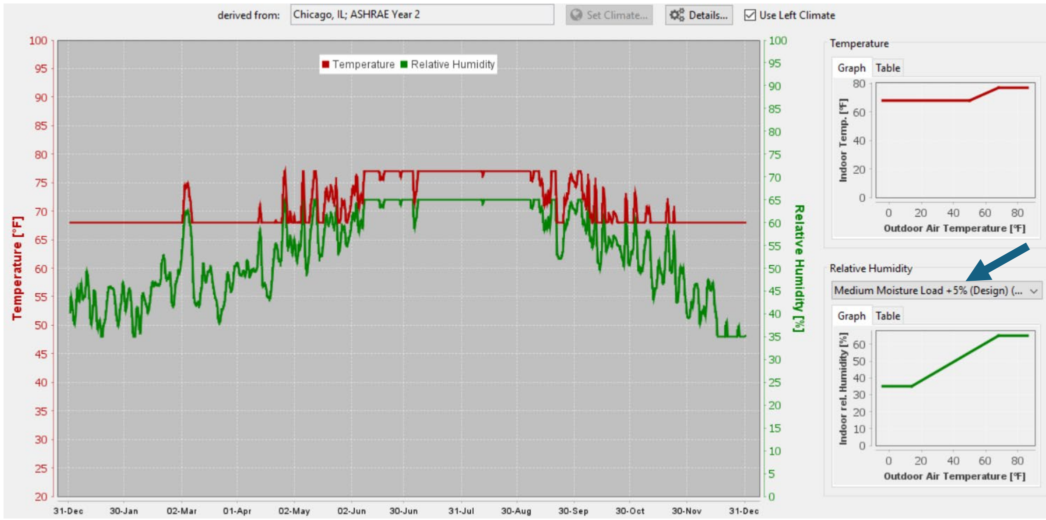

Figure 20: Interior climate used for the examples within this guide.

Section 2.6.2b Known Interior Climate

In many cases, the interior climate is known either from the client or having been measured at the site. When the interior climate is known, the sine curve tab should be used and "User-Defined" selected from the dropdown menu. The interior temperature and RH range can be specified.

Section 2.6.2c Interior Climate File from Datalogging (Project Specific)

If weather data has been recorded at a project specific location, it should be used in the model. The data from the logging equipment needs to be converted into the proper weather file format (.WET, .TRY, .DAT, .WAC, .WC, .WBC, or .KLI).

Commentary: Calculation issues can occur if the time step of a .KLI file does not match the exterior climate file time step.

CHAPTER 3: MODELING OUTPUT

With the information and guidance provided in Chapter 2, and assuming that the user has working knowledge of the WUFI software to run models, the general purpose of the following sections is to guide and educate the user on the interpretation of the results and the assessment of any convergence failures and imbalances.

Section 3.1 Status of Last Calculation

At the end of the calculation of each Case, a dialog box titled the Status of Last Calculation (SLC) is shown automatically. The SLCs for the SSR and Metal Wall Panel Assemblies are shown in Figures 21 and 22, respectively. However, if several Cases are run all at once, the SLC box will not appear for each Case after the calculation. In order to open the SLC box, the user may click on the icon below the Database Tab or under the Outputs Tab (Figure 23).

Status of Calculation

Calculation: Time and Date	5/11/2025 9:30:48 PM
Computing Time	20 min,22 sec.
Begin / End of calculation	10/1/2025 / 10/1/2030
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[lb/ft²]	0.0 -0.11
Integral of fluxes, right side (kr,dr)	[lb/ft²]	0.0 -0.05
Balance 1	[lb/ft²]	-0.02
Balance 2	[lb/ft²]	-0.02

Figure 21: Status of Last Calculation Dialog Box for the SSR Model.

Status of Calculation

Calculation: Time and Date	5/11/2025 9:51:11 PM
Computing Time	7 min,52 sec.
Begin / End of calculation	10/1/2025 / 10/1/2030
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[lb/ft²]	0.0 -0.05
Integral of fluxes, right side (kr,dr)	[lb/ft²]	0.0 -0.05
Balance 1	[lb/ft²]	-0.02
Balance 2	[lb/ft²]	-0.02

Figure 22: Status of Last Calculation Dialog Box for the Metal Wall Panel Model.

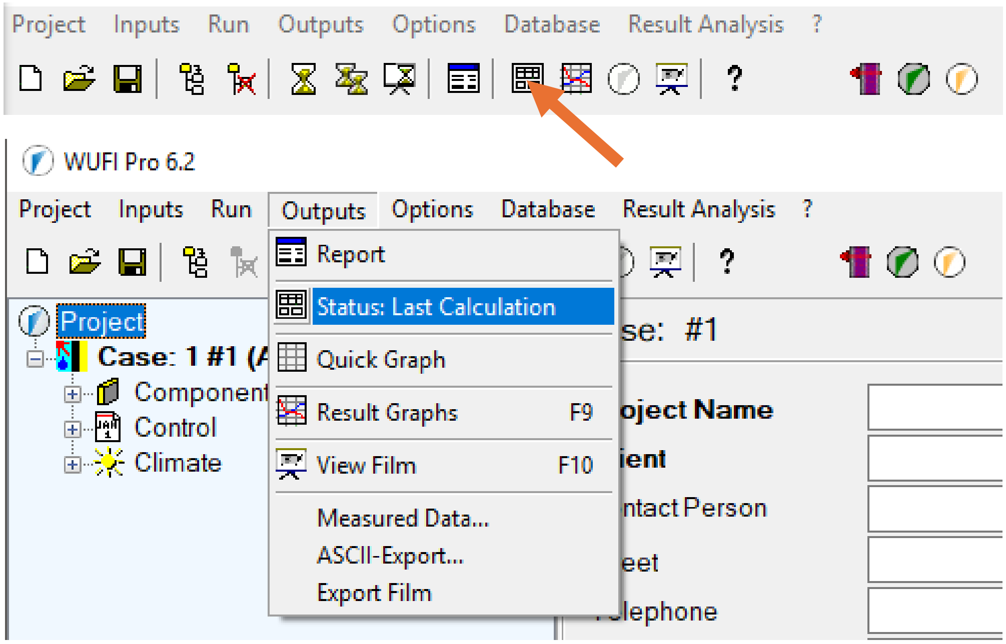

Figure 23: The Status of Last Calculation can be opened via the icon (arrow) or under the Outputs tab.

Section 3.1.1 Convergence Failures

Under that Status of Calculation in the SLC, the computing time and number of convergence failures is listed. The computing time indicates whether the analysis was difficult or if a slow solution of the equations occurred. The equation solution at each time step terminates after a maximum number of iterations. If the convergence criterion is not yet reached at the last iteration, or diverging iterations are calculated, a convergence failure occurs.

Commentary: Some convergence failures cause small differences in moisture balances and are usually acceptable. Generally, these types of convergence failures are a result of needing more iterations to achieve the convergence criterion (Figure 24).

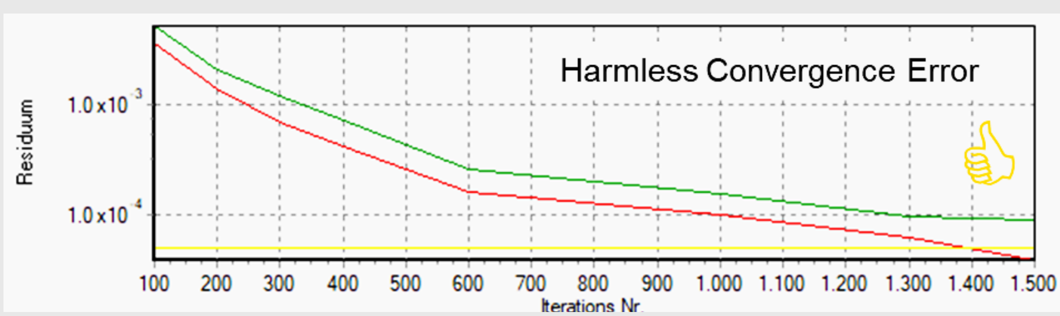

Figure 24: Convergence criterion was nearly met at the maximum number of iterations; however, this still constitutes a convergence failure.

However, divergent results, as shown in Figure 25, typically result in moisture imbalances and are not reliable. Adjustment to the input parameters is generally necessary to rectify these failures.

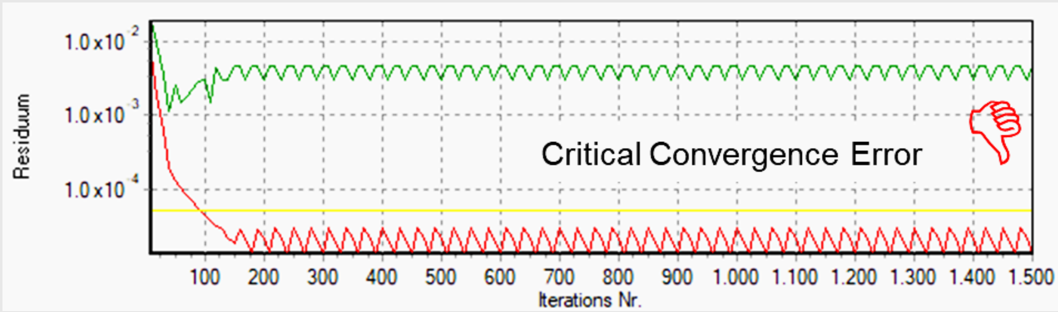

Figure 25: Divergent result after the maximum number of iterations.

Section 3.1.2 Moisture Balances

The moisture balance should be evaluated in tandem with the convergence failures (Figure 26).

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[lb/ft²]	0.0 -0.11
Integral of fluxes, right side (kr,dr)	[lb/ft²]	0.0 -0.05
Balance 1	[lb/ft²]	-0.02
Balance 2	[lb/ft²]	-0.02

Figure 26: Moisture Balances from the SLC.

Moisture Balance 1 is the water content at the end of the calculation minus the water content at the start of the simulation; Moisture Balance 2 is the sum of the moisture fluxes through the surfaces and released by sources. The difference between Balance 1 and 2 should be zero or very small (1% or less).

Commentary: Differences in the moisture balances could be caused by numerical errors or inaccuracies causing water to “appear” or “disappear” in the assembly. If the difference between moisture balances is small relative to the total amount of water taken up or dried out, or relative to the total water content, this may not have a significant impact on the results, depending on the type of construction. Conversely, high relative and absolute differences indicate unreliable results.

Section 3.2 Quick Graph Results

After each Case is run, a Quick Graph section will be added below Climate (Figure 27). The Quick Graphs display the total water content of the assembly, the water content in each individual layer, temperature, relative humidity, and isopleths at monitor positions. WUFI places two default monitor positions at the exterior and interior surfaces. If there are surfaces within the model that are of interest to the user, then monitor positions should be placed per Section 2.3.

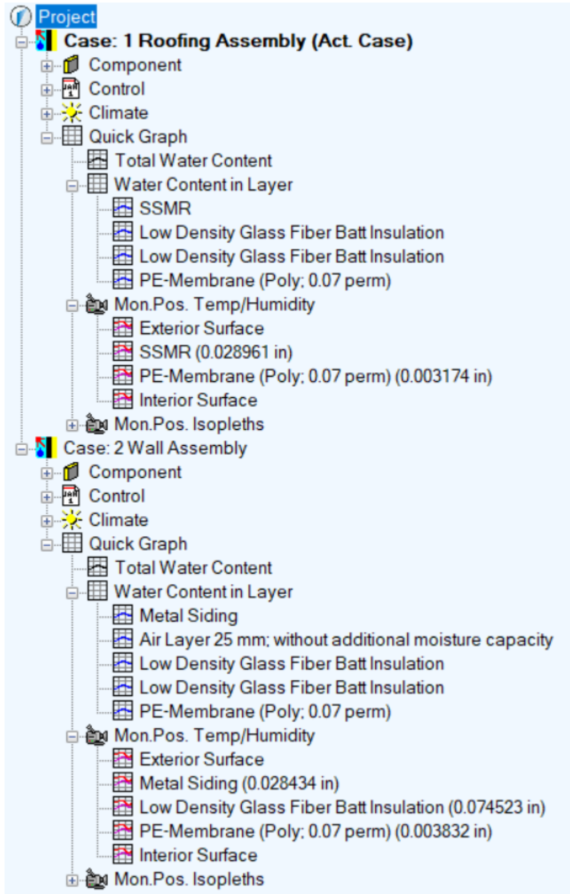

Figure 27: Quick Graph section added after running a case.

Section 3.2.1 Water Content

Section 3.2.1a Total Water Content

The total water content for the assembly is the summation of the water contents of the individual layers multiplied by their respective thickness. The trend of this graph after the initial properties are calculated can be an initial insight into the performance of the assembly. For instance, a general decreasing tread indicates that the assembly has a greater drying capacity; whereas, an increasing trend could suggest that the drying potential is hindered or wetting and redistribution events overwhelm the drying capacity of the assembly.

Conditions where a steady state equilibrium or cyclical profile develops, an assessment of individual layer water contents is recommended to determine trends of a critical layer (i.e., moisture sensitive material).

Section 3.2.1b Water Content in Layer

The water content in each layer can be assessed for the qualitative moisture balance of individual materials and the quantitative assessment of moisture values. The latter can be compared to the accepted maximum moisture content of the material in question (e.g., 20% MC for wood decay or 2% MC for gypsum). If the moisture content is not taken at a monitor position, the data provided is an average of the moisture content across the entire thickness of material, which can give skewed results.

Section 3.2.2 Temperature and Relative Humidity Monitor Positions

WUFI defaults to two monitor positions: exterior and interior surface. The user needs to manually insert monitor positions in the material section (Refer to Section 2.3). Manually inserted monitor positions will be populated in the Quick Graphs to view the surface temperatures, relative humidity, and dew point temperature at each monitor position created.

These Quick Graphs allow the user to quickly reference the RH and temperature trends for a material of interest. If the user wants to produce graphs outside of those developed by WUFI, the output file can be downloaded as an ASCII file that can be imported into Excel. This data can be further manipulated by the user to add into reports or other work product. Figure 28 below shows the temperature and relative humidity outputs for the monitor position placed on the inboard face of the metal panel.

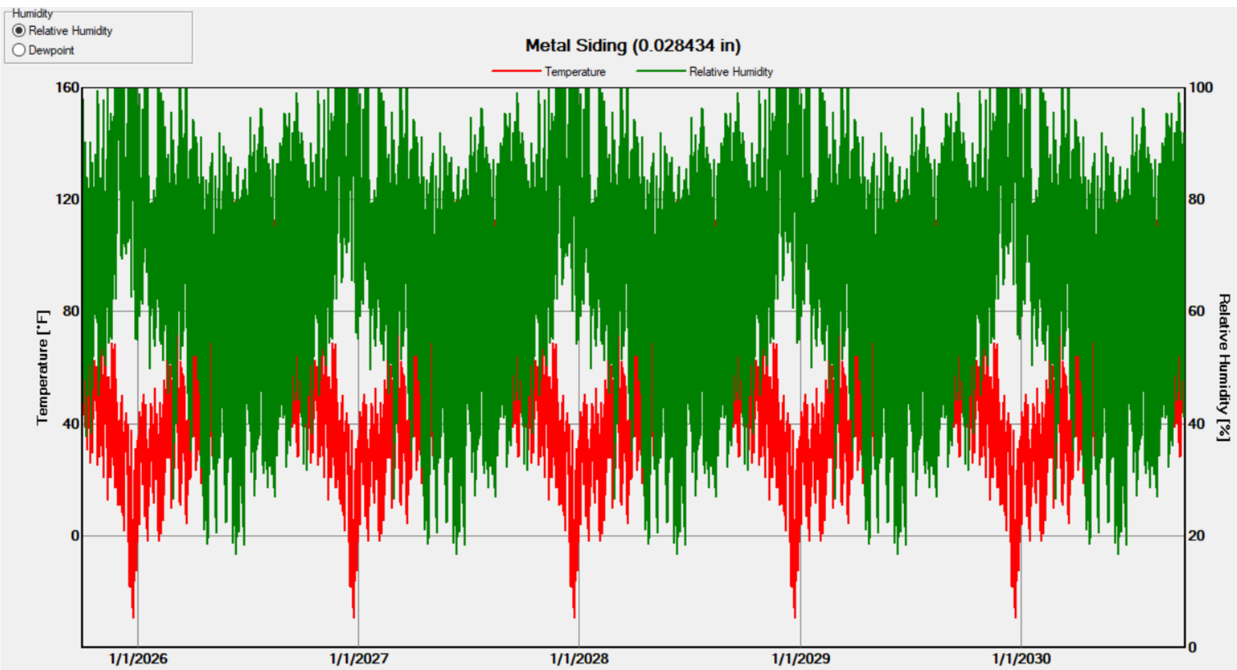

Figure 28: Surface temperature (red) and RH (green) response on the inboard face of the metal panel.

Section 3.2.3 WUFI Animation 1D

The WUFI Animation 1D is an evaluation tool that displays boundary conditions, profiles of temperature and moisture, heat and moisture fluxes, and the variation range of temperature, relative humidity, and water content.

In order to view the WUFI Animation 1D film for a run Case, the user can click the projection screen icon below the Result Analysis tab, clicking "View Film" under the Outputs tab, or pressing F10 (Figure 29).

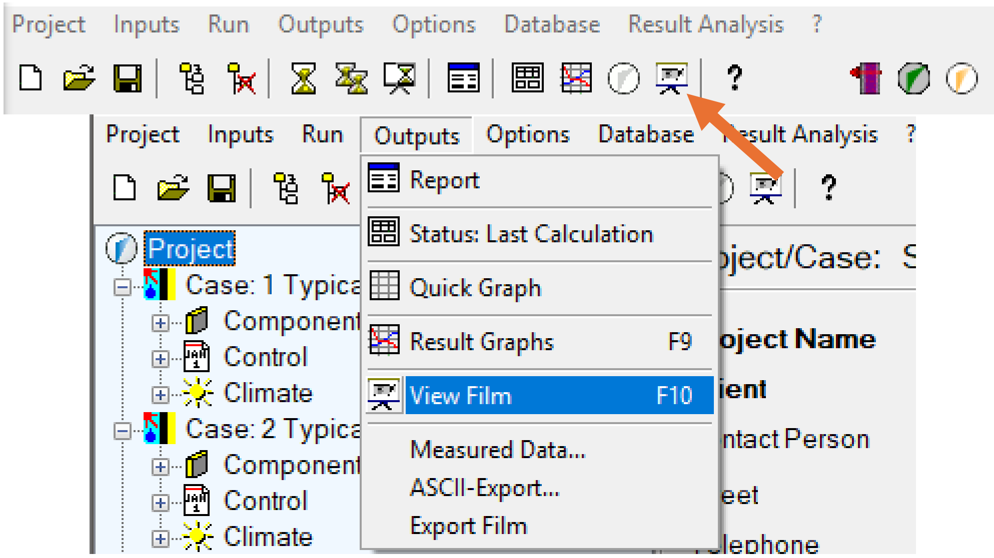

Figure 29: WUFI Animation 1D film can be opened via the icon (arrow), under the Outputs tab, or pressing F10.

Section 3.3 ASHRAE 160 Evaluation Criteria

As the WUFI software developed better approaches to analyze North American construction, its use became more prevalent; however, this use was wildly variable in areas of input and output interpretation. The goal of this guide to coalesce around a more common approach. Outside of MBMA, ASHRAE created the Standing Standard Project Committee 160, which developed the ASHRAE 160 Standard in 2009 and updated it in 2016 and 2021 with the sole purpose to specify the type of procedure, the implementation of inputs (see Chapter 2), and the evaluation of the output.

Section 3.3.1 ASHRAE 160

Section 3.3.1.1 Failure Criteria

In order to account for material sensitivity which includes nutrient levels, chemical composition, and the pH of materials that we are analyzing, the ASHRAE SSPC 160 committee included the mold index in the ASHRAE 160 standard based on the research by Hannu Viitanen, et al. The Mold Index has a scale of 0 to 6 with a value of 3 being the threshold for failure in hygrothermal modeling.

Index	Description of Growth Rate
0	No growth
1	Small amounts of mold on surface (microscope), initial stages of local growth
2	Several local mold growth colonies on surface (microscope)
3	Visual findings of mold on surface, < 10% coverage, or **< 50% coverage of mold (microscope)**
4	Visual findings of mold on surface, 10%–50% coverage, or **> 50% coverage of mold (microscope)**
5	Plenty of growth on surface, > 50% coverage (visual)
6	Heavy and tight growth, coverage about 100%

Section 3.3.1.1a Sensitivity Classes

In order to incorporate the mold index and fuse it with the 2009 criteria, the ASHRAE 160 standard needed to add material sensitivity classes of which there are four: Very Sensitive, Sensitive, Medium Resistant, and Resistant.

Sensitivity Class	Materials
Very Sensitive	Pine sapwood
Sensitive	Glued wooden boards, polyurethane insulation with paper surface, spruce
Medium Resistant	Concrete, aerated and cellular concrete, glass wool, polyester wool
Resistant	Polyurethane insulation with polished surface

Each class has a different equation and factors for calculating the Mold Index, which increases at a specific increment when conditions are favorable based on the 2009 criteria and decreases when they are not. The rate at which the increments are calculated are a function of surface RH and temperature. Note that the only difference between the sensitive and resistant materials is a shift from 80%RH to 85%RH and a decrease in the critical temperature.

Commentary: The ASHRAE 160 listing for the sensitivity classes is vague and there is discussion within the ASHRAE SSPC 160 Committee and Technical Committee 4.4 to create a more specific list for typical building materials. Until consensus within those committees is reached, users are recommended to relate the following materials to the standard sensitivity classes.

Sensitivity Class	Building Materials
Very Sensitive	Untreated wood
Sensitive	Kraft Paper, Paper-faced materials (e.g. interior gypsum wallboard) Plywood and OSB
Medium Resistant	Glass-fiber faced materials (e.g. Densglass), Fiber Cement boards
Resistant	Glass Metals (e.g. steel, aluminum, copper, etc.) Stone, concrete, and brick masonry

Section 3.3.1.1b Mold Growth Index Calculation

The Mold Growth Index (MGI) looks simple and benign, but that delta M term has a lot involved based on the research done on pine sapwood samples. The mold index will never be a negative number; therefore, the minimum index number is 0; however, the delta M term can either intensify the mold growth or cause decline.

$$M_t = M_{t-1} + \Delta M$$

Section 3.3.1.1c Graphical Output for ASHRAE 160

WUFI users have two options for post-processing the output data for evaluation with the criteria set forth in ASHRAE 160: download WUFI add-ons such as the Mold Index VTT or extract the data from WUFI and insert into your own spreadsheet.

WUFI Mold Index VTT Plug-in

A plug-in for WUFI can be downloaded to enable the user to calculate the MGI within the software without external data manipulation. The plug in can be downloaded at https://wufi.de/en/2017/03/31/wufi-mould-index-vtt/.

Once installed, the VTT icon ( ) should appear in your task bar and will be listed under the Result Analysis tab.

Once a case has been run, clicking on the VTT icon will open the dialog box shown below and will automatically extract the hourly temperature and RH data from that run case and display the MGI (Figure 35). If started, as shown above, the interior surface will be evaluated. To evaluate other locations within the assembly, the VTT plug-in needs to be used in the Animation 1D (Refer to Section 3.2.3).

Under the inputs section, the user needs to select the sensitivity class and decline coefficient for the material of interest. (Refer to Section 3.3.1.1a).

To evaluate locations of interest within the assembly, the plug-in needs to be used in the Animation 1D film (See Section 3.2.3) using the following steps:

Step 1: Right click on within the assembly and select “Jump to…”

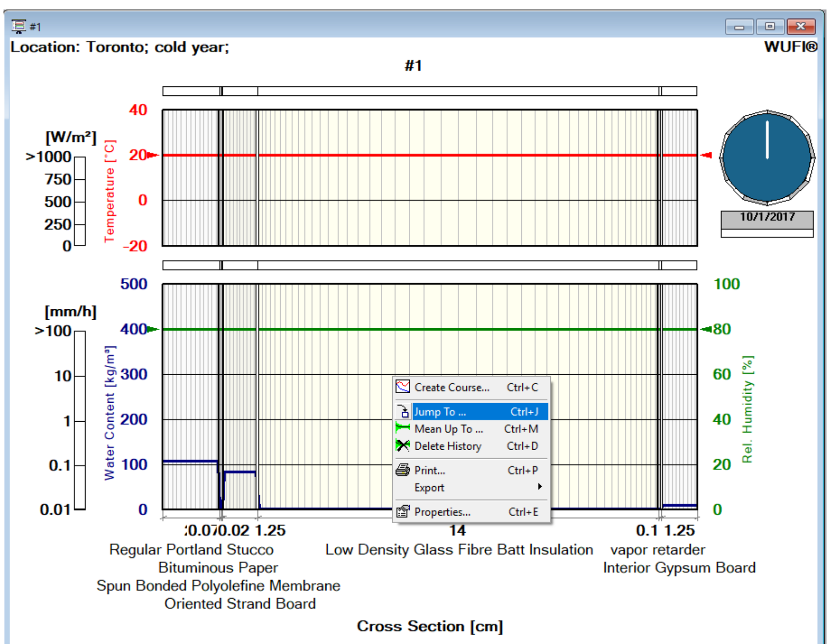

Figure 30: Right click on the assembly and select “Jump To… .”

Step 2: Change the year to the year before the last calculated year. For example, if the model is running for five years (2019 to 2024), then change the year to Year 4 of 2023.

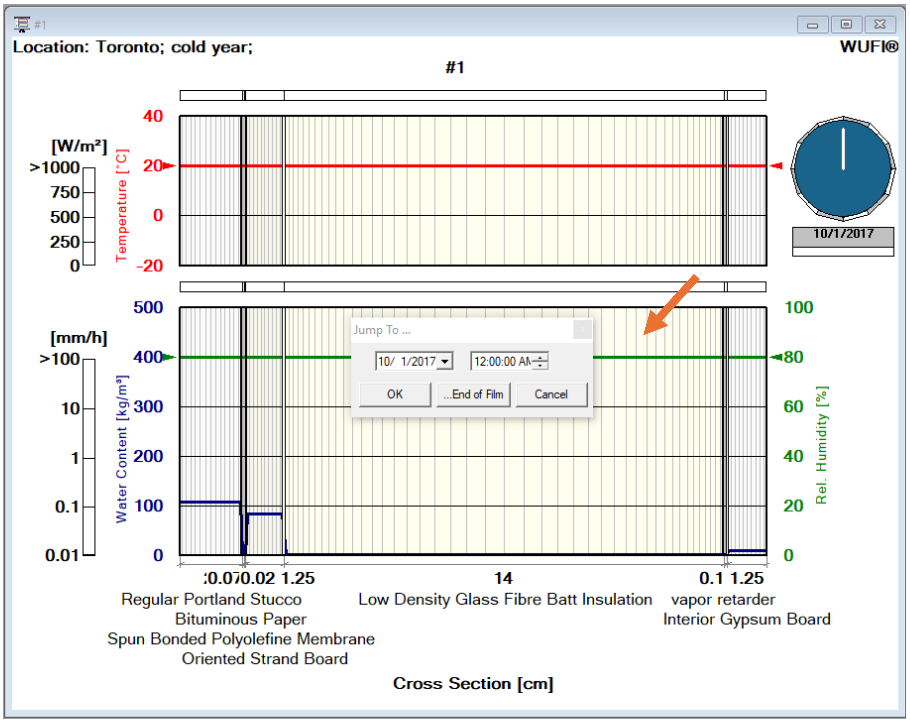

Figure 31: Change the year to the year before the last calculated year.

Step 3: Right click on screen again and select "Mean Up To..." and select "...End of Film."

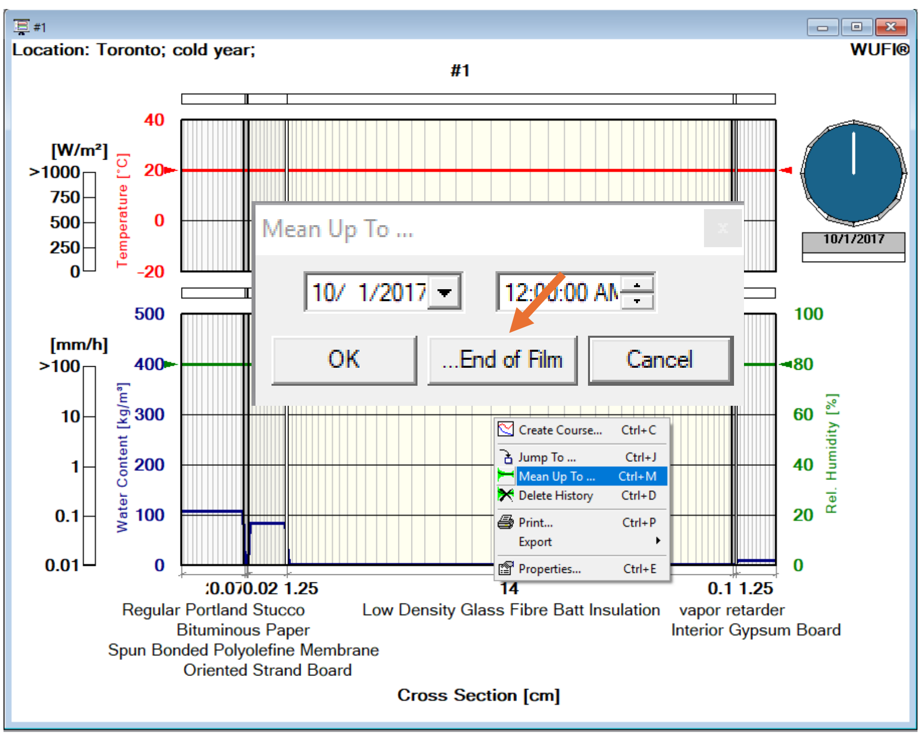

Figure 32: Right click on the assembly and select "Mean Up To..." and click "...End of Film" (arrow).

Step 4: Click the Mold Growth VTT Icon in the Animation ID task bar or from Results Analysis tab.

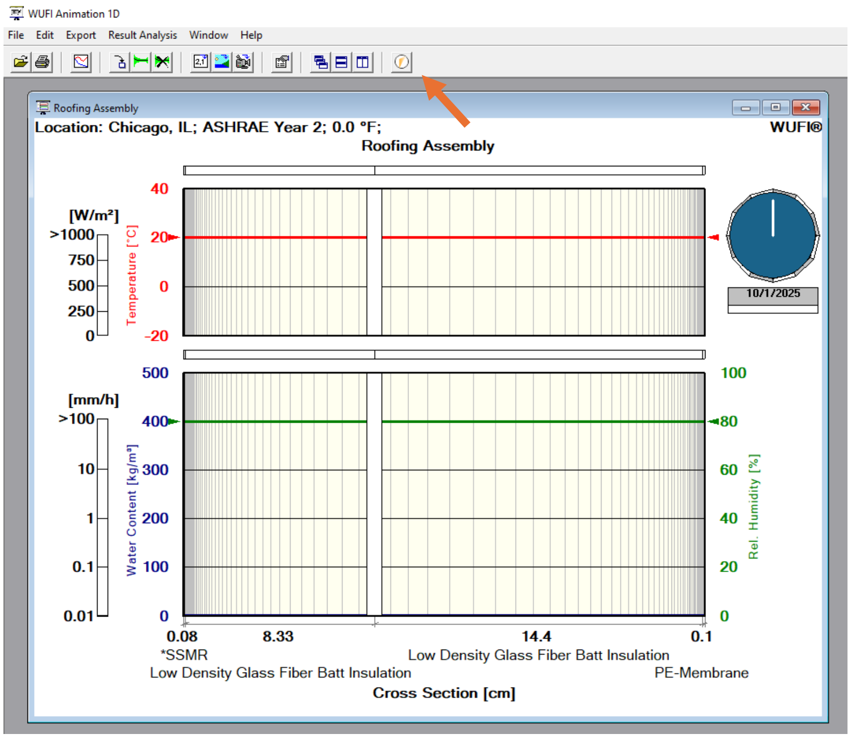

Figure 33: Click on the VTT icon (arrow) and then click on the surface of interest.

Step 5: Click on the layer/surface of interest and the results will be calculated. Select the appropriate sensitivity class and decline coefficient for the material of interest.

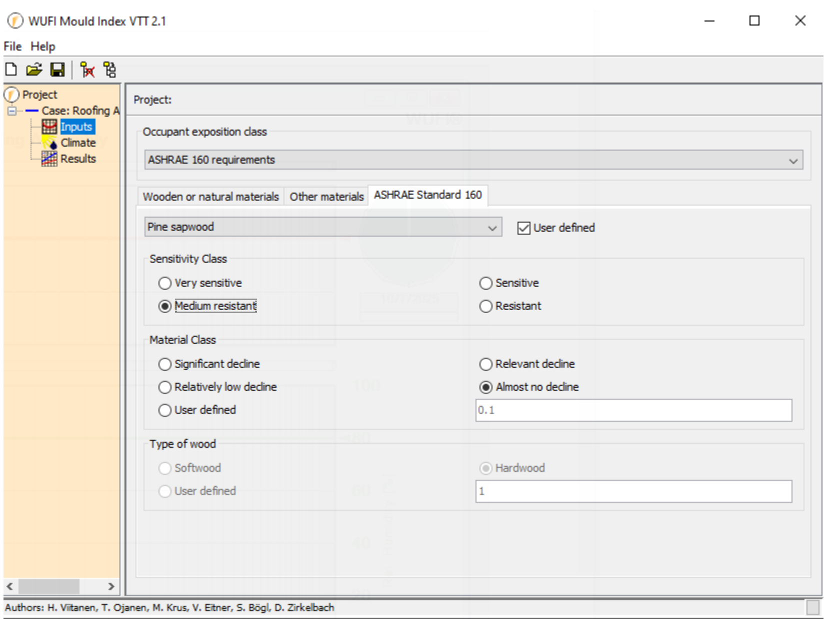

Figure 34: VTT Input page to select the material sensitivity class and decline coefficient which should remain at the default value of "Almost no decline" for worst case results.

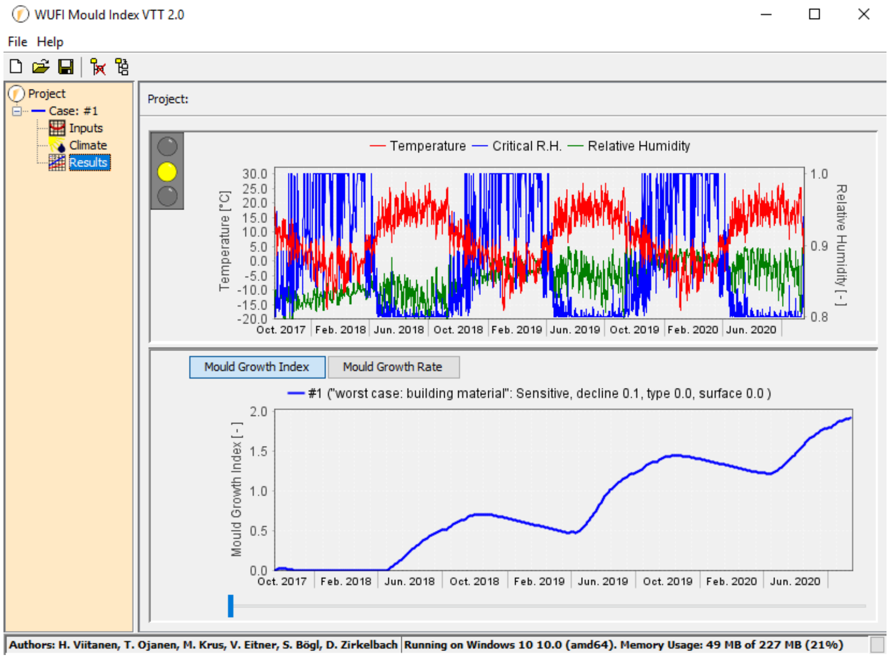

Figure 35: MGI output.

Spreadsheet

Using the monitor position data output (refer to Section 3.2.2), the data can be copied from the ASCII file and pasted in a spreadsheet to manually perform the MGI calculations specified in ASHRAE 160.

Section 3.3.1.2 Corrosion Index

Another evaluation criteria that is listed in ASHRAE 160 is the Corrosion Index. The current standard uses the previous criteria from 2009, which lists the running average RH of 80% or higher as the threshold. However, it can be reduced to 70% or higher for nickel and air containing trace amounts of sulfur dioxide (0.01%). This method does not account for time of wetness, which is a critical threshold for corrosion. WUFI has an add-on for corrosion that is shown below and can be downloaded at https://wufi.de/en/2017/03/31/wufi-corr/ .

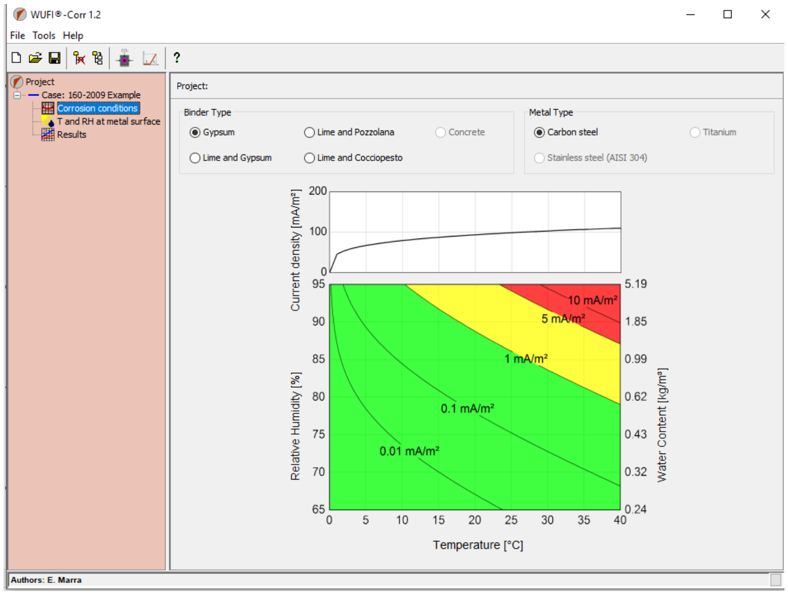

Figure 36: Corrosion Index output.

This plug-in will appear as an icon ( ), under the Results Analysis, and is used in the same way that the Mold Index VTT is utilized (See Steps 4 and 5 above).

Commentary: This plug-in only applies to rebar within concrete.

Section 3.3.2 Building Material Reference Criteria

For special cases, ASHRAE 160 may not provide failure criteria or may not be able to address other known failure mechanisms such as structural degradation or significant dimensional fluctuation at high moisture contents.

Similar to the temperature and RH output data at monitor positions discussed in Section 3.2.2, the water content of the material of interest can also be exported as an ASCII file and imported into an Excel spreadsheet.

Commentary: It is important to understand that the water content data from the monitor position is the mean water content of the entire material layer. While this may be sufficient for some analyses, if the surface water content is of particular significance (outboard face or inboard face of sheathing boards), then the water content should be extracted using the Animation 1D method outlined below or break the modeled material into smaller thicknesses to account for near surface anomalies.

Step 1: Right click inside the assembly and select "Mean Up To..." and click "...End of Film."

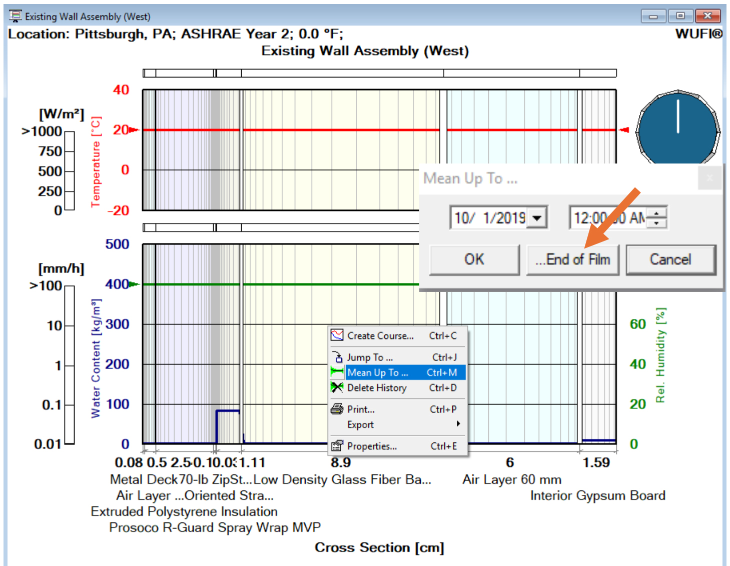

Figure 37: Animation 1D Film.

Step 2: Right click within the assembly again and select "Create Course" and select the material surface of interest.

Step 3: Right click within the dialog box that was created, hover over Export, and select "ASC – Course."

Step 4: Save file and open. The data under Water Content is the content at that surface. The Mean Water Content is also listed, which is the same as the ASCII file created via the monitor position.

REFERENCES

ANSI/ASHRAE 160-2016 - *Criteria for Moisture-Control Design Analysis in Buildings* (ASHRAE 160)

ASHRAE RP-1091 – *Development of Design Strategies for Rainscreen and Sheathing Membrane Performance in Wood Frame Walls*

ASHRAE *Handbook of Fundamentals*

EN15026, *Hygrothermal performance of building components and building elements - Assessment of moisture transfer by numerical simulation*

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