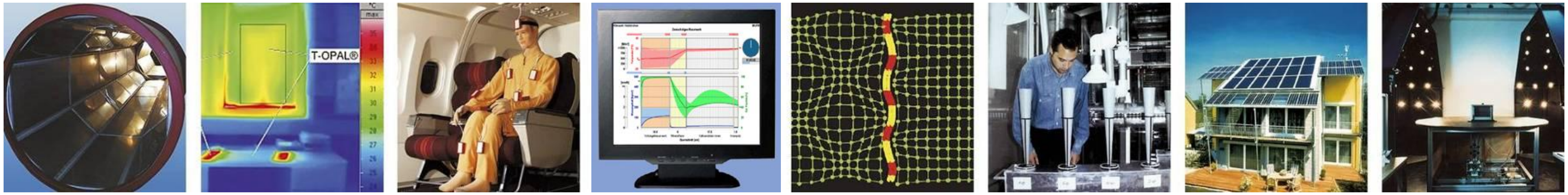

WUFI®

Guideline for the Calculation of Ventilated Pitched Roofs

Date: July 2026

Fraunhofer
IBP

Content

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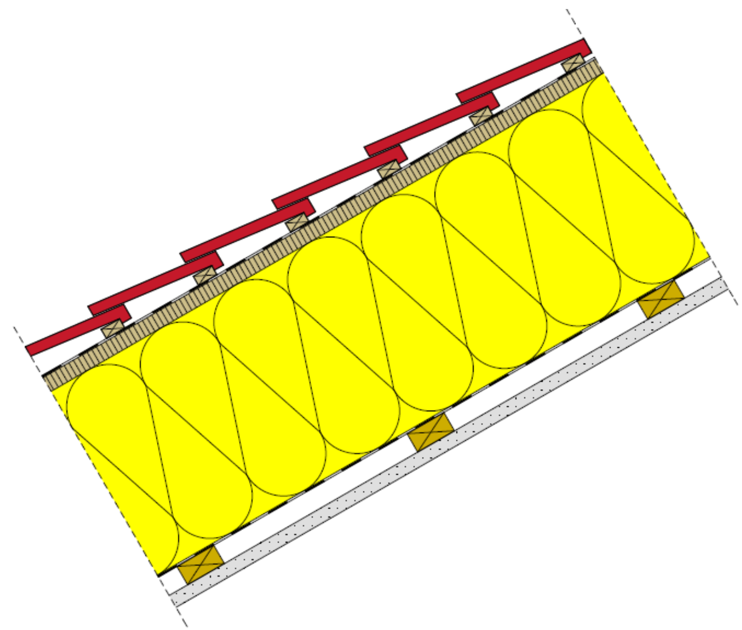
Introduction

This guideline explains the procedure of the calculation and evaluation of pitched roofs with a vapour retarder applied on the whole interior surface.

In the first step all necessary input data and the evaluation criteria are described.

The procedure from input to evaluation is then explained using an example case.



Notes on the Input: Component Assembly

Component - Assembly

Roof Cladding with Tiles

The ventilated roof cladding is replaced in the simulation by effective transfer parameters corresponding to the pitched roof model [1] directly on the surface of the sub-roof.

Underlay / Weather Protection Membrane

The underlay / weather protection membrane is also not included in the calculation as a component layer but is considered as an s_d-value in the surface transfer parameters. This leads to practically identical results but speeds up the calculation significantly compared to taking the roofing membrane into account in the component structure.

Underlying Roof Assembly

The underlying layers are to be entered according to the assembly in the cross section of the insulated cavity.

Notes on the Input: Infiltration Source

Component - Assembly

Moisture Source – Infiltration

According to EN 15026 [7], the amount of moisture which enters the construction by convection depending on the air tightness of the envelope always needs to be assessed for wooden structures. In the simulation it is considered using the IBP infiltration model.

The moisture source must be placed at the position in the model where the condensation water will form in practice – usually this is below the second airtight layer on the cold side of the component.

For roof constructions we recommend the following settings:

- with wooden sheathing: moisture source in the interior 5 mm of the wooden sheathing
- without wooden sheathing: moisture source in the exterior 5 mm of the insulation layer

Notes on the Input: Infiltration Source

Component – Assembly

Moisture Source – Infiltration

The source strength is automatically determined depending on the overpressure due to the building's thermal buoyancy (temperature difference between outside and inside as well as specified air space height), the indoor air humidity and the specified airtightness of the building envelope [3].

For more information on using the infiltration source in WUFI®, click here: Guideline for Using the Air Infiltration Source in WUFI®

Notes on the Input: Initial Conditions

Component – Initial Conditions

Initial Temperature and Moisture:

A constant initial relative humidity of 80 % and an initial temperature of 20 °C is recommended as a default setting.

If increased built-in moisture contents are known, these can be specified separately for the corresponding layer.

Notes on the Input: Outdoor Climate

Boundary Conditions (exterior) – Climate

Outdoor Climate:

A climate appropriate for the location of the building should be used.

For Germany:

The hygrothermal reference years (HRY), which were created for 11 locations in Germany as part of a research project [5], are useful here. These locations are representative for the respective climate region. For more information, please refer to the
WUFI® Help (F1) → Topic: Hygrothermal Reference Years

The Holzkirchen location, with 20% reduced radiation, is considered critically representative of German locations up to altitudes of 700 m. This can be considered in the simulation by reducing the absorption coefficient from a to a*0.8. This climate was also used for the exemption of deemed-to-satisfy constructions in DIN 4108-3 [4].

Notes on the Input: Orientation / Inclination

Boundary Conditions (exterior) – Orientation

Orientation

The relevant orientation usually is North where the lowest radiation gains occur. Alternatively, the most unfavourable orientation of the building part can be used for specific projects.

Inclination

The inclination of the roof must be specified according to the planned roof inclination.

Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface

Heat Transfer

The heat transfer coefficient is set according to the following tables based on the pitched roof model [1]; the value for long-wave radiation parts must be set to 0 W/m²K, as the radiation is calculated explicitly.

Usually „normally ventilated“ can be assumed!

Strong ventilated	$a_{k,e}$ = 30 [W/m²K]
Normal ventilated	$a_{k,e}$ = 19 [W/m²K]
Low ventilated	$a_{k,e}$ = 13,5 [W/m²K]

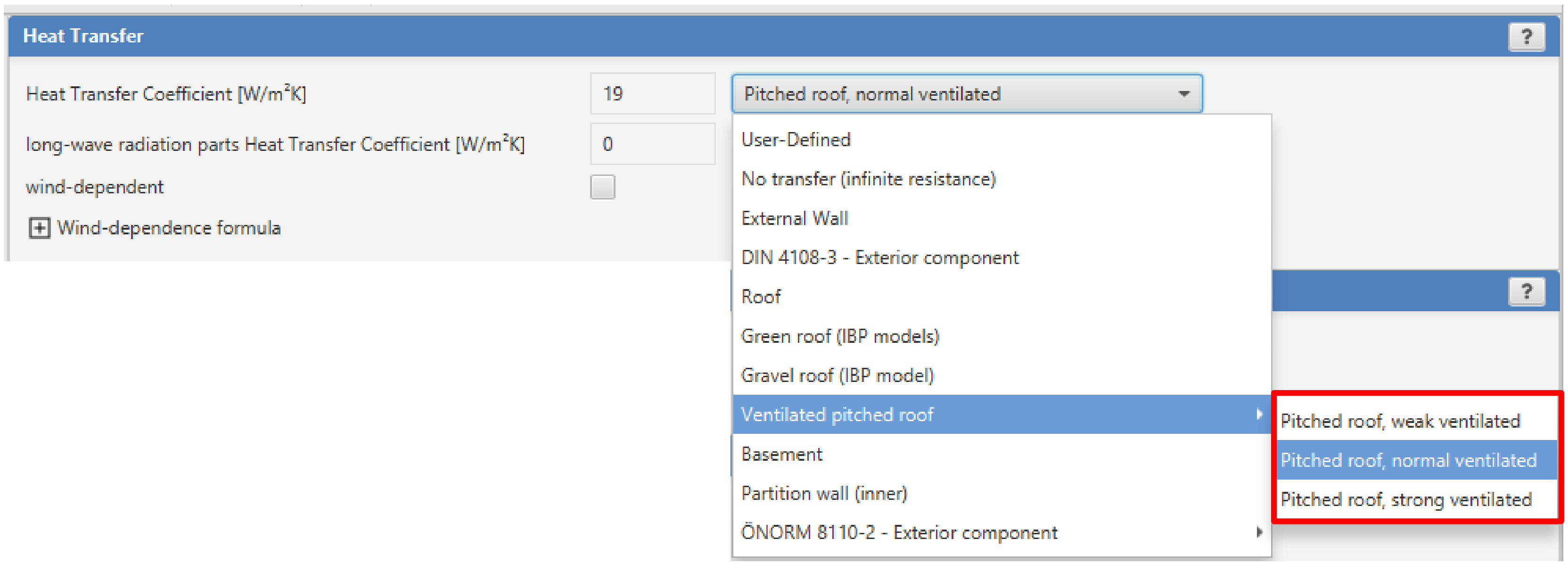
$a_{k,e}$: convective heat transfer coefficient

Strong ventilated	Eaves open without any ventilation grid etc.	Ridge open with a low flow resistance	
Normal ventilated	Eaves openings with insect protection grid or eave comb	Ridge closed with ridge / arris roll	
Low ventilated	Small openings at the eaves	Small openings at the ridge	No counter battens

Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface

Heat Transfer



Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface

Vapor Transfer (Additional diffusion resistance)

The underlay / weather protection membrane is considered as s_d-value in the surface transfer parameters, instead of modelling it as a layer.

For underlay membranes with s_d-values less than 0.1 m, it should be noted that this value may increase over time due to dust and deposits. This effect should be verified if necessary.

The German Standard DIN 4108-3 [4] generally recommends using low s_d-values with a minimum of 0.1 m, as this is always the safer option for the Glaser Calculation. In the simulation, a change in the s_d-value can affect the results in either direction; therefore, in case of doubt, the declared value and a potentially higher value should be considered.

Notes on the Input: Surface Transfer Coefficients (exterior)

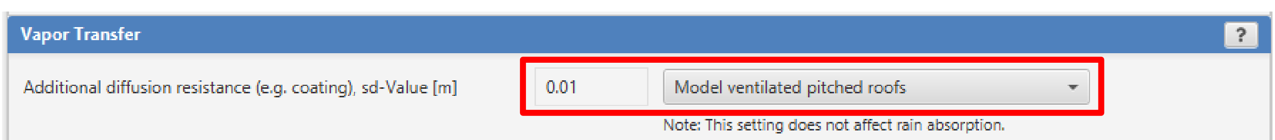
Boundary Conditions (exterior) – Surface

Vapor Transfer (Additional diffusion resistance)

Note for constructions with absorbent underlay materials:

In the case of assemblies with exterior wooden sheathing or wood-based materials, an additional s_d-value of 0.01 m must be applied to the external surface to avoid unrealistically high condensation on the substructure caused by the absence of roof tiles in the simulation.

For a more detailed explanation, see Hygrothermal Simulation of ventilated pitched roofs with effective transfer parameters, chapter 8.



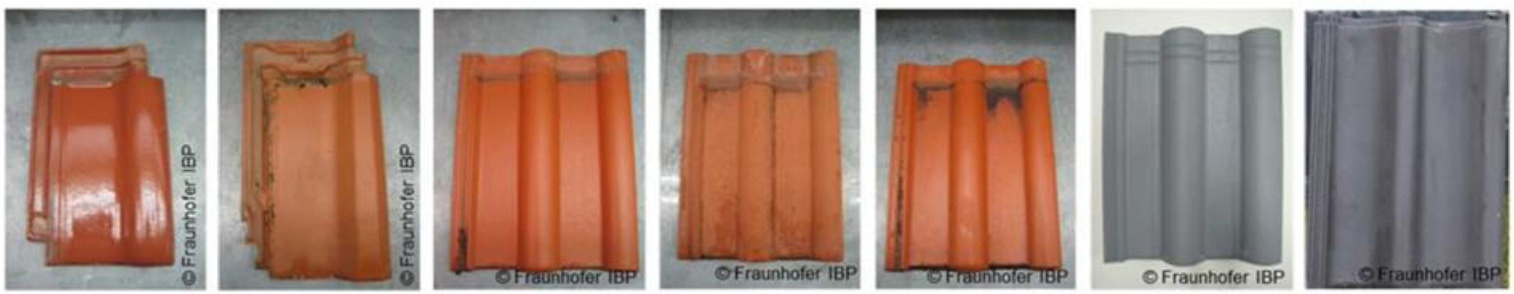
Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface

Radiation: Short-wave absorptivity

The short-wave radiation absorptivity should be selected depending on the colour of the roof tiles (examples below or in right table) and, if necessary, be reduced according to the pitched roof models [1], [10] (see slides 16 to 25).

Red tiles	a = 0.67 – 0.78
Grey tiles	a ~ 0.85
Dark tiles	a = 0.9 – 0.94



Red, high gloss glazed	Brick red	Light red, semi-matt	Light red, matt (weathered)	Natural clay red, matt	Light grey	Black
0.72	0.74	0.75	0.76	0.78	0.85	0.94

Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface

Radiation: Long-wave emissivity

The long-wave radiation emissivity depends on the surface condition of the clay / concrete tiles and varies between 0.82 and 0.91.

Clay tile, high gloss glazed	ε ~ 0.82
Clay tile, matt	ε ~ 0.84
Concrete tile, in general	ε = 0.9 – 0.91

To consider the (night-time) overcooling, the “radiative overcooling” must always be switched on for roofs due to its large field of view to the sky.

Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface

Radiation: Reduction factors

Ventilated pitched roof

To evaluate typical conditions, it is recommended to use the middle position, especially if the coldest position (30 cm from the eave opening) is still within the roof overhang.

The reduction in absorption/emission for the middle position of the roof can be selected directly from the drop-down menu under “Reduction Factors” in WUFI®.

The following options are available:

- Pitched roof, ventilated, middle position
- Pitched roof, ventilated, rooftop PV modules*
- Pitched roof, ventilated, vacuum tubes*

* available from WUFI® Pro 7.2.2

Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface

Radiation: Reduction factors

Ventilated pitched roof

If the simulation is to consider the coldest or warmest position, the reduction factors must be specified as user-defined values in accordance with the tables on the following slides.

Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface

<u>Radiation: Reduction factors</u>

Ventilated pitched roof [1]

	Coldest position	Middle position	Warmest position
Strong ventilated	$a_e = a \cdot 0.7$	$a_e = a \cdot 0.9$	$a_e = a$
Normal ventilated	$a_e = a \cdot 0.7$	$a_e = a \cdot 0.9$	$a_e = a$
Low ventilated	$a_e = a \cdot 0.75$	$a_e = a \cdot 0.9$	$a_e = a$

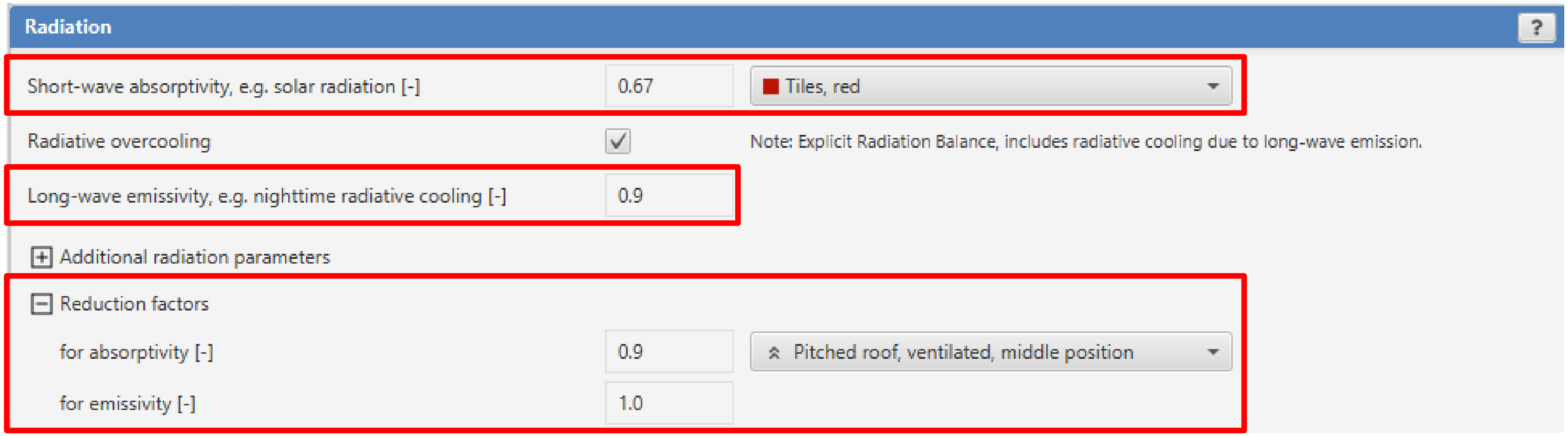
with
a_e: effective absorption coefficient
a: absorption coefficient of the roof cladding

Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface

Radiation: Reduction factors

Ventilated pitched roof [1]



Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface shaded

Radiation: Reduction factors

Ventilated pitched roof with rooftop PV modules [10]

	Coldest position	Middle position	Warmest position
Strong ventilated Normal ventilated Low ventilated	$a_e = a_{PV} \cdot 0.33$ $a_e = 0.18$ $\varepsilon_e = \varepsilon_{PV} \cdot 0.115$ $\varepsilon_e = 0.09$	$a_e = a_{PV} \cdot 0.4$ $a_e = 0.22$ $\varepsilon_e = \varepsilon_{PV} \cdot 0.115$ $\varepsilon_e = 0.09$	$a_e = a_{PV} \cdot 0.53$ $a_e = 0.29$ $\varepsilon_e = \varepsilon_{PV} \cdot 0.115$ $\varepsilon_e = 0.09$

with
a_e: effective absorption coefficient
$a_{PV} = 0.55$

ε_e: effective emission coefficient
$\varepsilon_{PV} = 0.8$

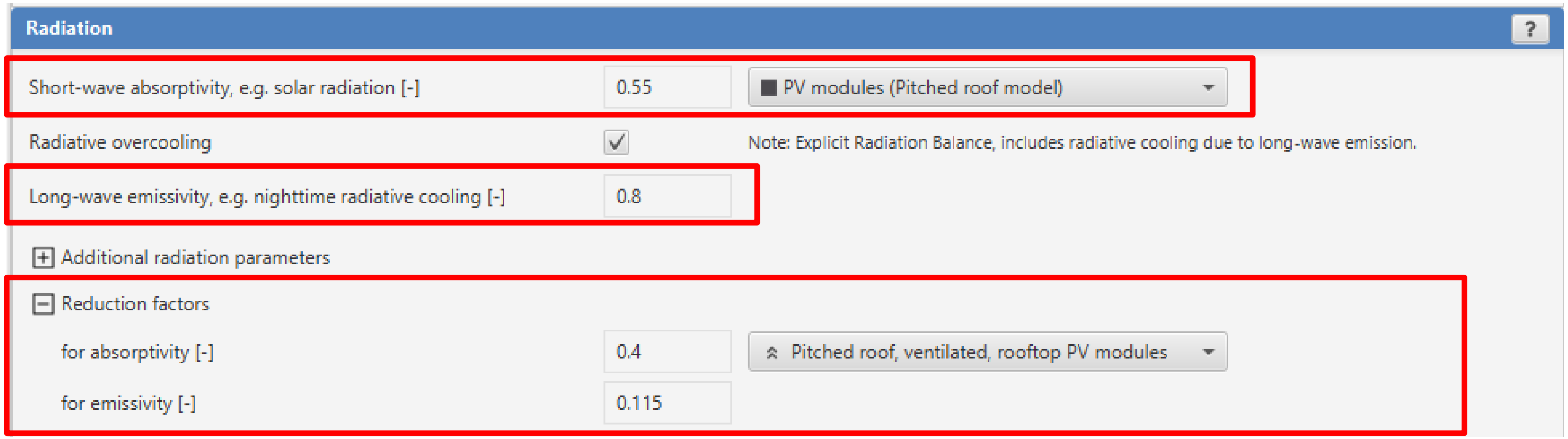
Note:
The absorption and emission values for the PV modules were determined as part of the studies [10].

Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface shaded

Radiation: Reduction factors

Ventilated pitched roof with rooftop PV modules [10]



Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface shaded

Radiation: Reduction factors

Ventilated pitched roof with vacuum tubes [10]

	Coldest position	Middle position	Warmest position
Strong ventilated	$a_e = a \cdot 0.28$ $\varepsilon_e = \varepsilon \cdot 0.2$	$a_e = a \cdot 0.36$ $\varepsilon_e = \varepsilon \cdot 0.2$	$a_e = a \cdot 0.4$ $\varepsilon_e = \varepsilon \cdot 0.2$
Normal ventilated			
Low ventilated	$a_e = a \cdot 0.3$ $\varepsilon_e = \varepsilon \cdot 0.2$		

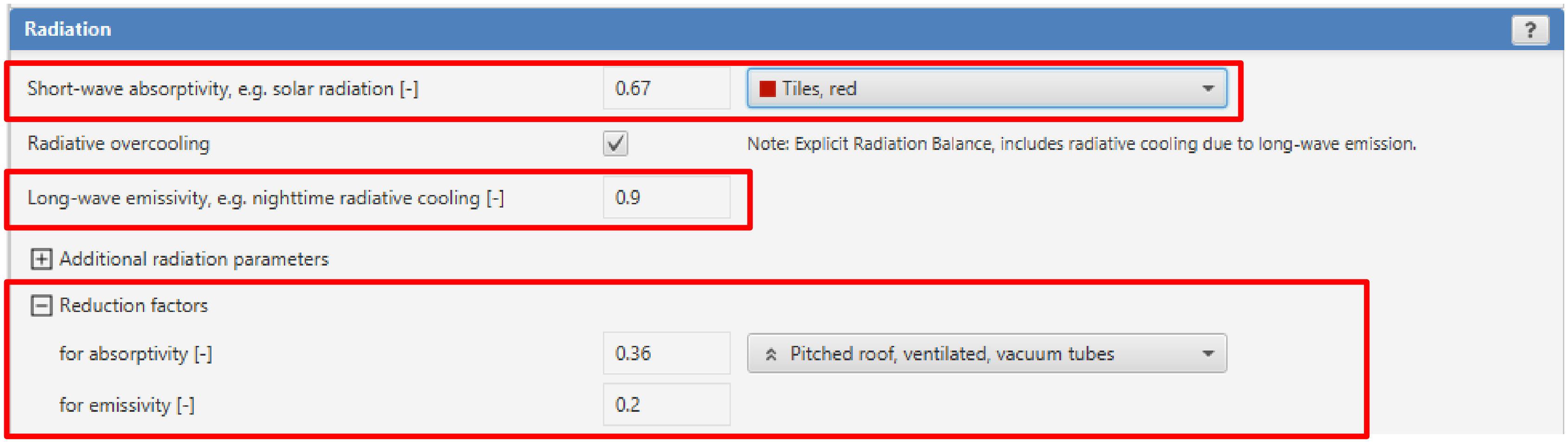
with
a_e: effective absorption coefficient
a: absorption coefficient of the roof cladding
ε_e: effective emission coefficient
ε: emission coefficient of the roof cladding

Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface shaded

Radiation: Reduction factors

Ventilated pitched roof with vacuum tubes [10]



Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface shaded

Radiation: Reduction factors

Ventilated pitched roof with in-roof PV modules [10]

	Coldest position	Middle position	Warmest position
Strong ventilated	$a_e = a_{PV} \cdot 0.7$ $a_e = 0.385$ $\varepsilon_e = \varepsilon_{PV}$ $\varepsilon_e = 0.8$	$a_e = a_{PV} \cdot 0.9$ $a_e = 0.495$ $\varepsilon_e = \varepsilon_{PV}$ $\varepsilon_e = 0.8$	$a_e = a_{PV}$ $a_e = 0.55$ $\varepsilon_e = \varepsilon_{PV}$ $\varepsilon_e = 0.8$
Normal ventilated			
Low ventilated	$a_e = a_{PV} \cdot 0.75$ $a_e = 0.413$ $\varepsilon_e = \varepsilon_{PV}$ $\varepsilon_e = 0.8$		

with

a_e: effective absorption coefficient
$a_{PV} = 0.55$

ε_e: effective emission coefficient
$\varepsilon_{PV} = 0.8$

Note:
Values have not yet been validated!
Use at your own risk.

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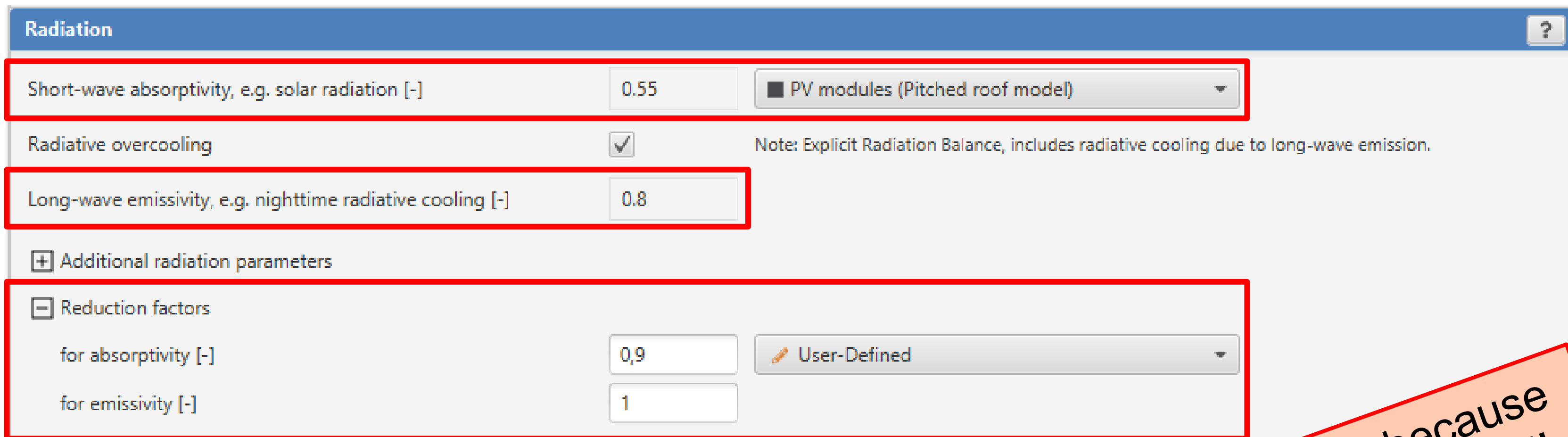
Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface shaded

Radiation: Reduction factors

Ventilated pitched roof with in-roof PV modules [10]



User-defined input is required, because the model has not yet been validated!

Notes on the Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface

Rain

The roofing is assumed to be waterproof, so the absorption of rainwater must be switched off.

Note: The setting for the s_d-value in the boundary condition only affects the diffusion behaviour of the surface and not the liquid water absorption.

Notes on the Input: Indoor Climate

Boundary Conditions (interior) – Climate / Surface

Indoor Climate:

By default, we recommend to use the indoor climate with medium moisture load + 5% for design purposes according to German Standard DIN 4108-3 [4] and EN 15026 [7].

Alternatively, depending on the use of the building, the indoor climate can also be set with low moisture load (according to EN 15026 [7]) or with normal or high moisture load (according to DIN 4108-3 [4] and EN 15026 [7]). Constant or measured conditions can also be set, for example.

Heat Transfer

The heat transfer coefficient on the interior surface is set to 8 W/m²K in accordance with DIN 4108-3 [4].

Notes on the Input: Control

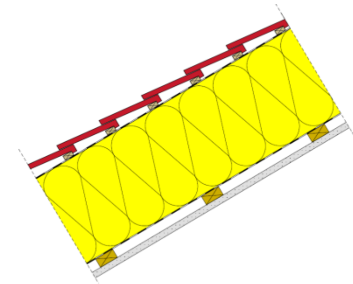
Control

Calculation Period:

It is recommended to start the calculation on October 1st, because the component usually moistens up further in the following winter months before drying to the inside possibly starts in spring. This start date is therefore usually an extra stressing of the component.

The calculation time depends on the time the construction needs to reach steady state conditions. Usually, a calculation time of 5 years is sufficient. In the case of diffusion-open building components, the calculation times tend to be shorter, in the case of diffusion-tight building components, the calculation times tend to be longer.

Notes on the Evaluation: Mineral Wool Insulation



Roofs with mineral wool insulation and underlay membrane

These assemblies do not have any moisture-sensitive materials in the standard cross-section (insulated cavity). Below the roofing felt, due to the higher diffusion resistance compared to the insulation, temporarily increased moisture or condensation may occur.

The amount of condensation occurring below the roofing felt is used for result evaluation. For this purpose, the maximum water content in [kg/m³] in the outer area of the mineral wool insulation is evaluated. The guideline "Assessing the risk of interstitial condensation runoff" presents the condensation water retention capacity (RC) as a practical limit value and describes how to assess the risk of condensation water runoff using hygrothermal simulation.

The assessment method recommended until 2023 for hydrophobic mineral fiber insulation materials has been replaced by new findings and extended to other fiber insulation materials.

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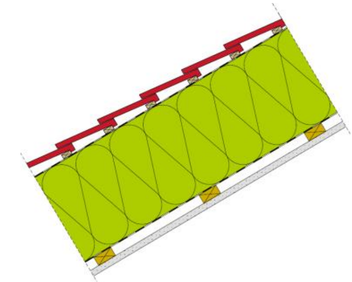
Notes on the Evaluation: Wood Fibre Insulation

Roofs with wood fibre insulation and underlay membrane

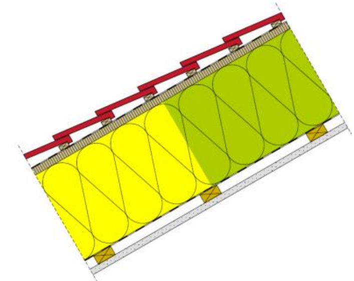


For assemblies with wood fibre insulation between the rafters, an evaluation of the wood moisture in the wood fibre insulation is performed.

For this purpose, the wood moisture content is evaluated in [% by mass] in the outer centimeter of the wood-fiber insulation in the settled state. The settled stage has been reached if the course of the water content does not change between the years any longer.

For evaluation purposes, the general limit value of 18 % by mass from DIN 68800 [2] can be used, which may be exceeded by a maximum of 20 % by mass for up to three months a year. Alternatively, the manufacturer can guarantee the maximum moisture content for which his product can be used.

Notes on the Evaluation: Wooden Sheathing



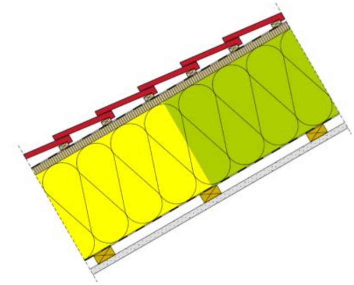
Roofs with insulation and wooden sheathing

For assemblies with exterior wooden sheathing, the insulation between the rafters (mineral wool or wood fibre) is evaluated according to slide 29+30.

For the evaluation of the wooden sheathing, the course of the wood moisture content in [% by mass] in the wooden sheathing in the settled state is used. The value of 20 % by mass for wood and 18 % by mass for wood-based materials specified in DIN 68800 [2] is recommended as the limit value. If this limits are met, no further evaluation is necessary.

If the wood moisture exceeds the limit value according to DIN 68800 [2], an evaluation according to the WTA Guideline 6-8 [9] can also be carried out for solid wood. This allows a more precise evaluation considering the temperature and humidity conditions.

Notes on the Evaluation: Wooden Sheathing



Roofs with insulation and wooden sheathing

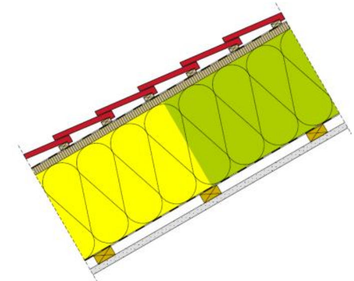
Evaluation according to DIN 68800 [2]

Critical moisture conditions regarding damage to the wood can occur, if the moisture content limits of 20 % by mass for wood and 18 % by mass for wood-based materials are exceeded over a long period.

However, this limit value includes high safety margins and, in contrast to the WTA guideline 6-8 [9], no specifications are made for the evaluation area. In the case of thin wooden sheathings, the entire section of the sheathing shall be evaluated, otherwise the most critical 1 cm thick section should be used in accordance with the WTA evaluation.

If the wood moisture remains below the limit values (see above), no further evaluation is necessary.

Notes on the Evaluation: Wooden Sheathing



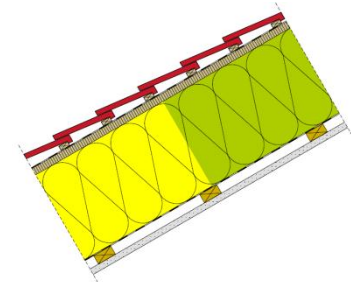
Roofs with insulation and wooden sheathing

Evaluation according to WTA Guideline 6-8 [9]

If the limit value for wood of 20 % by mass according to DIN 68800 [2] is exceeded, also an evaluation according to the WTA 6-8 [9] can be carried out. Here, the evaluation of wood structures is carried out based on temperature-dependent limit values for the relative pore air humidity in a 1 cm thick layer at the critical position of the wood. This allows a more accurate and realistic evaluation.

Please note: This evaluation cannot be used for wood-based materials, as other limit values for rotting processes may apply here.

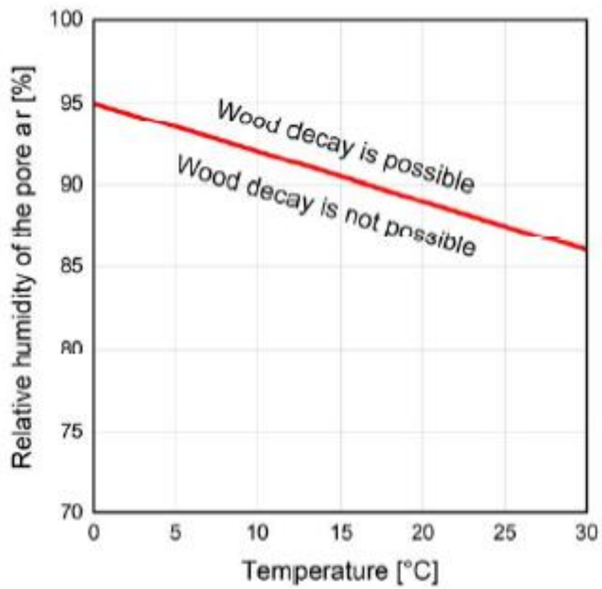
Notes on the Evaluation: Wooden Sheathing



Roofs with insulation and wooden sheathing

Limit curve for wood decay depending on temperature (x-axis) and relative humidity (y-axis) according to WTA 6-8 [9].

At conditions below the red limit line, wood decay is not possible in solid wood.



Literature

[1] Kölsch, Ph.: Hygrothermal simulation of ventilated pitched roofs with effective transfer parameters. 01/2017. (Guideline for the simulation of ventilated pitched roofs with effective transfer parameters)

[2] DIN 68800-2: Holzschutz – Teil 2: Vorbeugende bauliche Maßnahmen im Hochbau. Beuth Verlag, February 2022.

[3] Zirkelbach, D.; Künzel, H.M.; Schafaczek, B. und Borsch-Laaks, R.: Dampfkonvektion wird berechenbar – Instationäres Modell zur Berücksichtigung von konvektivem Feuchteeintrag bei der Simulation von Leichtbaukonstruktionen. Proceedings 30. AIVC Conference, Berlin 2009.

[4] DIN 4108-3: Klimabedingter Feuchteschutz, Anforderungen, Berechnungsverfahren und Hinweise für Planung und Ausführung. Beuth Verlag, March 2024.

[5] Research Report: Energieoptimiertes Bauen: Klima- und Oberflächenübergangsbedingungen für die hygrothermische Bauteilsimulation. IBP-Bericht HTB-021/2016. Durchgeführt im Auftrag vom Projektträger Jülich (PTJ UMW). July 2016.

[6] WTA-Guideline 6-2/E: Simulation of heat and moisture transfer. October 2025.

[7] EN 15026: Hygrothermal performance of building components and building elements – Assessment of moisture transfer by numerical simulation. Beuth Verlag, December 2023.

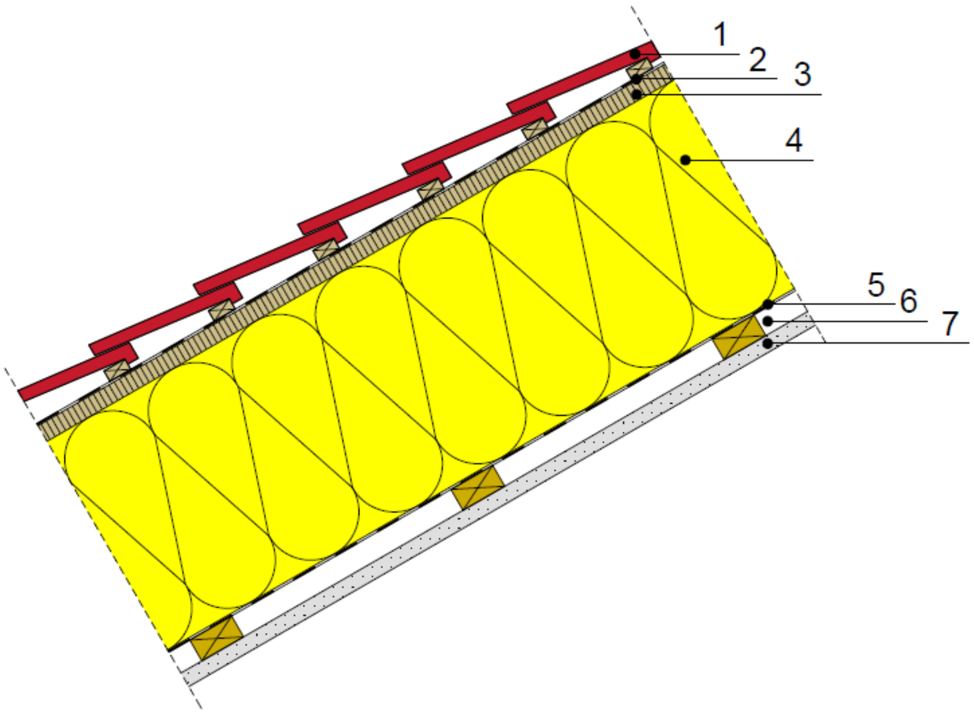
[8] EN ISO 13788: Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods. Beuth Verlag, May 2013.

[9] WTA-Guideline 6-8: Feuchtetechnische Bewertung von Holzbauteilen – Vereinfachte Nachweise und Simulationen. August 2016.

[10] Kölsch, P.: Hygrothermische Simulation von Steildächern mit Solaranlagen. Bauphysik 48, H.2, S.143-157. 2026. https://doi.org/10.1002/bapi.70041. Also available under: WUFI → Literatur

Example A: Pitched roof with vapour-permeable underlay membrane

Using the example of a pitched roof with a vapour-permeable underlay membrane, the following describes the procedure for input and evaluation of pitched roof assemblies.



1 Roofing and Battens
2 Weather Protection Membrane
3 Wooden Sheathing
4 Insulation
5 Vapour Retarder
6 Installation Layer
7 Gypsum Board

Example A: Assembly

Assembly (from outside to inside):

• Red Concrete Tiles		
• Weather Protection Membrane (s_d = 0.1 m)		
• Wooden Sheathing (Softwood)	0.025	m
• Mineral Wool (heat cond.: 0.04 W/mK)	0.24	m
• Moisture-Variable Vapour Retarder (Intello Plus)	0.001	m
• Air Layer	0.02	m
• Gypsum Board	0.0125	m

Example A: Boundary Conditions

Boundary Conditions:

- Pitched roof (30° to the North)
- Red concrete tiles
  (a = 0.67; ε = 0.9)
- Normal ventilated roof (middle position)
- Outdoor climate: Holzkirchen
- Indoor climate: medium moisture load + 5 %
- Air tightness of the envelope: q_{50} = 3 m³/m³h
- Stack Height: 5 m

Example A: Evaluation Matrix

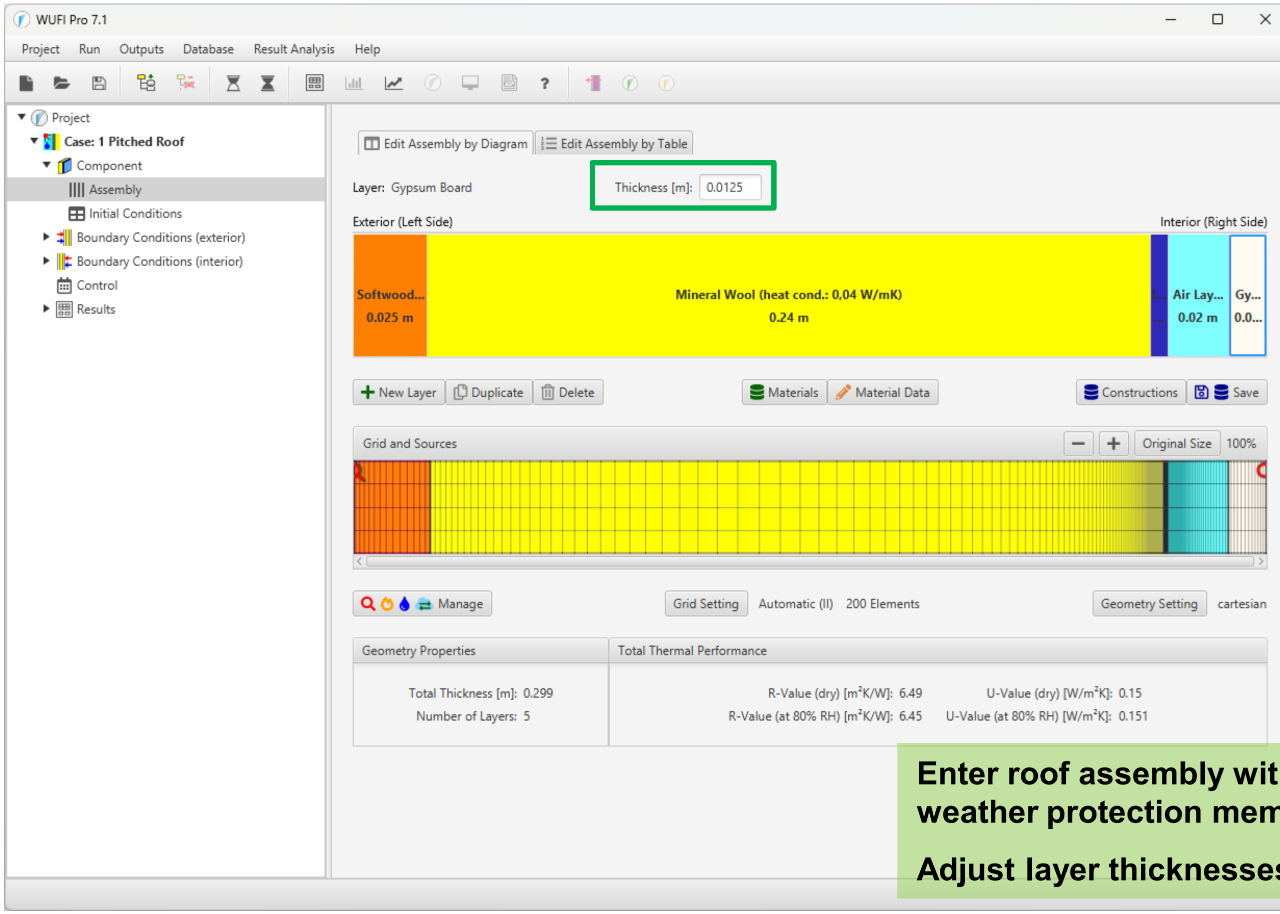
Evaluation Matrix:

The following matrix shows the evaluation criteria relevant to this design.

	Criteria
1) Numerics	No or only small differences in balances (especially in the case of convergence failures)?
	Consistent, periodic course of total water content?
2) Evaluation parameters	Total water content reach dynamic equilibrium or decreases?
	Risk of wood decay in the wooden sheathing? (limit values according to DIN 68800 or WTA 6-8)
	Amount of condensation in the insulation layer?

Example A: Component Assembly

Input: Component - Assembly



Enter roof assembly without roofing tiles and weather protection membrane

Adjust layer thicknesses if necessary

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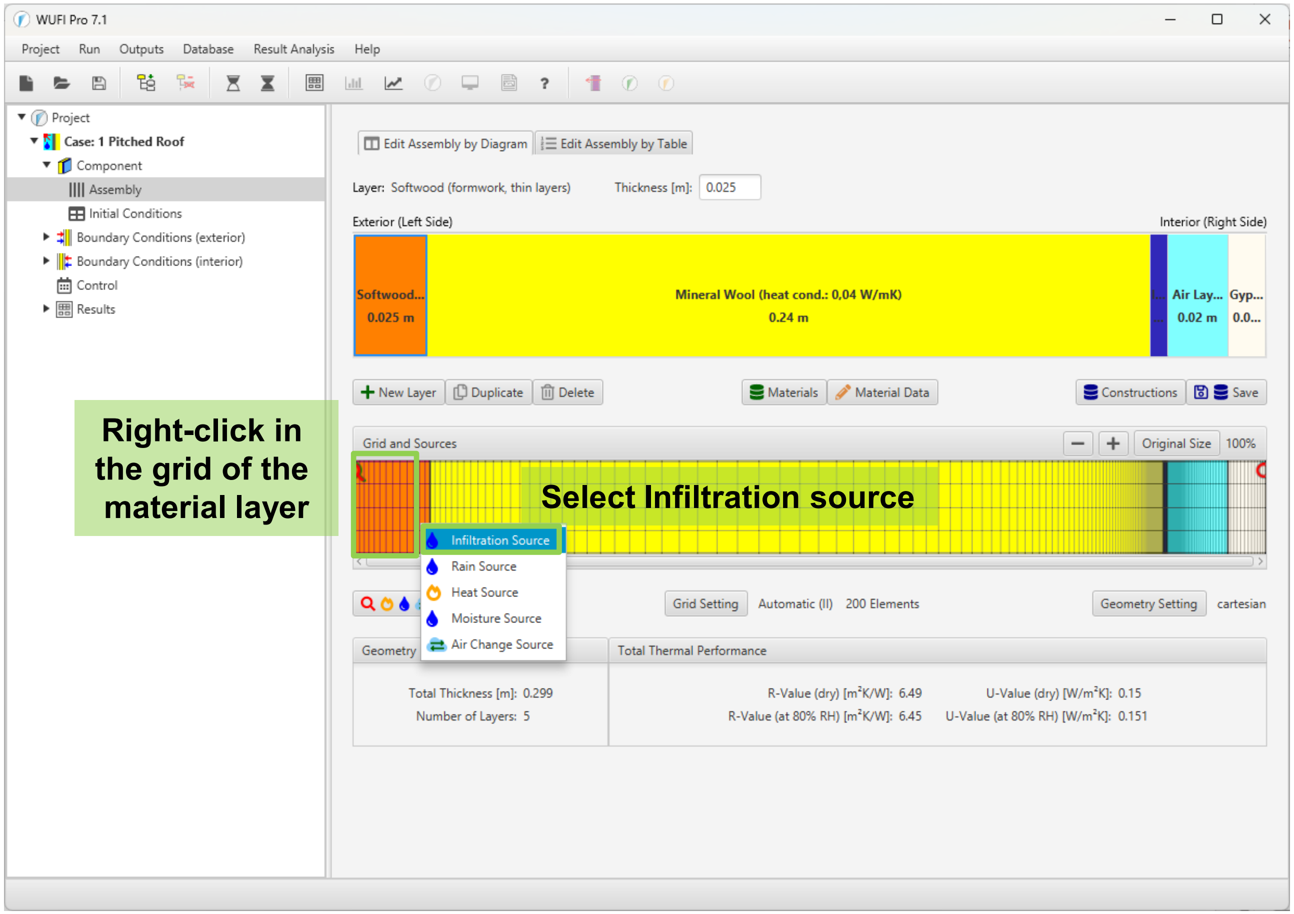
Example A: Infiltration Source

Input: Component - Assembly

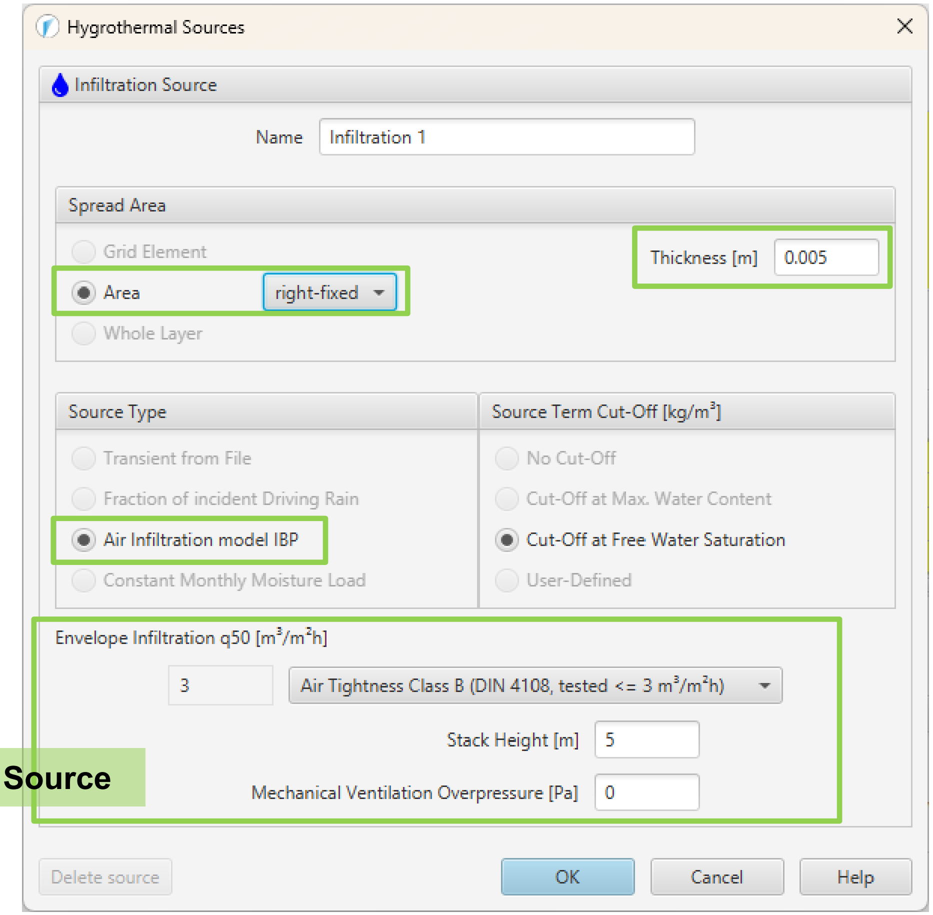
Infiltration source in the wooden sheathing according to EN 15026



Example A: Infiltration Source

Input: Component - Assembly

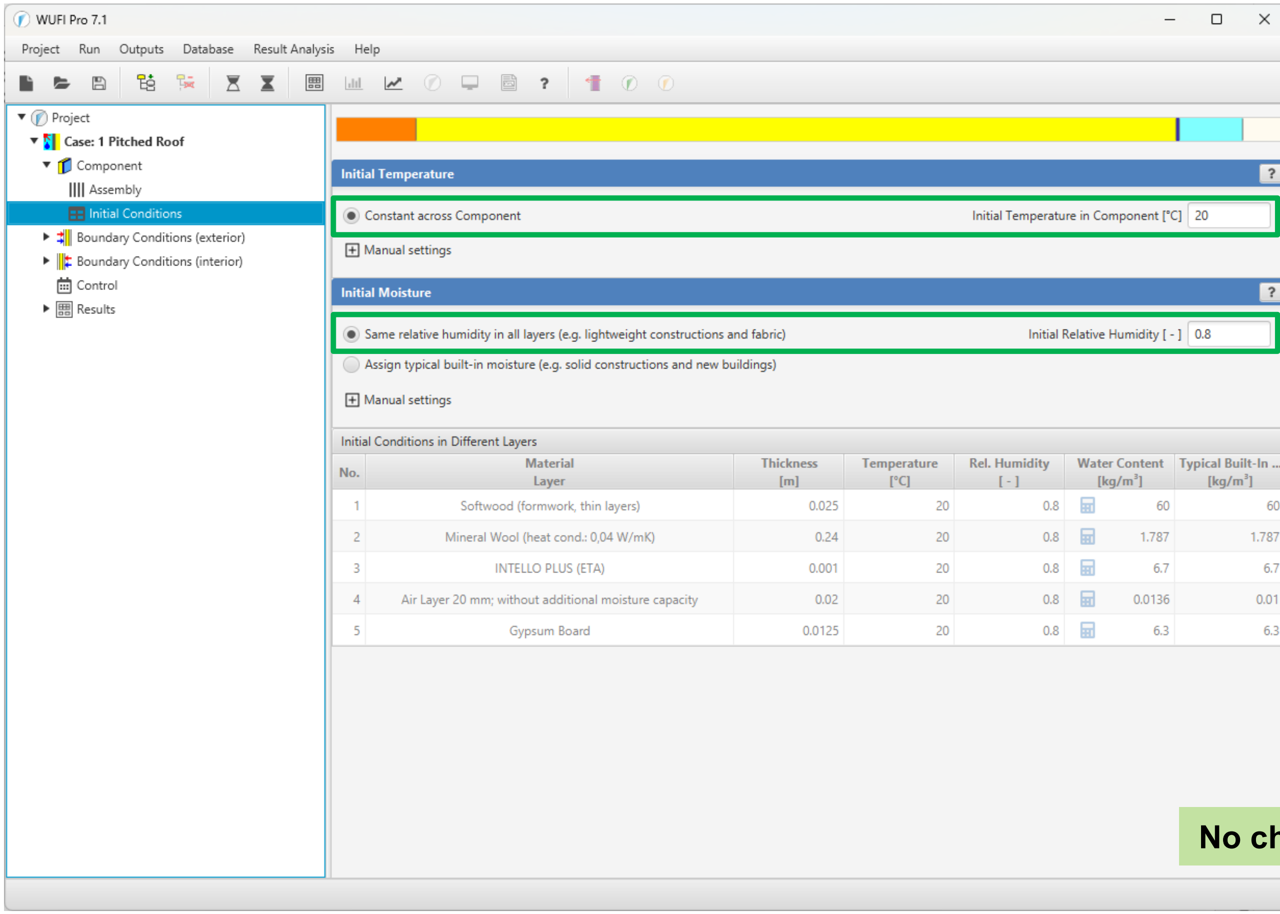
Moisture Source in the interior 5 mm of the wooden sheathing.



Adjust Infiltration Source

Example A: Initial Conditions

Input: Component – Initial Conditions



No changes required

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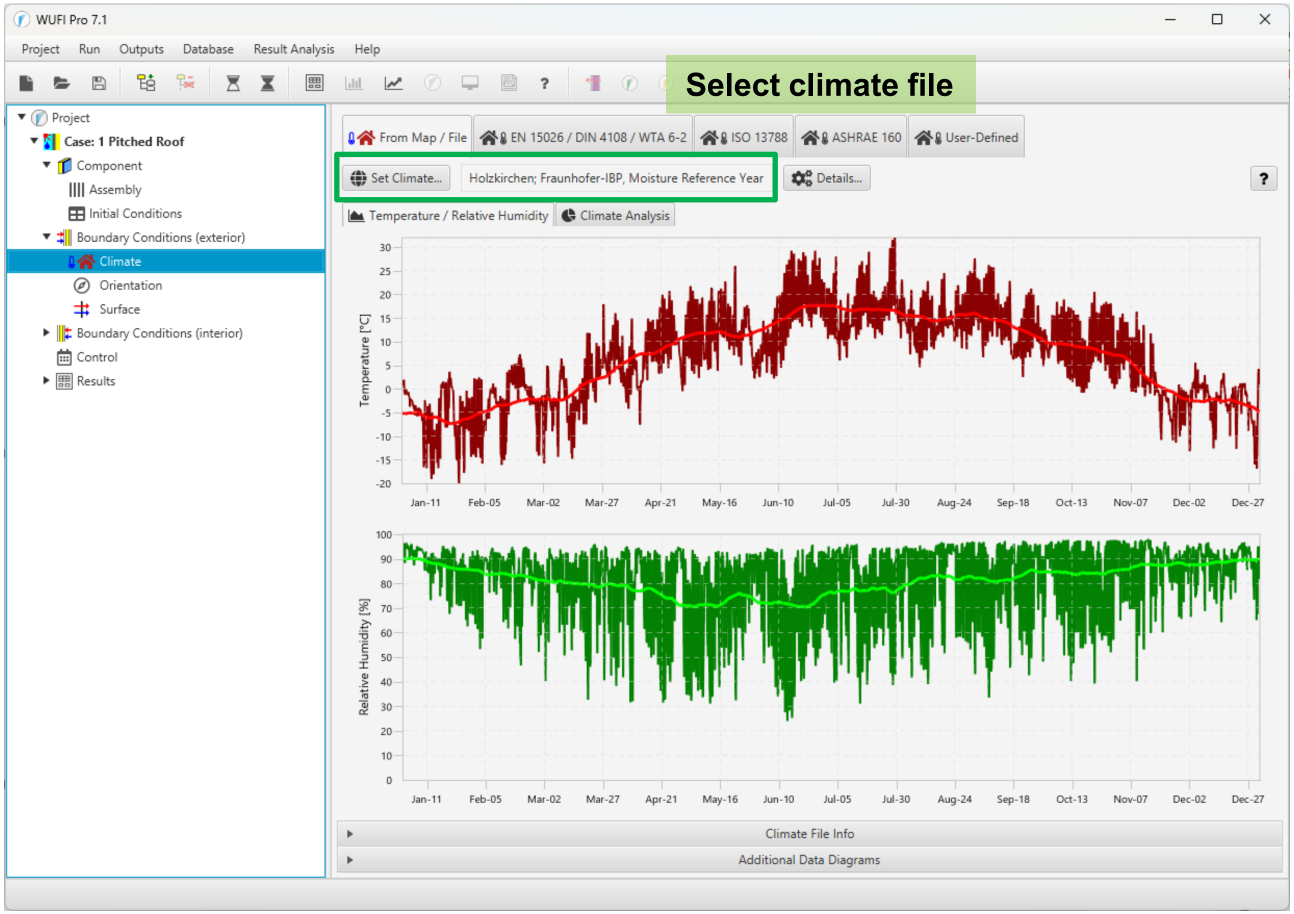
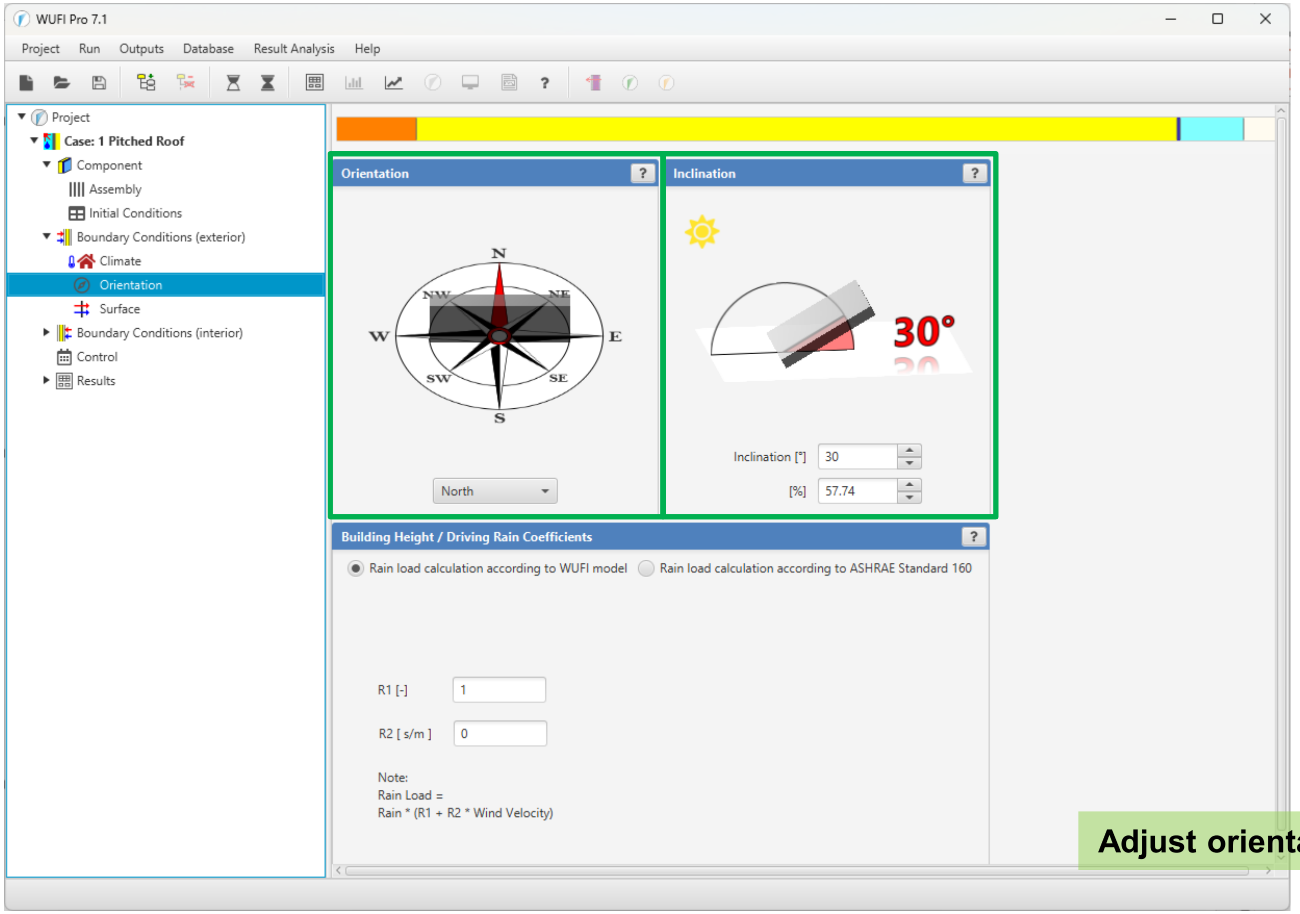
Example A: Outdoor Climate

<u>Input:</u> Boundary Conditions (exterior) – Climate



Example A: Orientation / Inclination

<u>Input:</u> Boundary Conditions (exterior) – Orientation

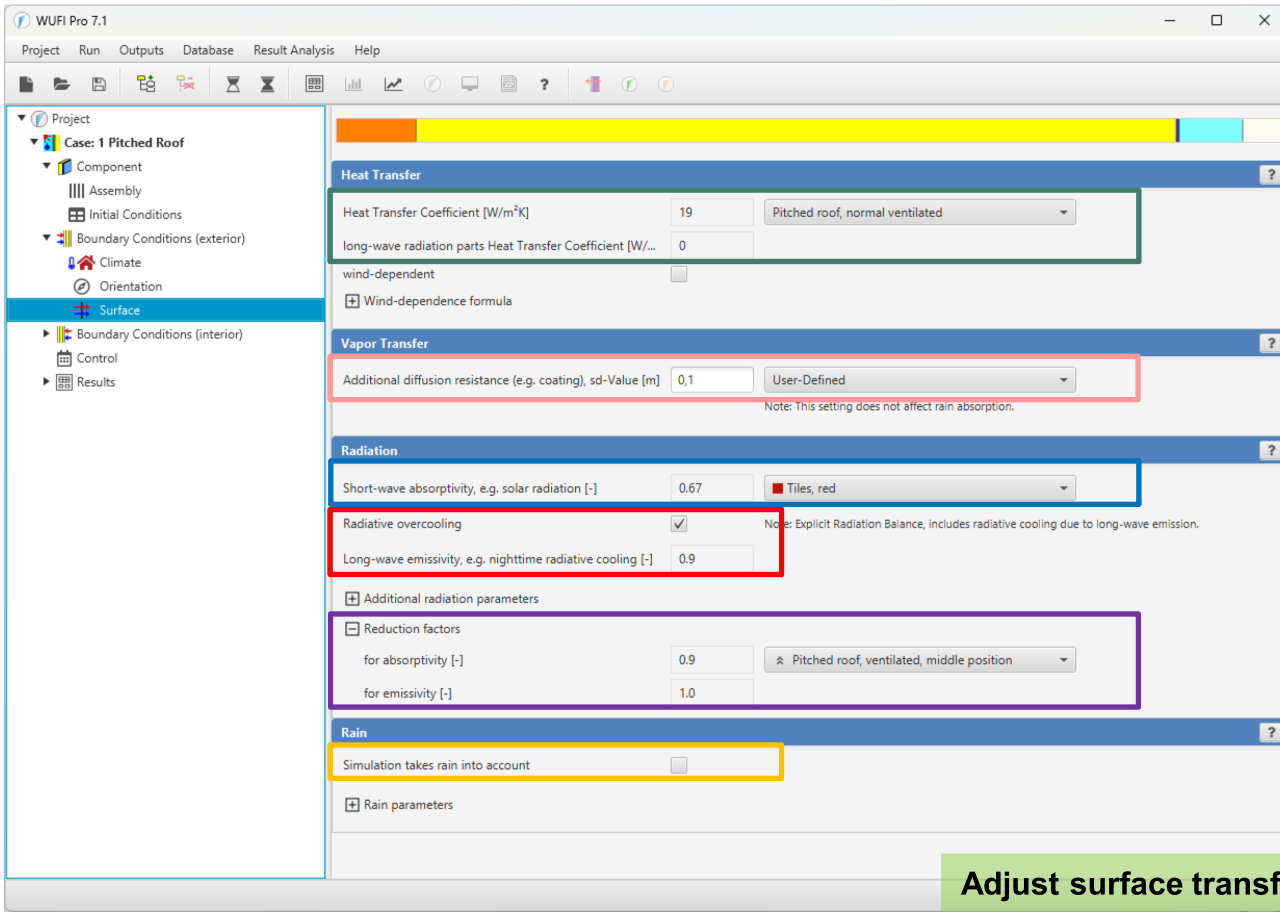


Adjust orientation and inclination

Fraunhofer IBP

Example A: Surface Transfer Coefficients (exterior)

Input: Boundary Conditions (exterior) – Surface



Heat transfer coefficient (from list: pitched roof, normally ventilated)

Weather protection membrane (s_d = 0,1 m)

Absorptivity (from list: Tiles, red)

Consider Radiative overcooling

Reduction factors (from list: Pitched roof, ventilated, middle position)

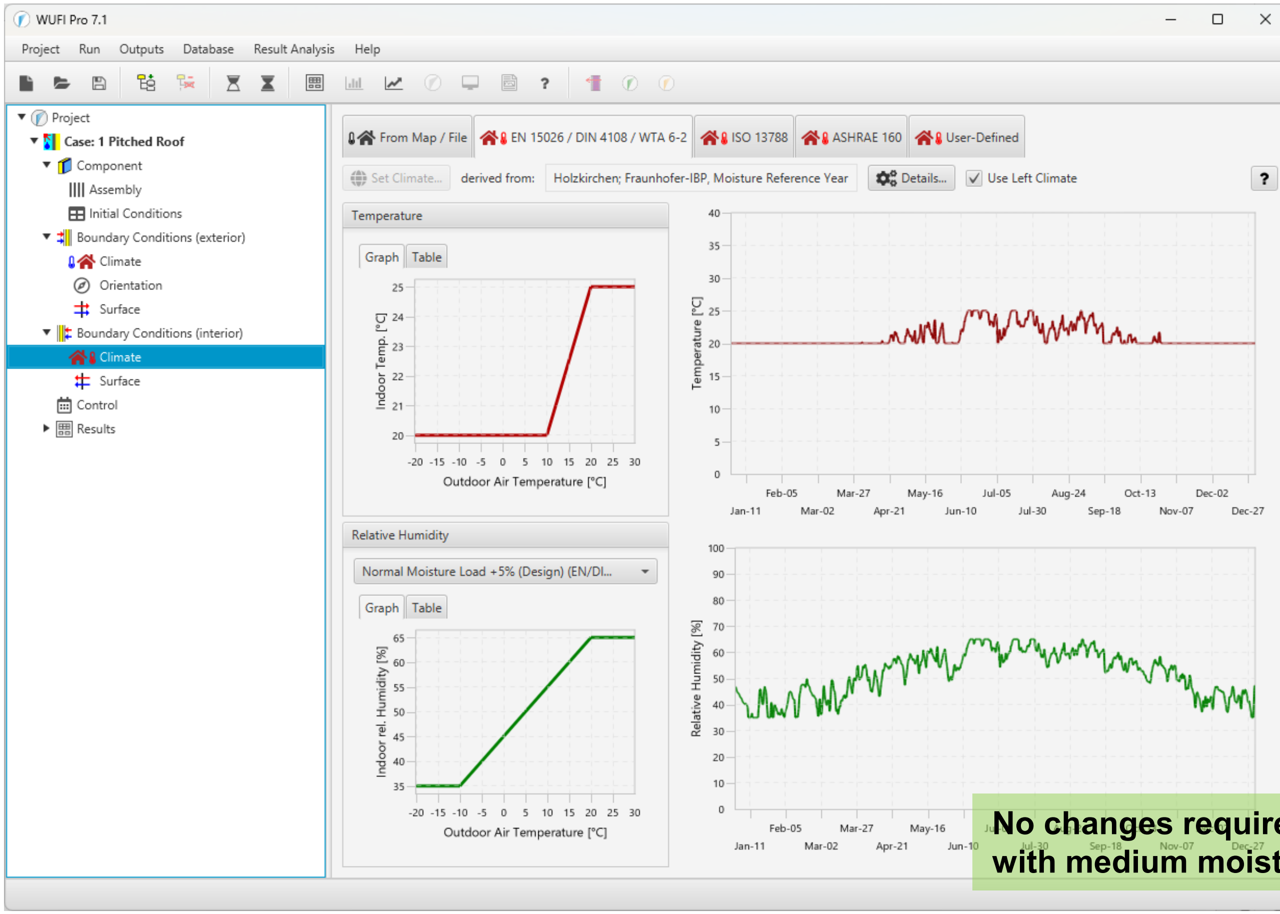
No rainwater absorption

Adjust surface transfer coefficients!

Fraunhofer IBP

Example A: Indoor Climate

Input: Boundary Conditions (interior) – Climate

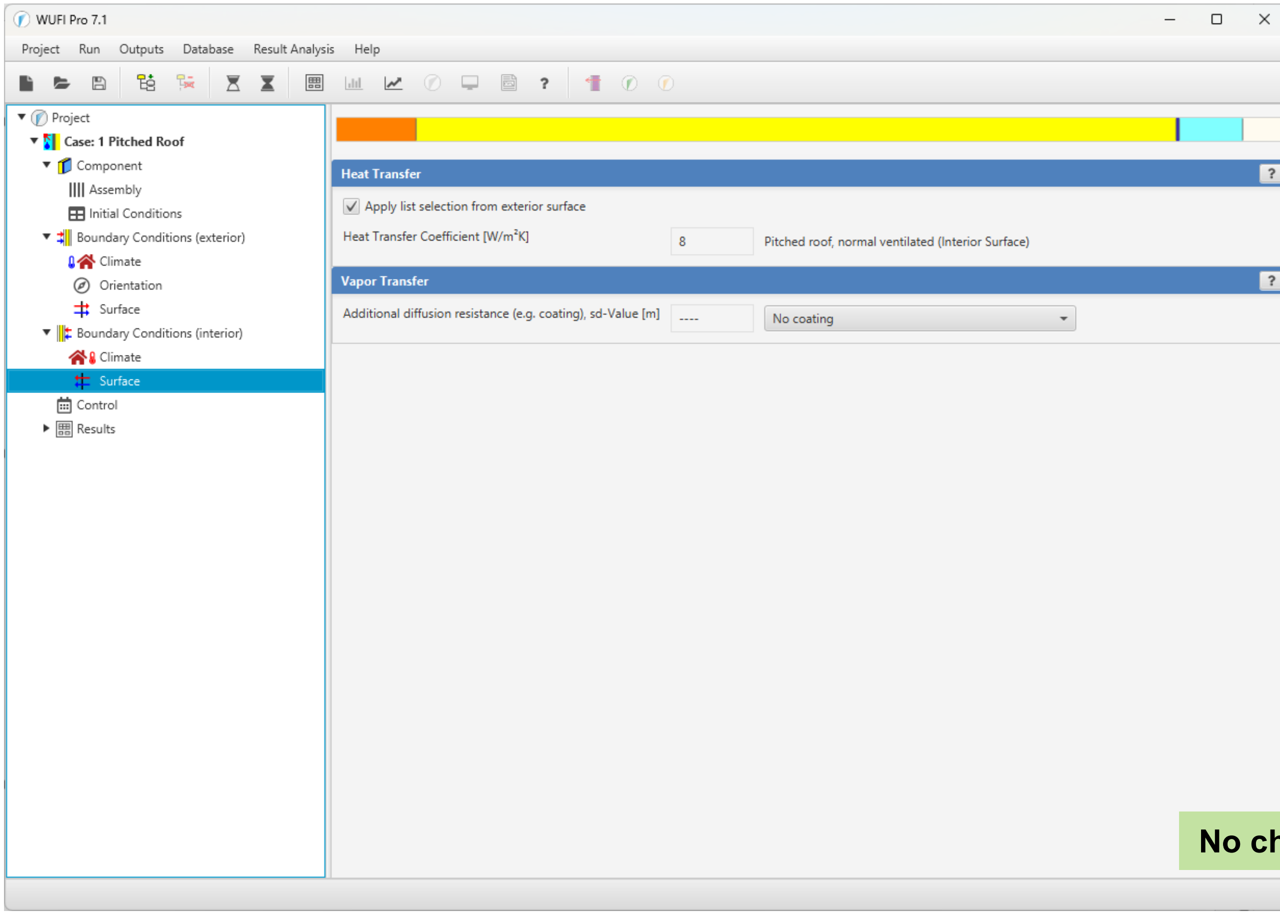


No changes required for indoor climate with medium moisture load + 5 %

Fraunhofer IBP

Example A: Surface Transfer Coefficients (interior)

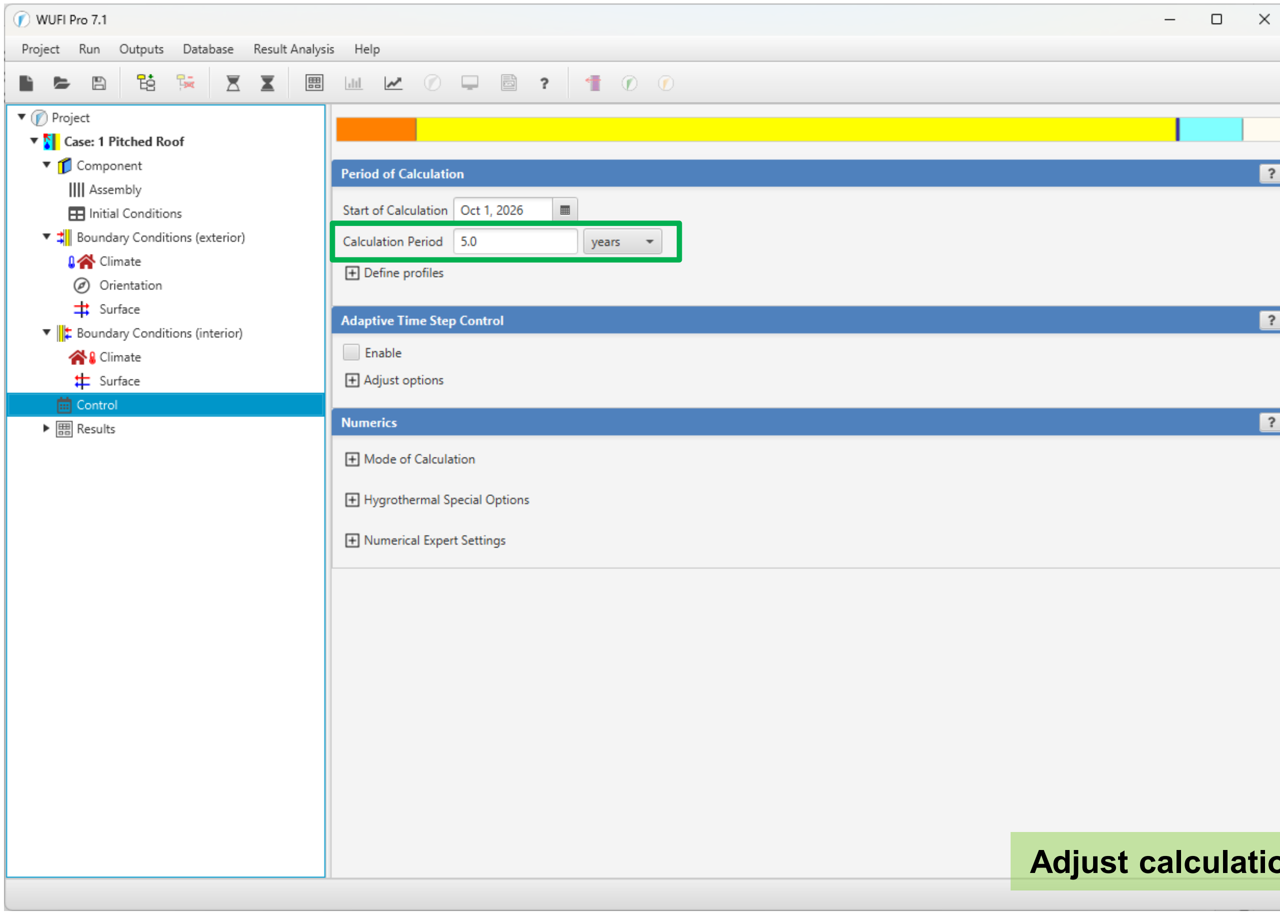
Input: Boundary Conditions (interior) – Surface



No changes required

Example A: Calculation Period and Numerics

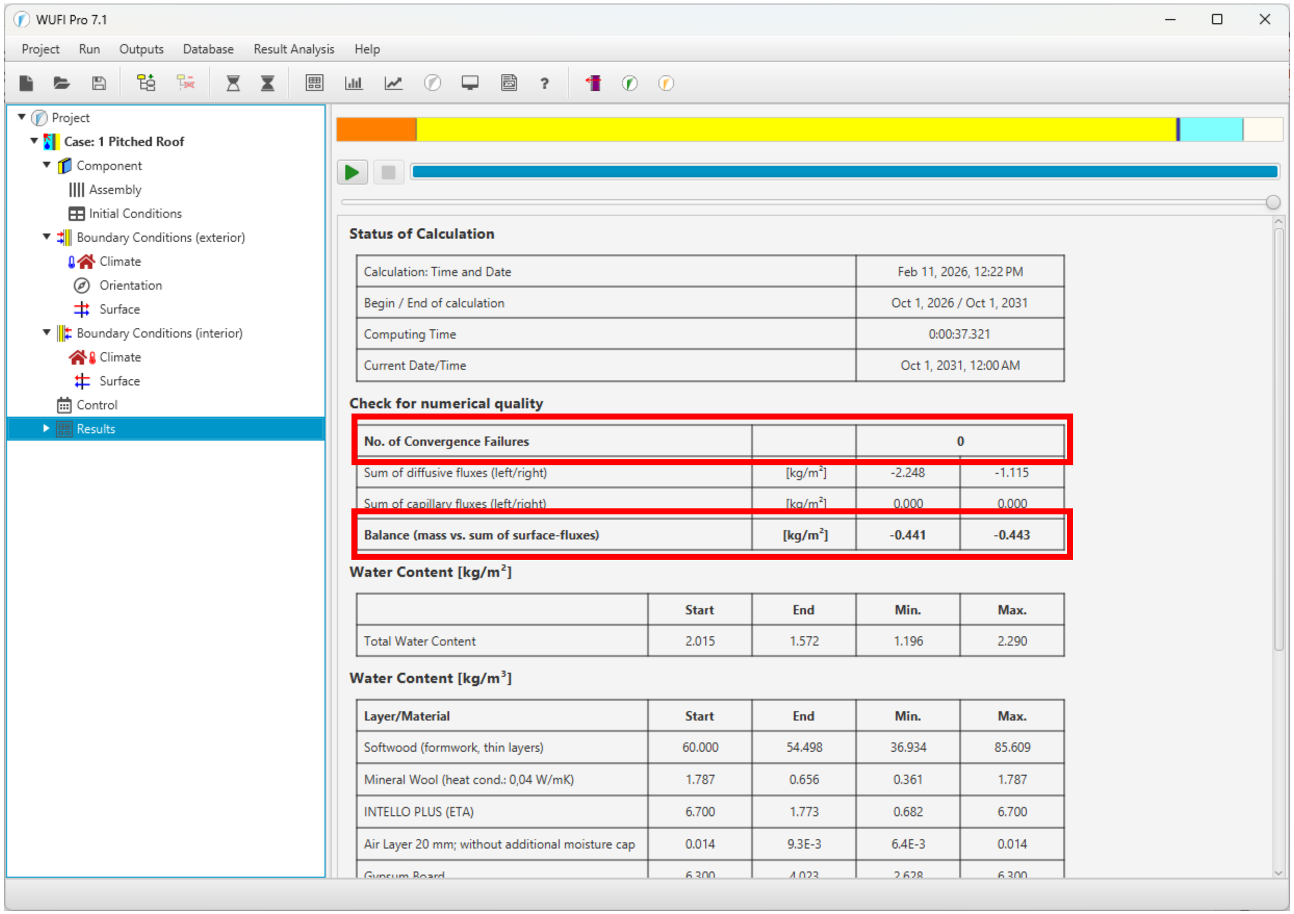
<u>Input:</u> Control



Adjust calculation period if necessary

Example A: Evaluation – Check for numerical quality

Evaluation:



Status of Calculation

Calculation: Time and Date	Feb 11, 2026, 12:22 PM
Begin / End of calculation	Oct 1, 2026 / Oct 1, 2031
Computing Time	0:00:37.321
Current Date/Time	Oct 1, 2031, 12:00 AM

Check for numerical quality

No. of Convergence Failures		**0**	
Sum of diffusive fluxes (left/right)	[kg/m²]	-2.248	-1.115
Sum of capillary fluxes (left/right)	[kg/m²]	0.000	0.000
Balance (mass vs. sum of surface-fluxes)	**[kg/m²]**	**-0.441**	**-0.443**

Water Content [kg/m²]

	Start	End	Min.	Max.
Total Water Content	2.015	1.572	1.196	2.290

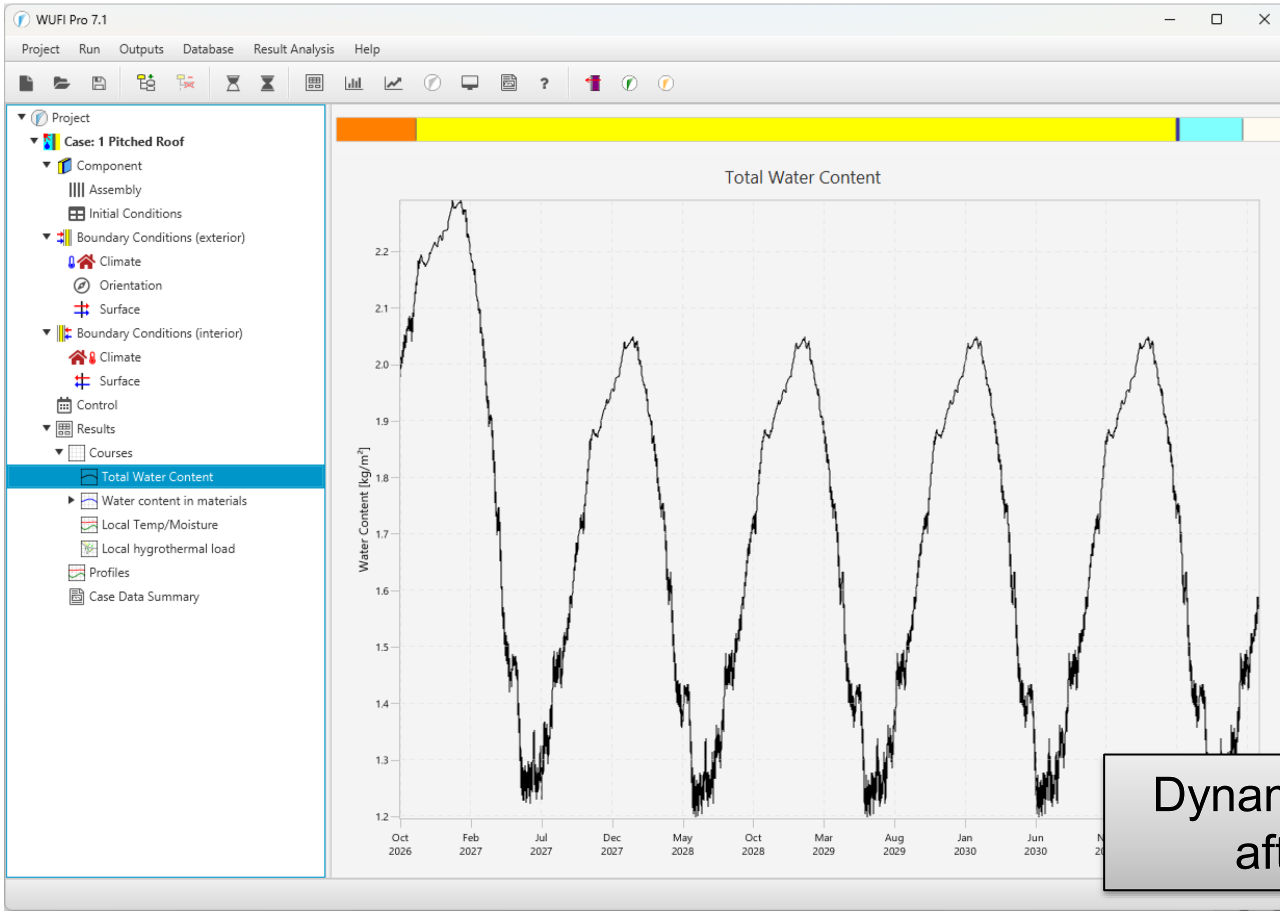
Water Content [kg/m³]

Layer/Material	Start	End	Min.	Max.
Softwood (formwork, thin layers)	60.000	54.498	36.934	85.609
Mineral Wool (heat cond.: 0,04 W/mK)	1.787	0.656	0.361	1.787
INTELLO PLUS (ETA)	6.700	1.773	0.682	6.700
Air Layer 20 mm; without additional moisture cap	0.014	9.3E-3	6.4E-3	0.014
Gypsum Board	6.300	4.023	2.628	6.300

Fraunhofer IBP

Example A: Evaluation – Total Water Content

<u>Evaluation:</u>
Total Water Content

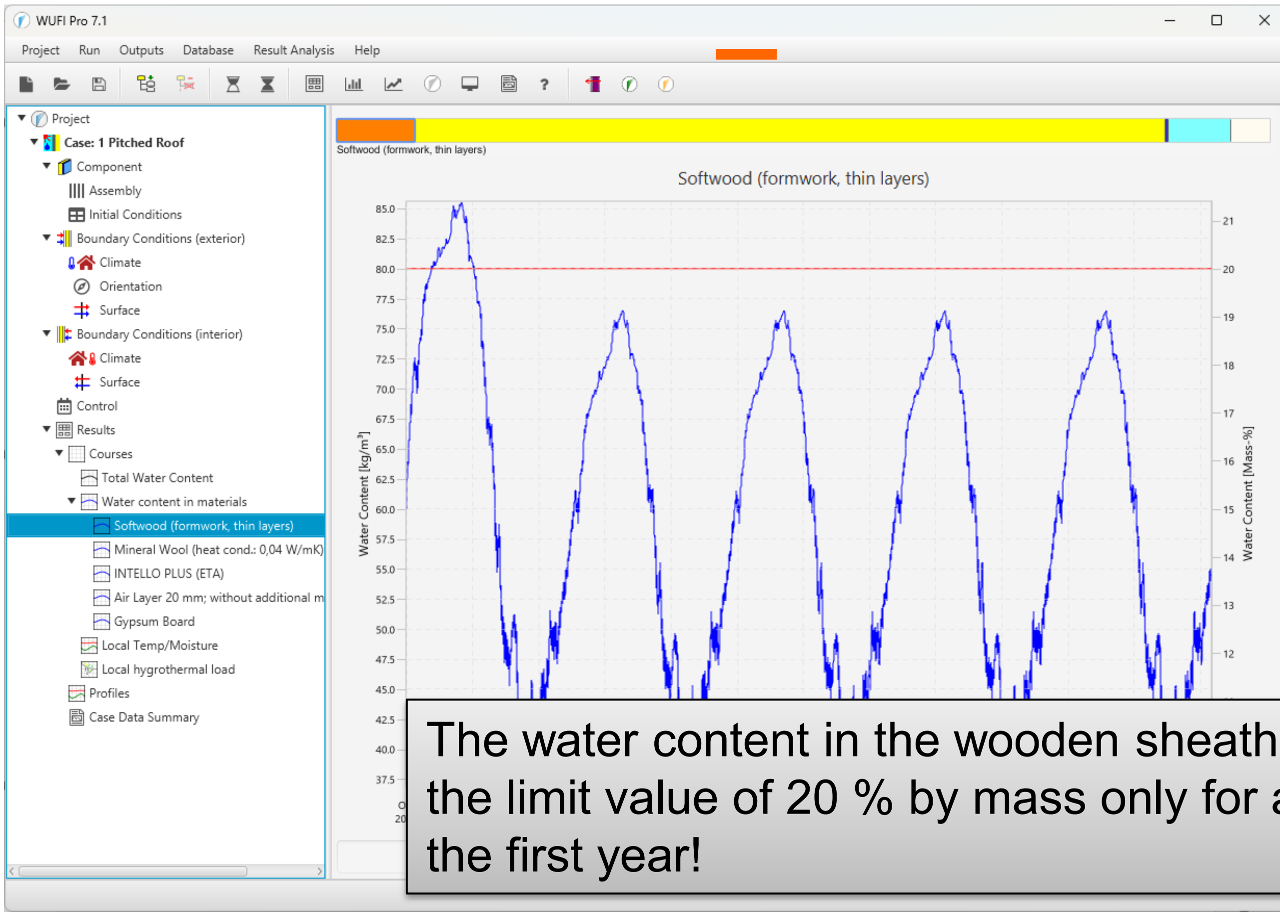


Dynamic equilibrium after 2 years

Example A: Evaluation – Wooden Sheathing

Evaluation:

Moisture Content in the Wooden Sheathing

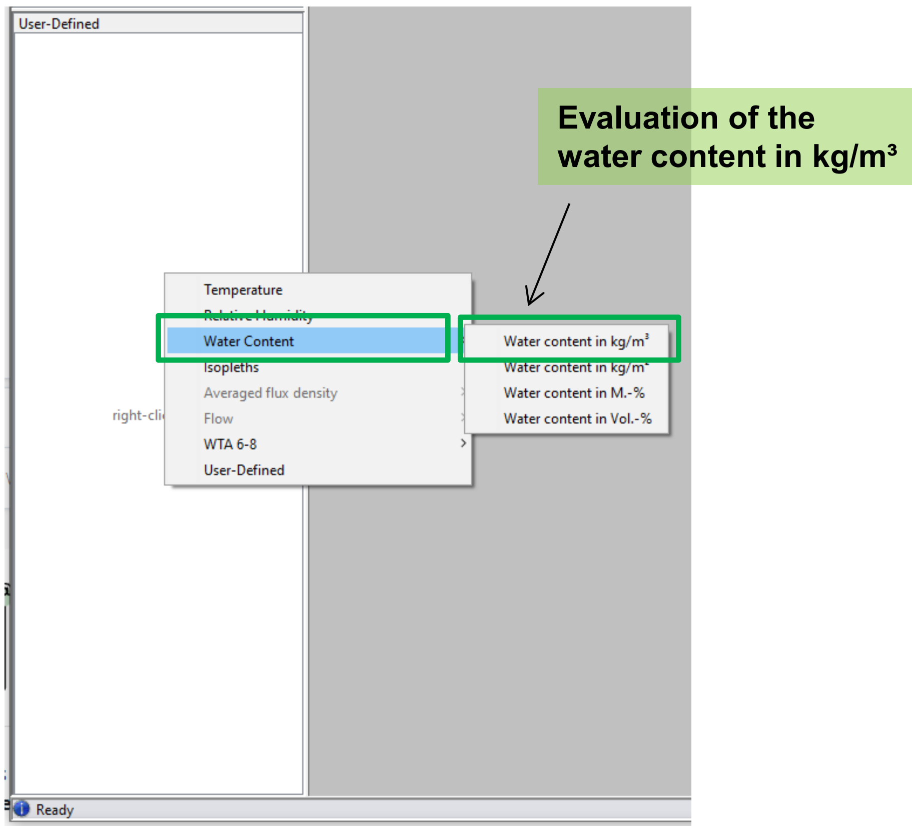


The water content in the wooden sheathing exceeds the limit value of 20 % by mass only for a short time in the first year!

Example A: Evaluation – Amount of Condensation

Evaluation:
Amount of condensation in the mineral wool insulation

→ Evaluation of the water content in the outer centimetre of the insulation

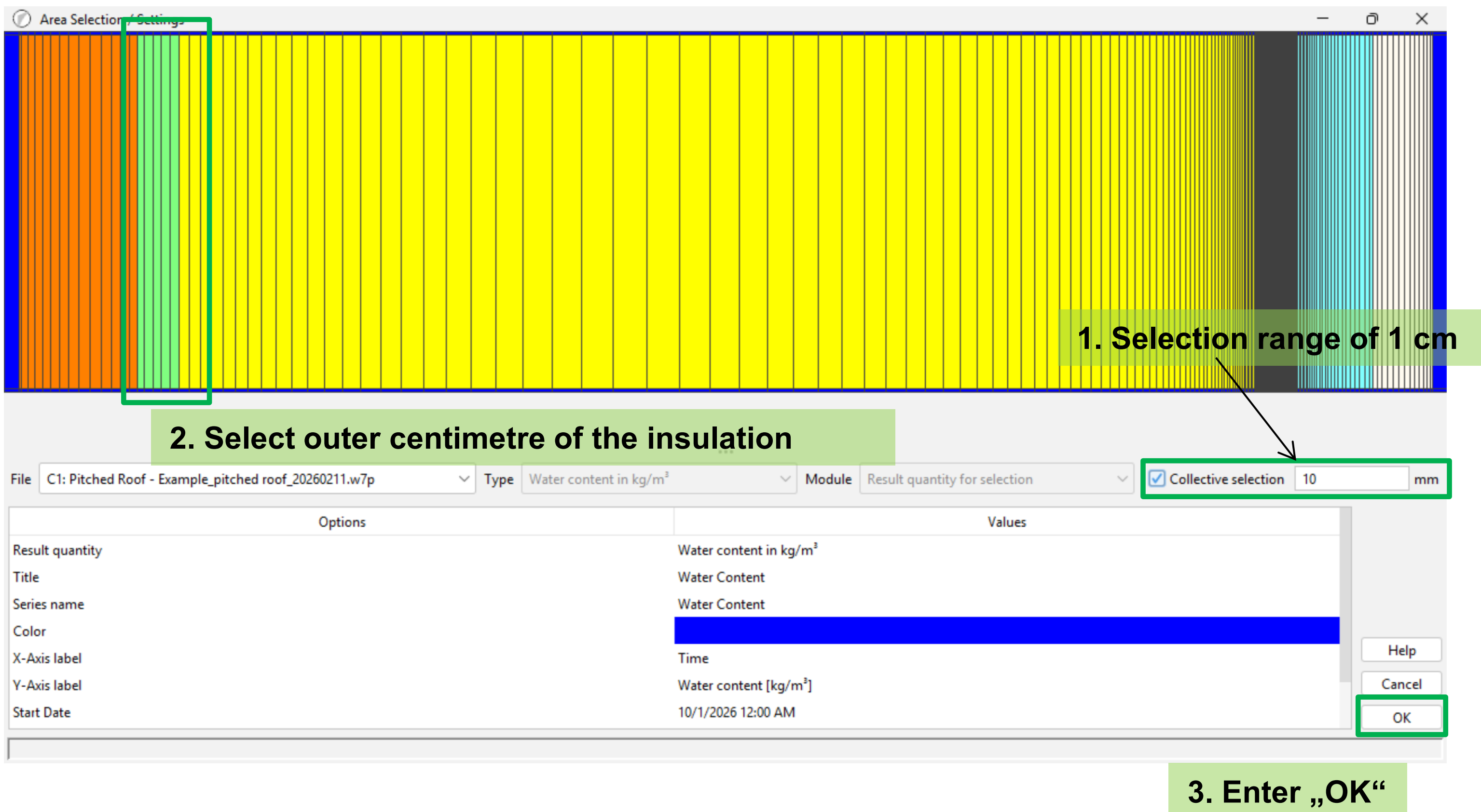


Note:
Further information, including information on inclination-dependent limit values, can be found in the guideline:
Guideline for assessing the risk of interstitial condensation runoff

Example A: Evaluation – Amount of Condensation

Evaluation: Amount of condensation in the mineral wool insulation

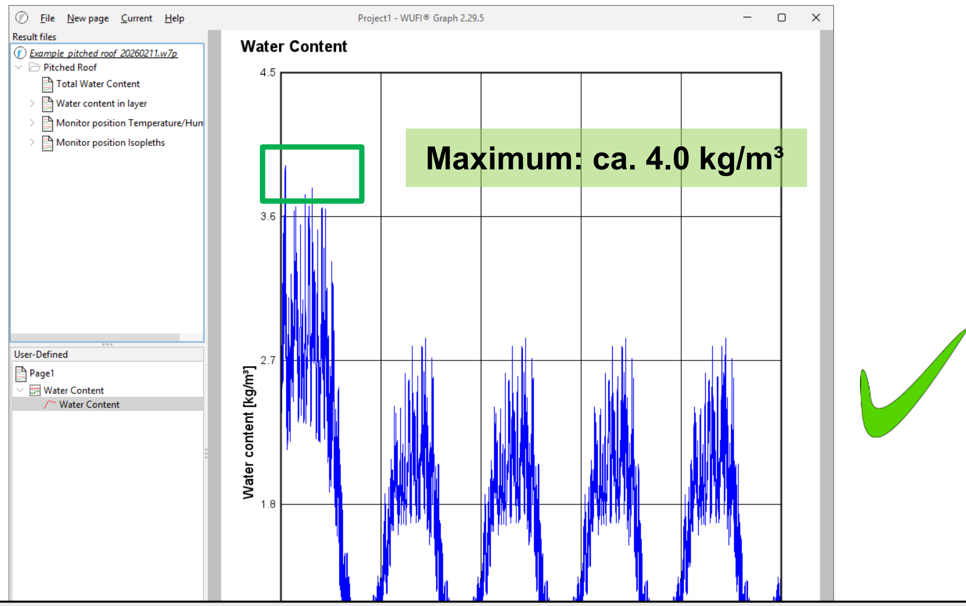
→ Evaluation of the water content in the outer centimetre of the insulation



Example A: Evaluation – Amount of Condensation

Evaluation: Amount of condensation in the mineral wool insulation

→ Evaluation of the water content in the outer centimetre of the insulation



Maximum water content = 4.0 kg/m³

4.0 kg/m³ * 0.01 m (layer thickness) = 0.040 kg/m² = 40 g/m²

→ Condensation remains below the minimum limit value of 100 g/m² (≙ minimum retention capacity)

Example A: Evaluation – Final Evaluation

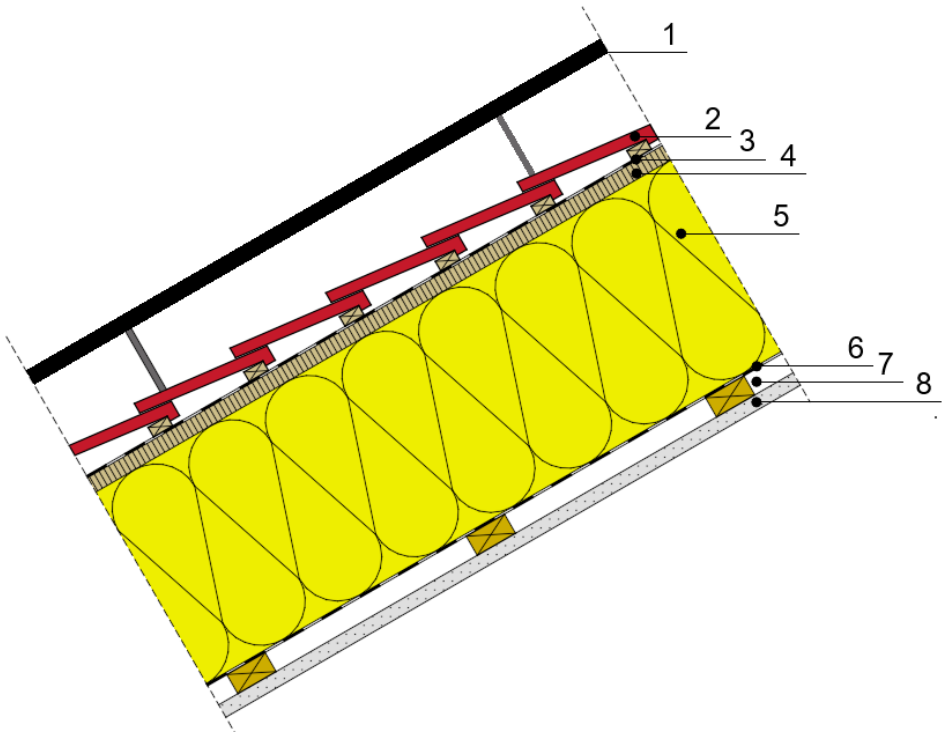
Final Evaluation:

	Criteria	Evaluation
1) Numerics	No or only small differences in balances (especially in the case of convergence failures)?	✓
	Consistent, periodic course of total water content?	✓
2) Evaluation parameters	Total water content reach dynamic equilibrium or decreases?	✓
	Risk of wood decay in the wooden sheathing? (limit values according to DIN 68800 or WTA 6-8)	✓
	Amount of condensation in the insulation layer?	✓

Construction unproblematic from the moisture point of view!

Example B: Pitched roof with vapour-retardant underlay membrane

Using the example of a pitched roof with a vapour-retardant underlay membrane, this section explains the procedure for considering rooftop PV modules. Finally, a hygrothermal assessment of the roof assembly is carried out, comparing configurations with and without rooftop PV modules.



1 Rooftop PV Modules
2 Roofing and Battens
3 Bitumen Membrane
4 Wooden Sheathing
5 Insulation
6 Moisture-Variable Vapour Retarder
7 Installation Layer
8 Gypsum Board

Example B: Assembly

Assembly (from outside to inside):

• Rooftop PV Modules		
• Red Concrete Tiles		
• Bitumen Membrane (s_d = 100 m)		
• Wooden Sheathing (Softwood)	0.025	m
• Mineral Wool (heat cond.: 0.04 W/mK)	0.24	m
• ISOVER Vario XtraSafe	0.001	m
• Air Layer	0.02	m
• Gypsum Board	0.0125	m

Example B: Boundary Conditions

Boundary Conditions:

- Pitched roof (40° to the East)
- Red concrete tiles ($a = 0.67$; $\varepsilon = 0.9$)
  or
  PV Modules ($a_{PV} = 0.55$; $\varepsilon_{PV} = 0.8$)
- Normal ventilated roof (middle position)
- Outdoor climate: Holzkirchen
- Indoor climate: medium moisture load + 5 %
- Air tightness of the envelope: $q_{50} = 3$ m³/m³h
- Stack Height: 5 m

Example B: Evaluation Matrix

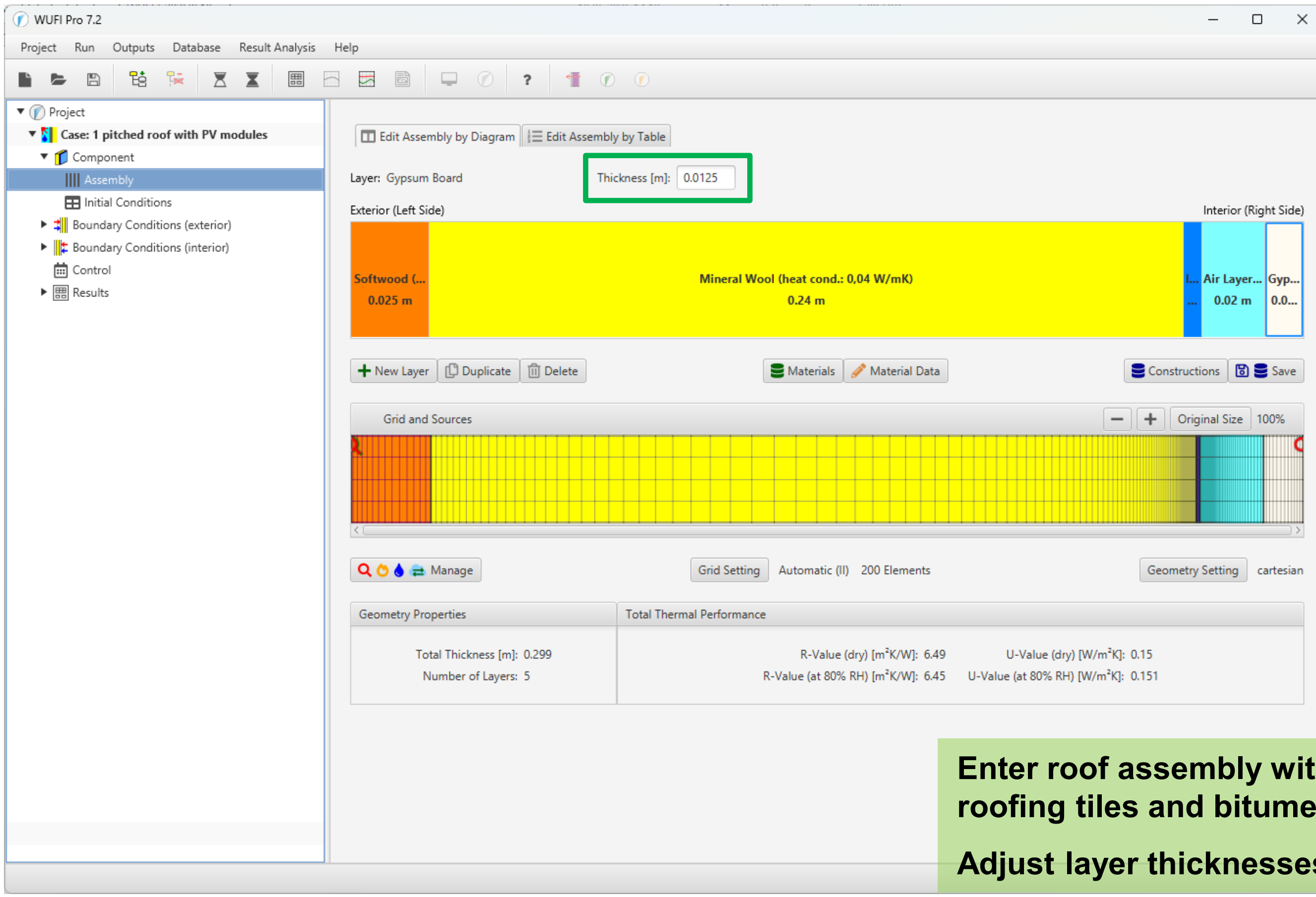
Evaluation Matrix:

The following matrix shows the evaluation criteria relevant to this design.

	Criteria
1) Numerics	No or only small differences in balances (especially in the case of convergence failures)?
	Consistent, periodic course of total water content?
2) Evaluation parameters	Total water content reach dynamic equilibrium or decreases?
	Risk of wood decay in the wooden sheathing? (limit values according to DIN 68800 or WTA 6-8)
	Amount of condensation in the insulation layer?

Example B: Component Assembly

<u>Input:</u> Component - Assembly



Enter roof assembly without PV modules, roofing tiles and bitumen membrane

Adjust layer thicknesses if necessary

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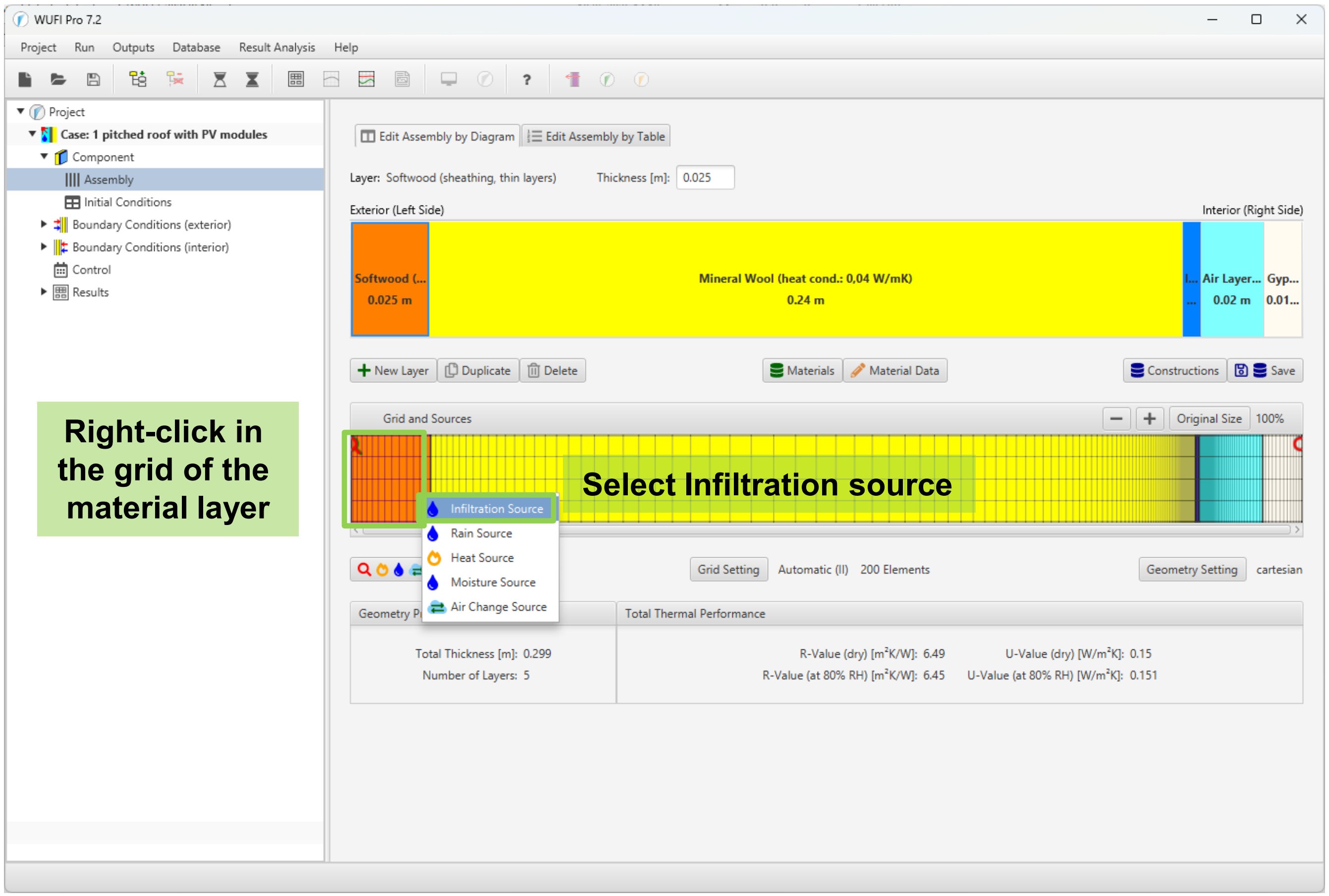
Example B: Infiltration Source

Input: Component - Assembly

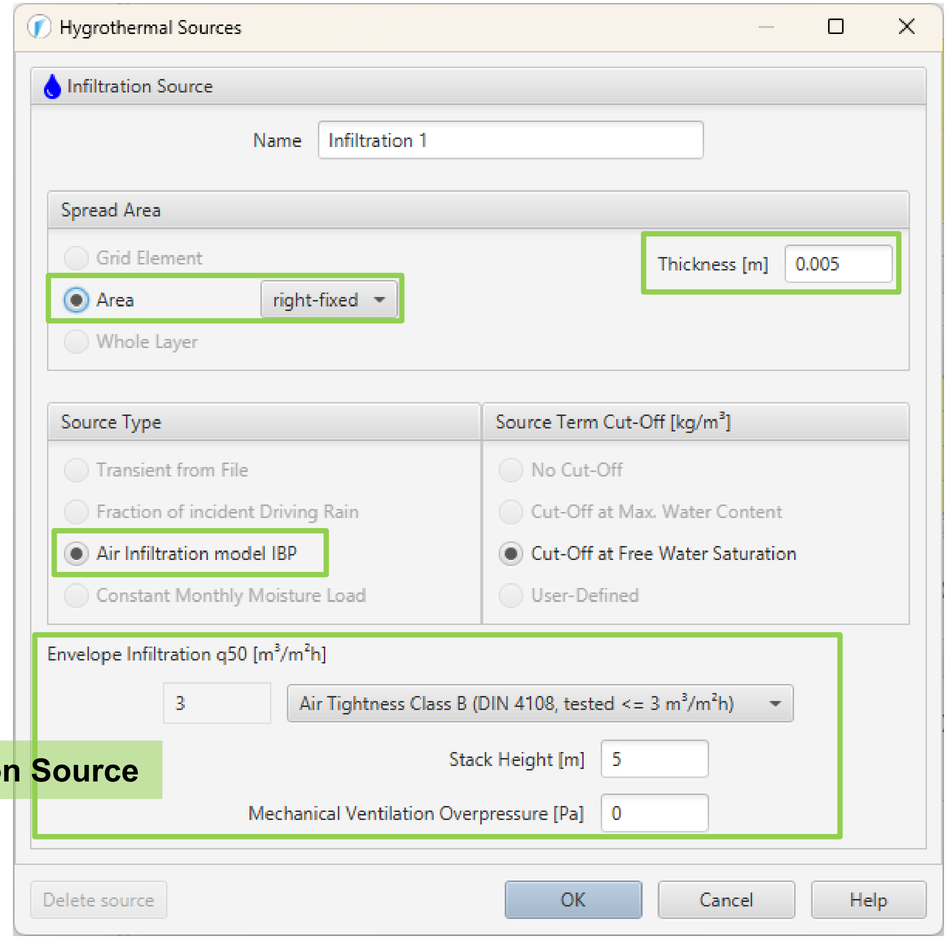
Infiltration source in the wooden sheathing according to EN 15026



Example B: Infiltration Source

Input: Component - Assembly

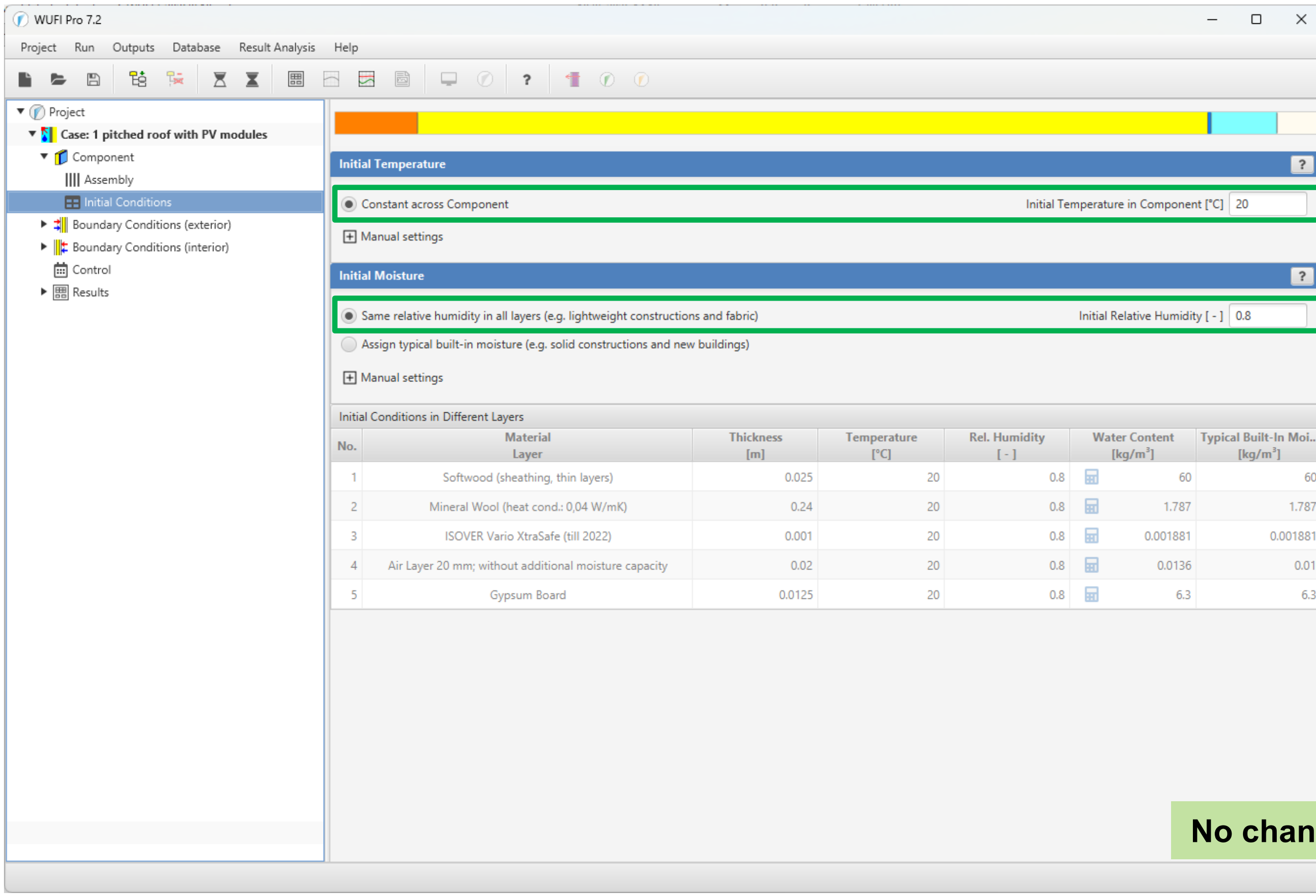
Moisture Source in the interior 5 mm of the wooden sheathing.



Adjust Infiltration Source

Example B: Initial Conditions

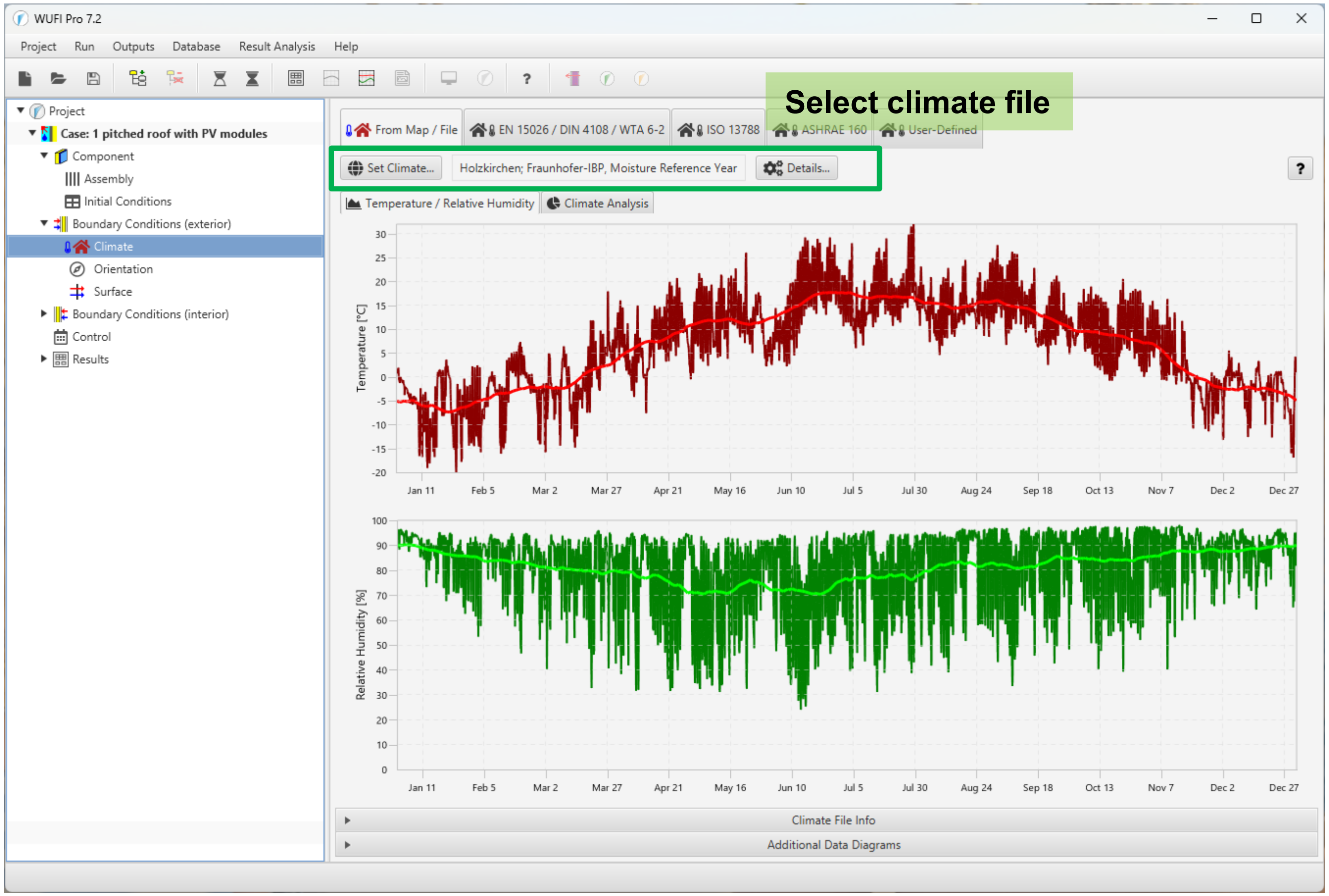
<u>Input:</u> Component – Initial Conditions



No changes required

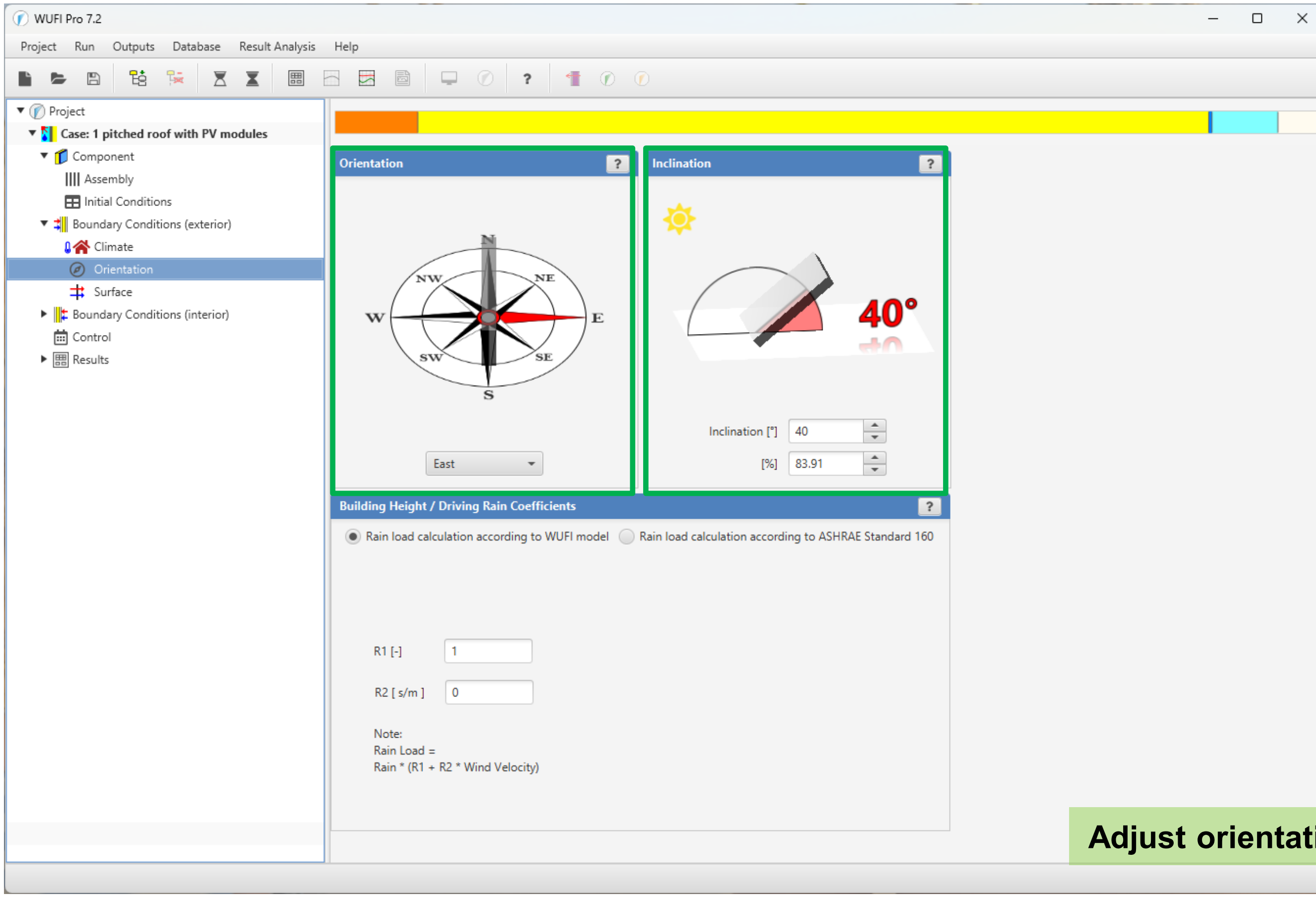
Example B: Outdoor Climate

<u>Input:</u> Boundary Conditions (exterior) – Climate



Example B: Orientation / Inclination

Input: Boundary Conditions (exterior) – Orientation

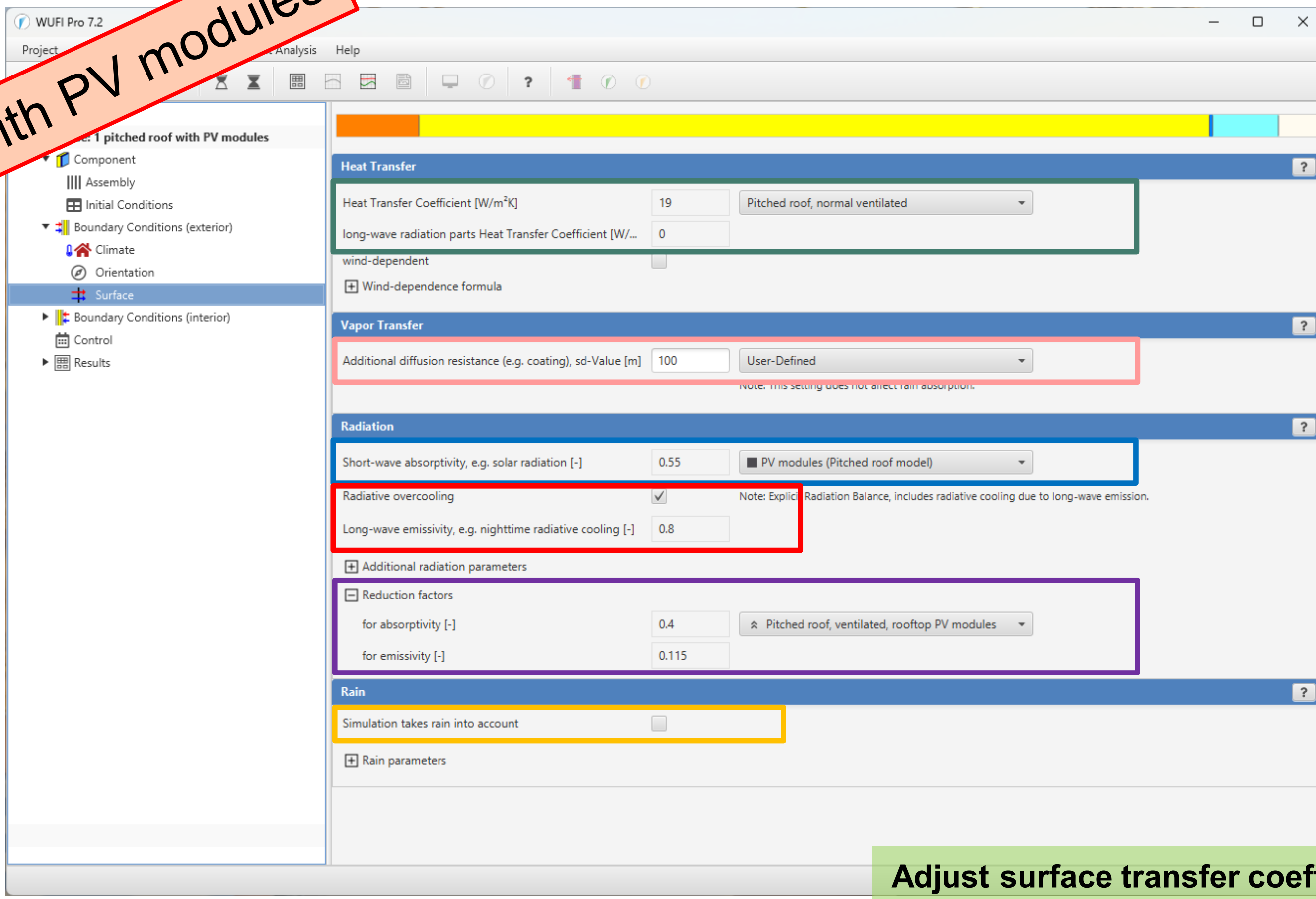


Adjust orientation and inclination

Example B: Surface Transfer Coefficients (exterior)

Input: Boundary Conditions (exterior) – Surface

with PV modules



Heat transfer coefficient (from list: pitched roof, normally ventilated)

Bitumen membrane (s_d = 100 m)

Absorptivity (from list: PV modules)

Consider radiative overcooling

Reduction factors (from list: Pitched roof, ventilated, rooftop PV modules)

No rainwater absorption

Adjust surface transfer coefficients!

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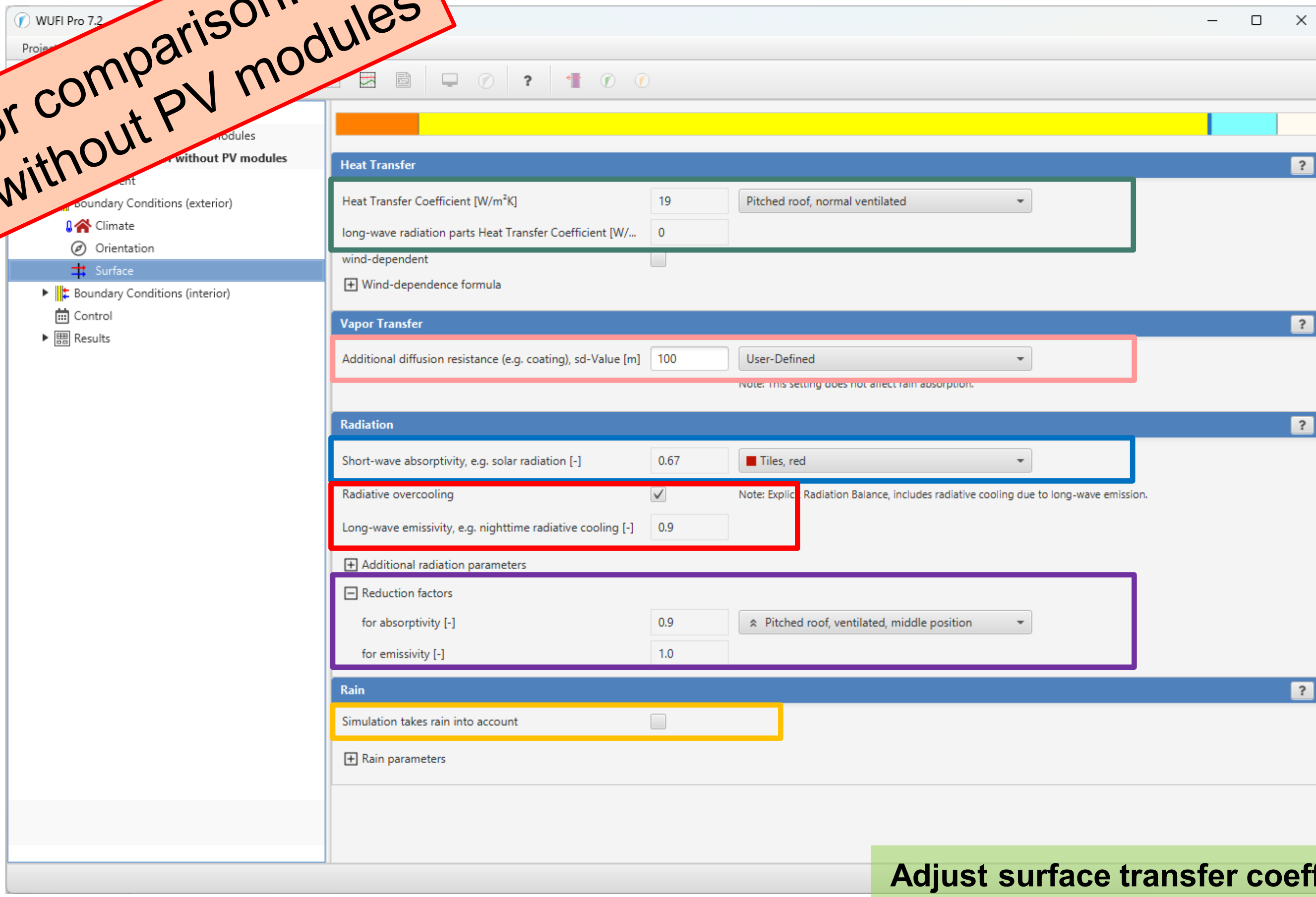
Example B: Surface Transfer Coefficients (exterior)

Input: Boundary Conditions (exterior) – Surface

For comparison:
Roof without PV modules



Heat transfer coefficient (from list: pitched roof, normally ventilated)

Bitumen membrane (s_d = 100 m)

Absorptivity (from list: Tiles, red)

Consider radiative overcooling

Reduction factors (from list: Pitched roof, ventilated, middle position)

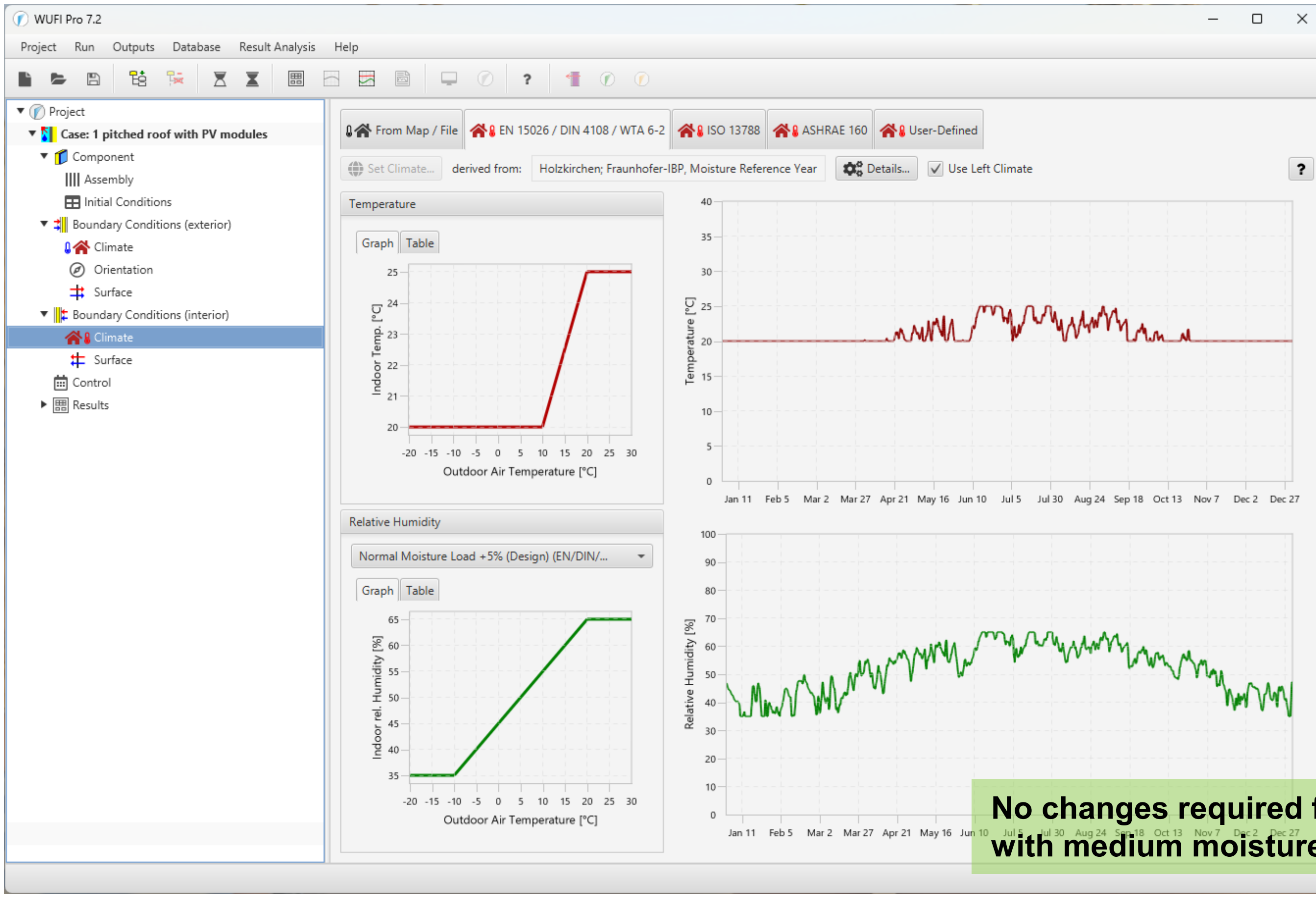
No rainwater absorption

Adjust surface transfer coefficients!

Fraunhofer
IBP

Example B: Indoor Climate

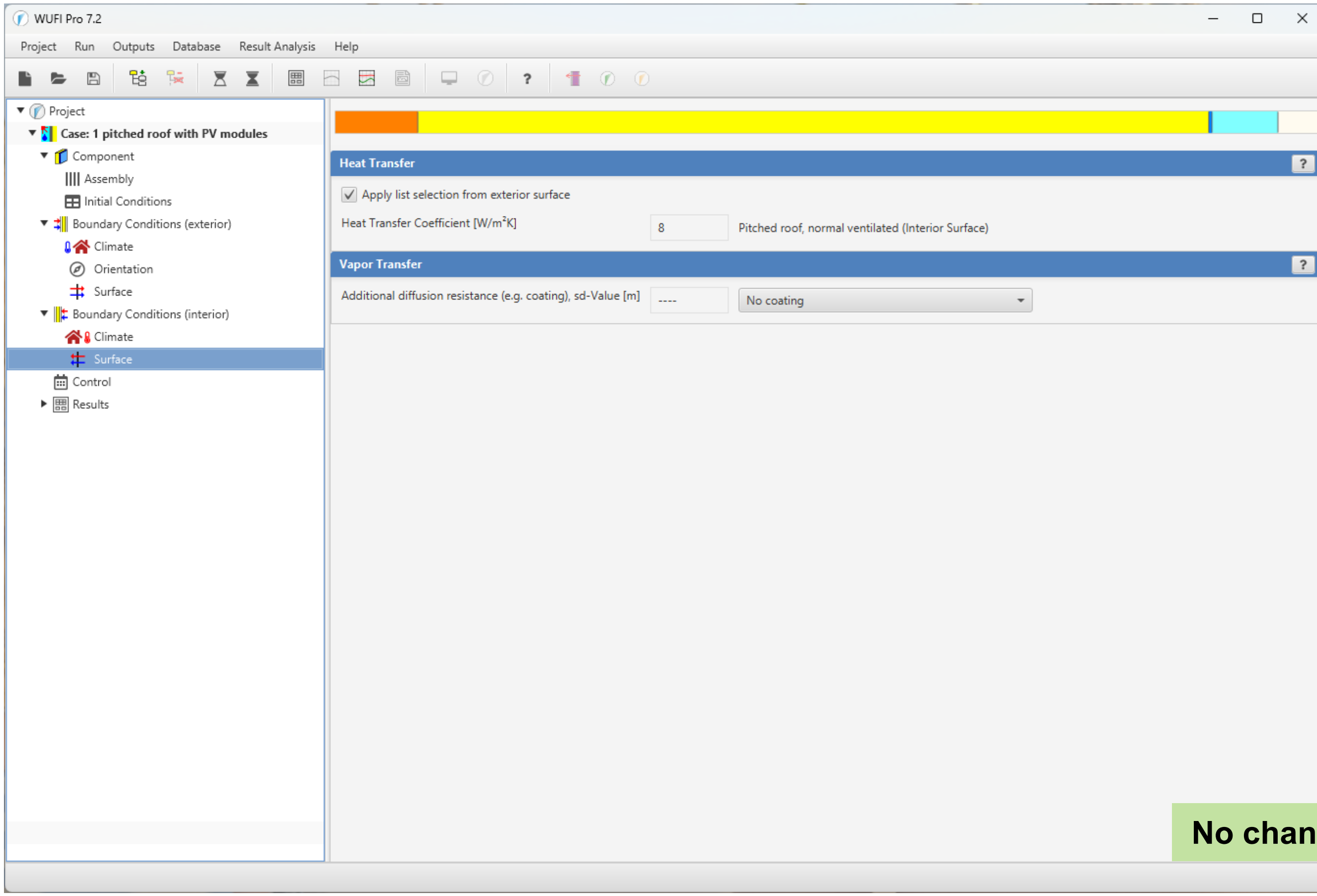
Input: Boundary Conditions (interior) – Climate



No changes required for indoor climate with medium moisture load + 5 %

Example B: Surface Transfer Coefficients (interior)

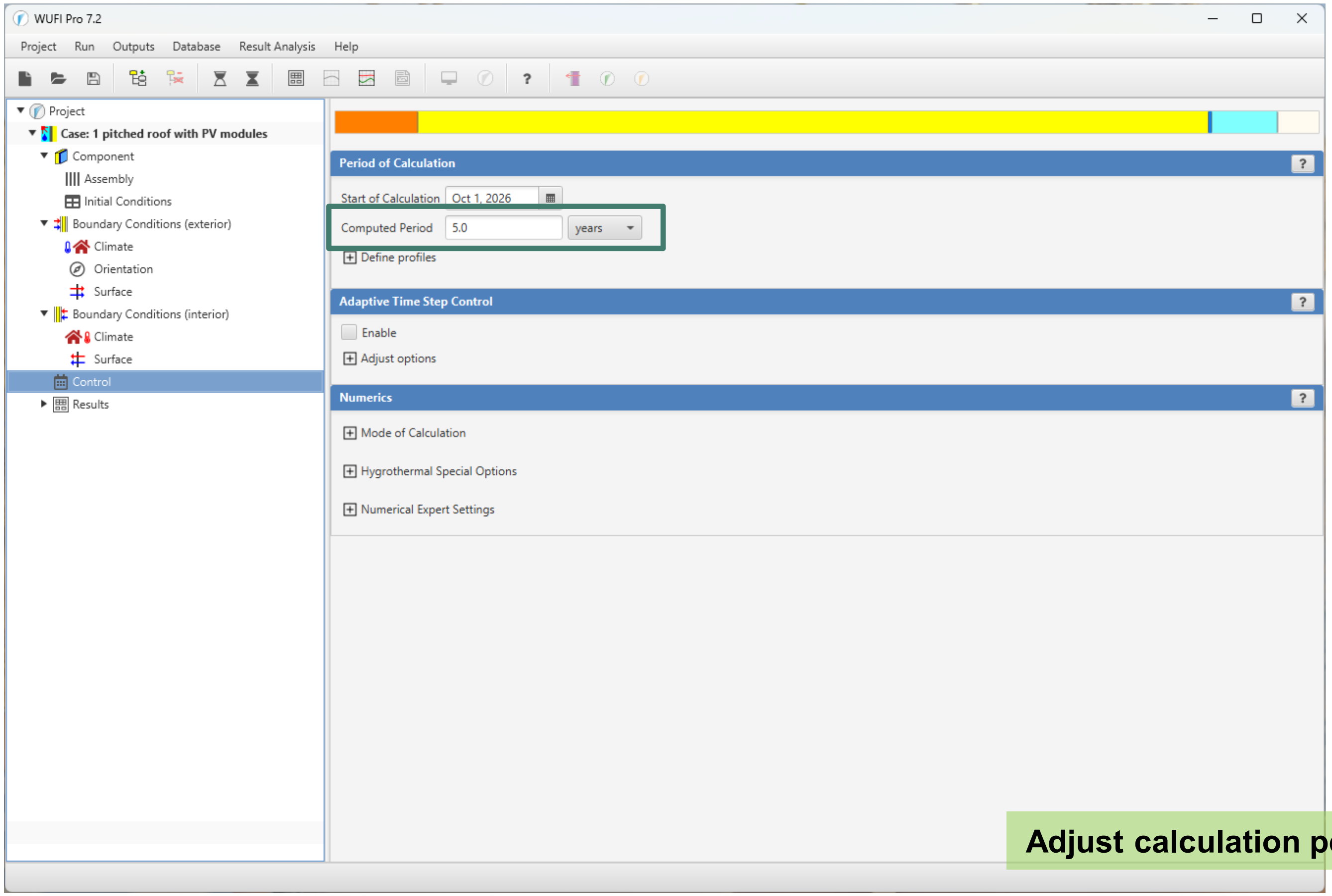
Input: Boundary Conditions (interior) – Surface



No changes required

Example B: Calculation Period and Numerics

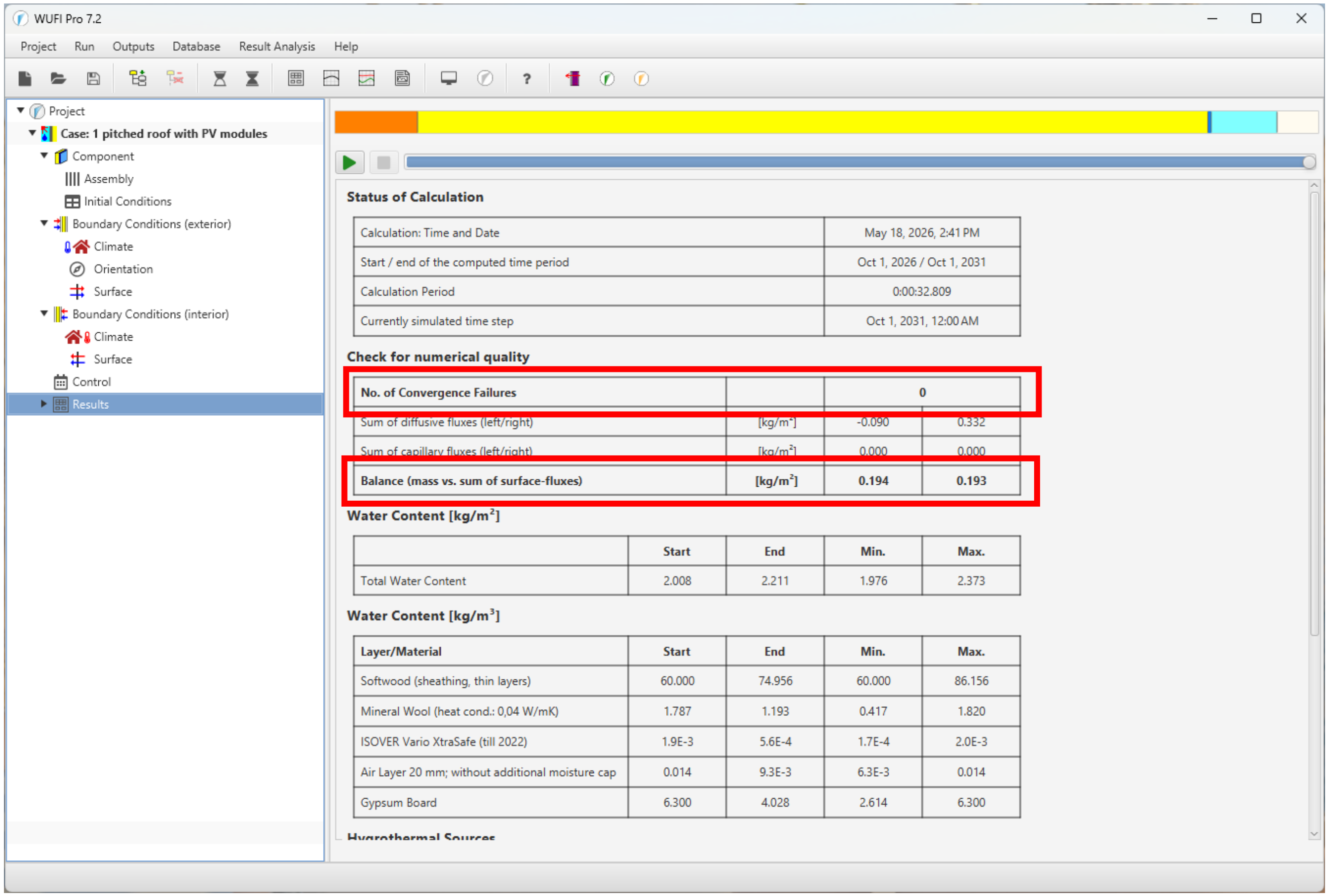
Input: Control



Adjust calculation period if necessary

Example B: Evaluation – Check for numerical quality

Evaluation:



Status of Calculation

Calculation: Time and Date	May 18, 2026, 2:41 PM
Start / end of the computed time period	Oct 1, 2026 / Oct 1, 2031
Calculation Period	0:00:32.809
Currently simulated time step	Oct 1, 2031, 12:00 AM

Check for numerical quality

No. of Convergence Failures		**0**	
Sum of diffusive fluxes (left/right)	[kg/m²]	-0.090	0.332
Sum of capillary fluxes (left/right)	[kg/m²]	0.000	0.000
Balance (mass vs. sum of surface-fluxes)	**[kg/m²]**	**0.194**	**0.193**

Water Content [kg/m²]

	Start	End	Min.	Max.
Total Water Content	2.008	2.211	1.976	2.373

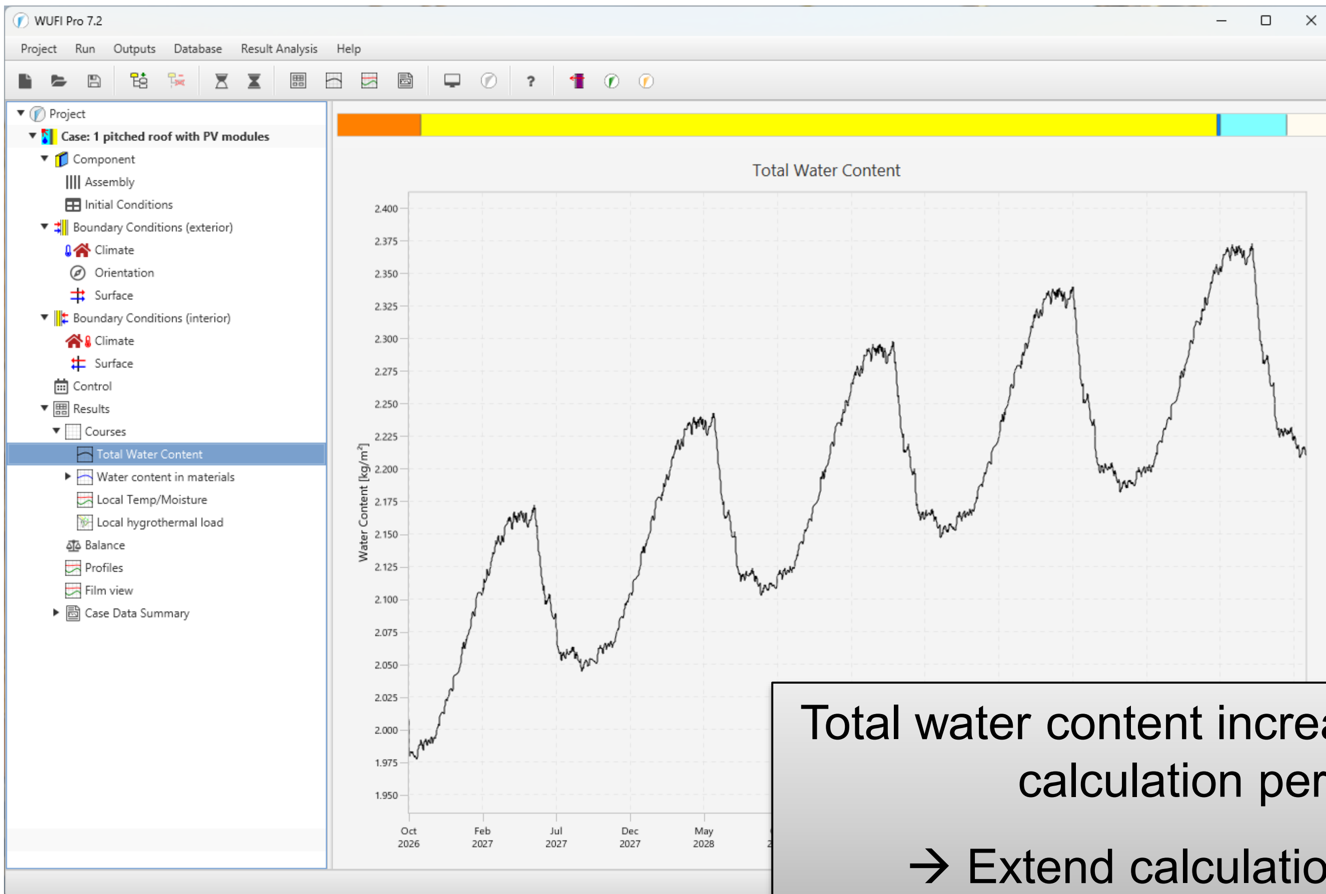
Water Content [kg/m³]

Layer/Material	Start	End	Min.	Max.
Softwood (sheathing, thin layers)	60.000	74.956	60.000	86.156
Mineral Wool (heat cond.: 0,04 W/mK)	1.787	1.193	0.417	1.820
ISOVER Vario XtraSafe (till 2022)	1.9E-3	5.6E-4	1.7E-4	2.0E-3
Air Layer 20 mm; without additional moisture cap	0.014	9.3E-3	6.3E-3	0.014
Gypsum Board	6.300	4.028	2.614	6.300

Hygrothermal Sources

Example B: Evaluation – Total Water Content

Evaluation:
Total Water Content



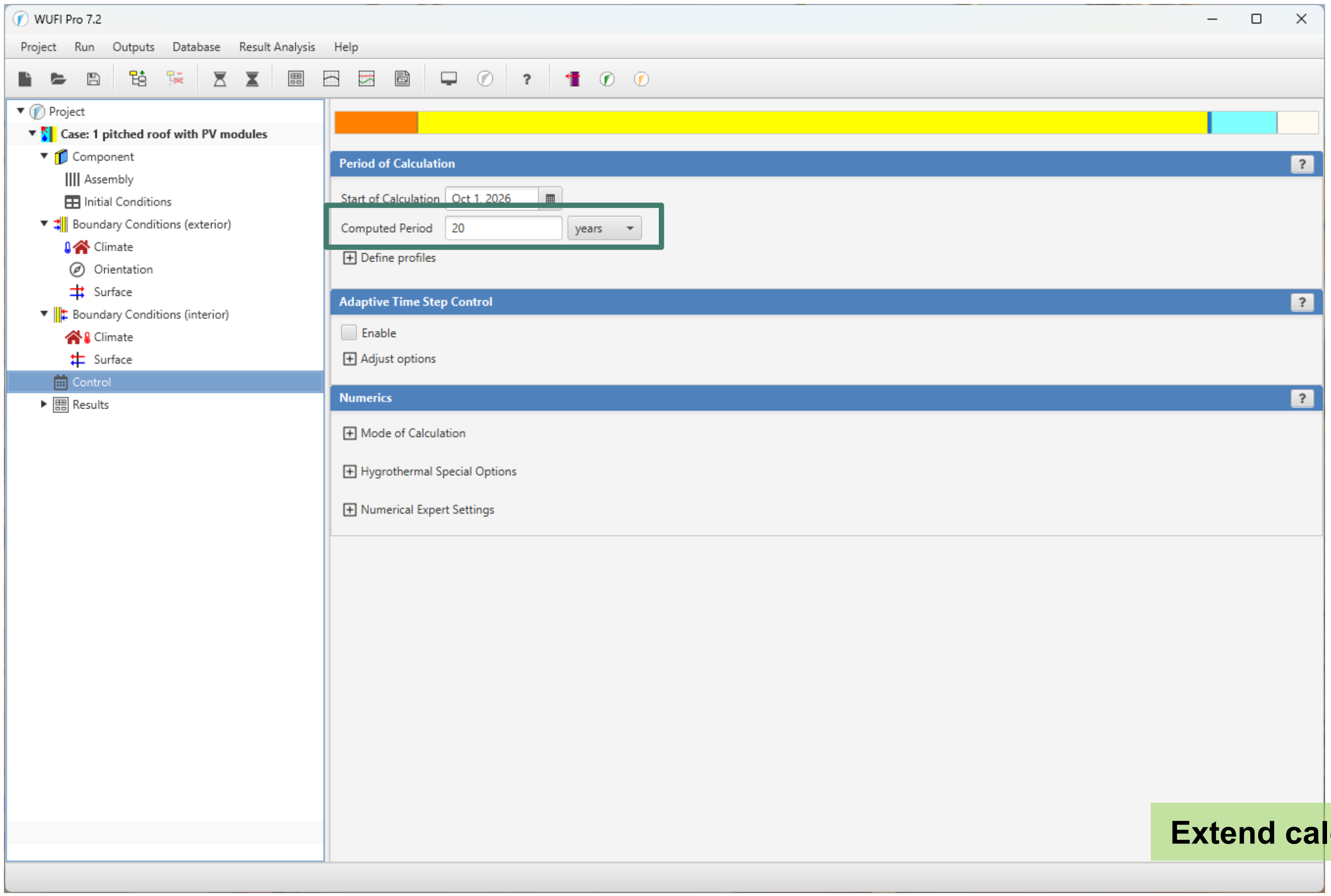
!

Total water content increases over the calculation period

→ Extend calculation period

Example B: Extend calculation period

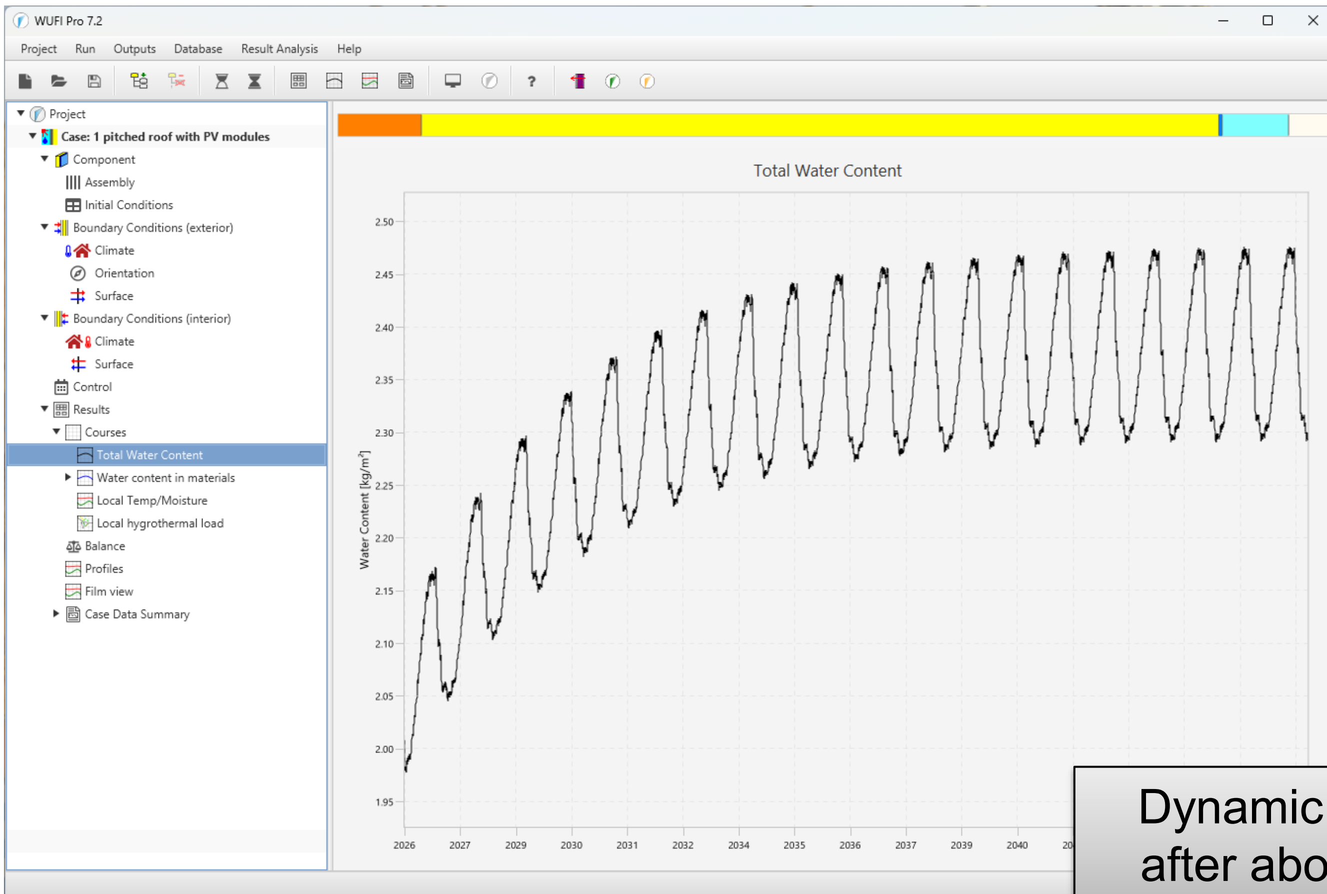
Input: Control



Extend calculation period!

Example B: Evaluation – Total Water Content

<u>Evaluation:</u>
Total Water Content



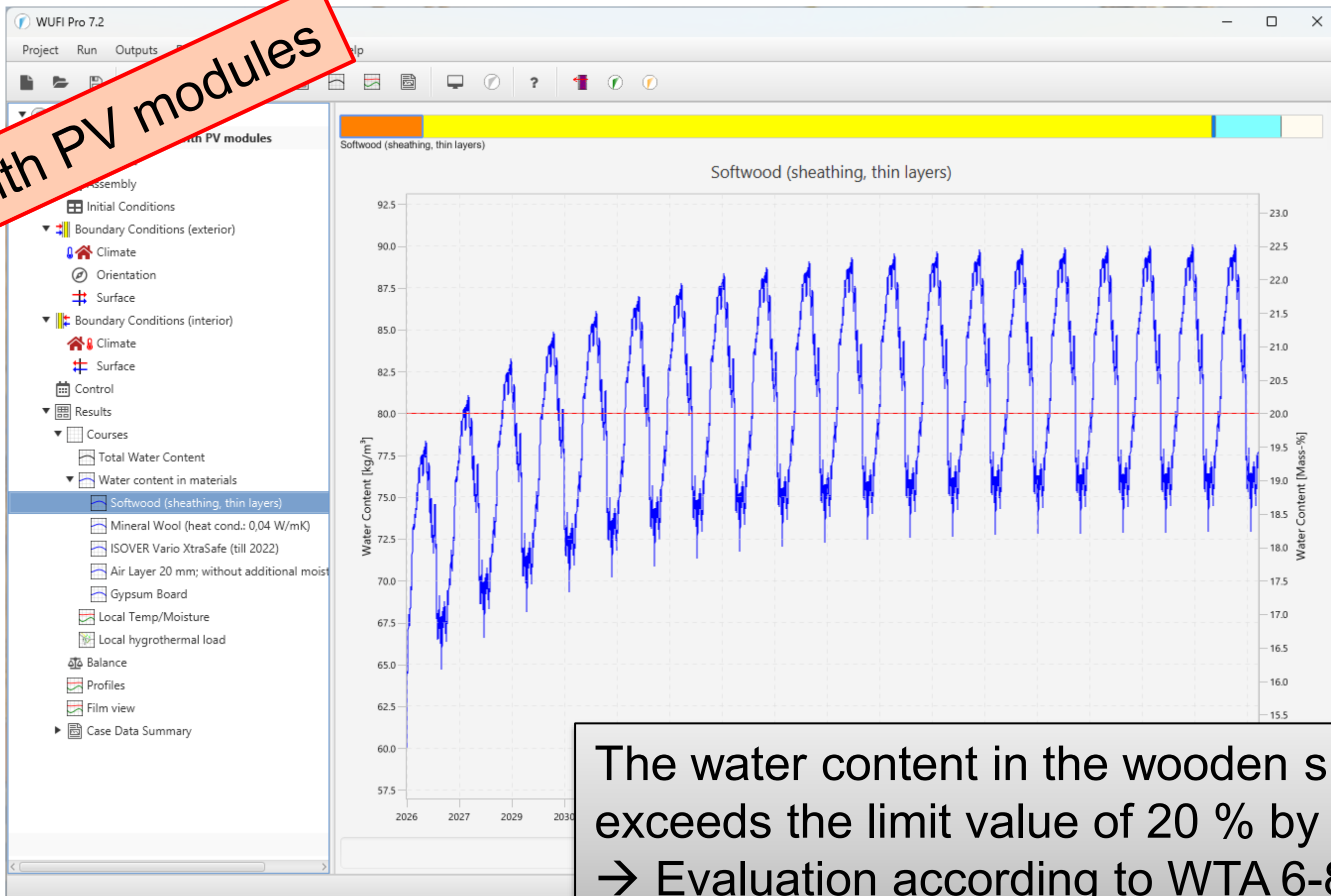
Dynamic equilibrium
after about 17 years

Example B: Evaluation – Wooden Sheathing

Evaluation:

Moisture Content in the Wooden Sheathing

with PV modules



!

The water content in the wooden sheathing exceeds the limit value of 20 % by mass!
→ Evaluation according to WTA 6-8!

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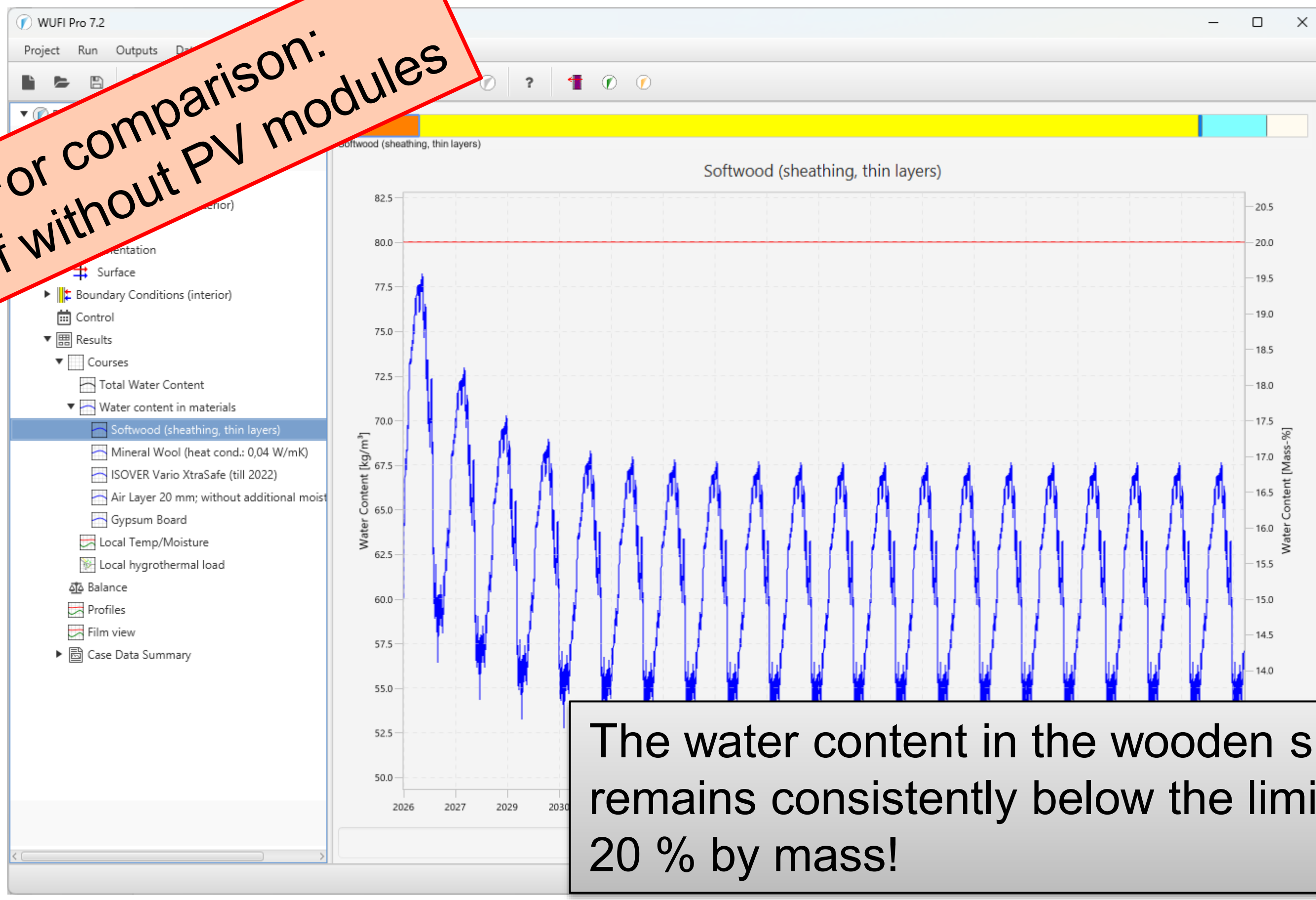
Example B: Evaluation – Wooden Sheathing

Evaluation:

Moisture Content in the Wooden Sheathing

For comparison:
Roof without PV modules



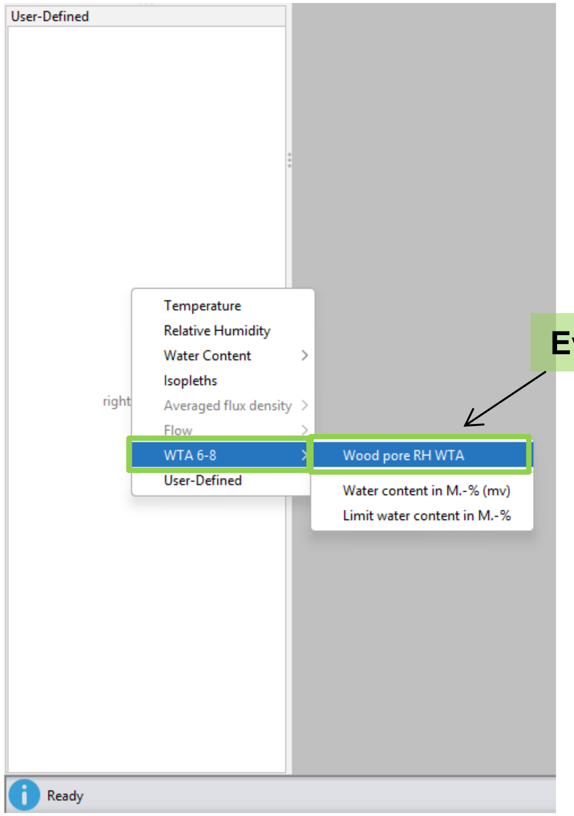
The water content in the wooden sheathing remains consistently below the limit value of 20 % by mass!

Example B: Evaluation – Wooden Moisture according to WTA

<u>Evaluation with WUFI® Graph:</u>

Wood moisture in the wooden sheathing according to WTA 6-8

→ Evaluation of the water content in the interior centimetre of the sheathing



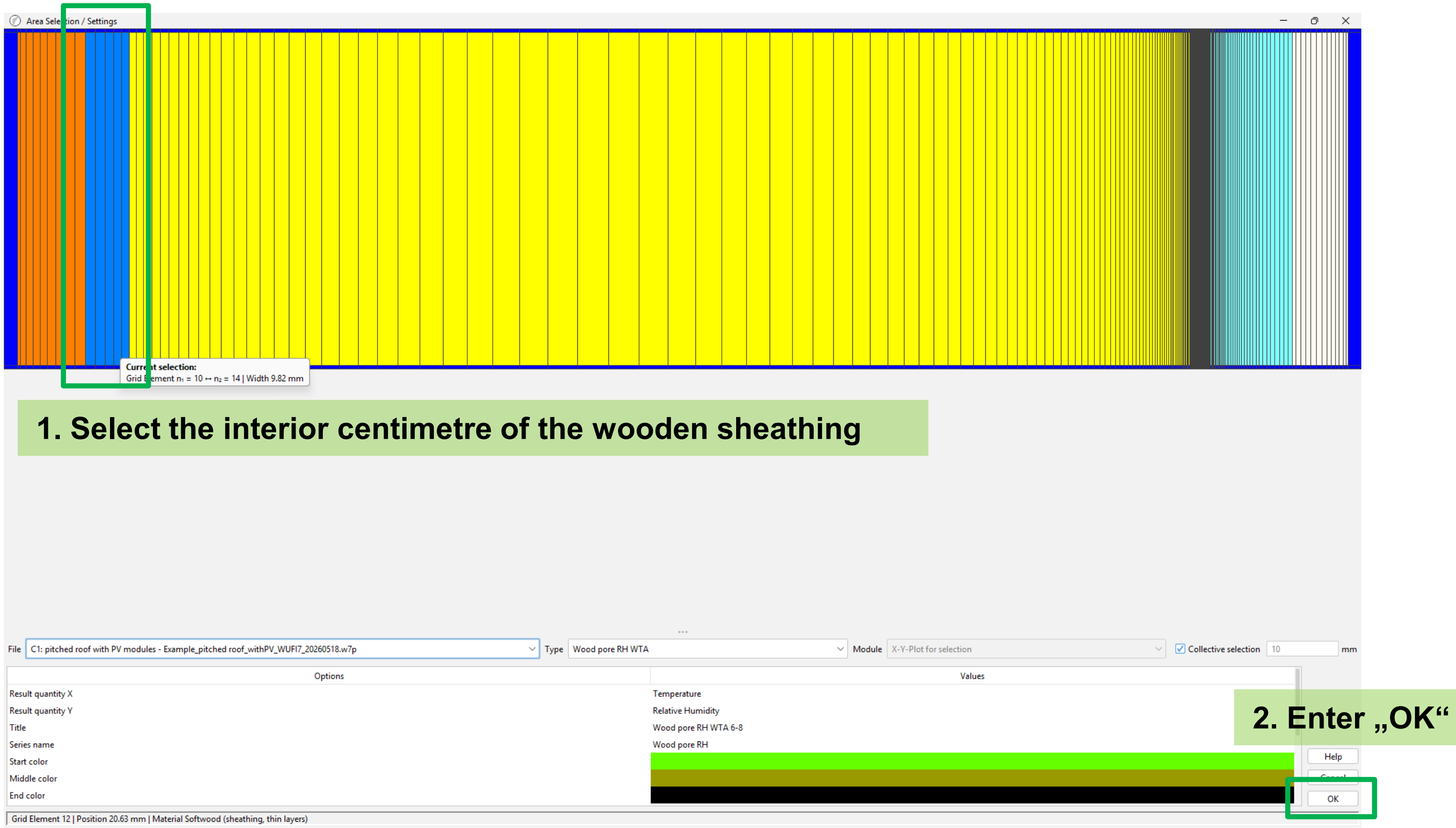
Evaluation of the wood pore RH according to WTA

Example B: Evaluation – Wooden Moisture according to WTA

Evaluation with WUFI® Graph:

Wood moisture in the wooden sheathing according to WTA 6-8

→ Evaluation of the water content in the interior centimetre of the sheathing

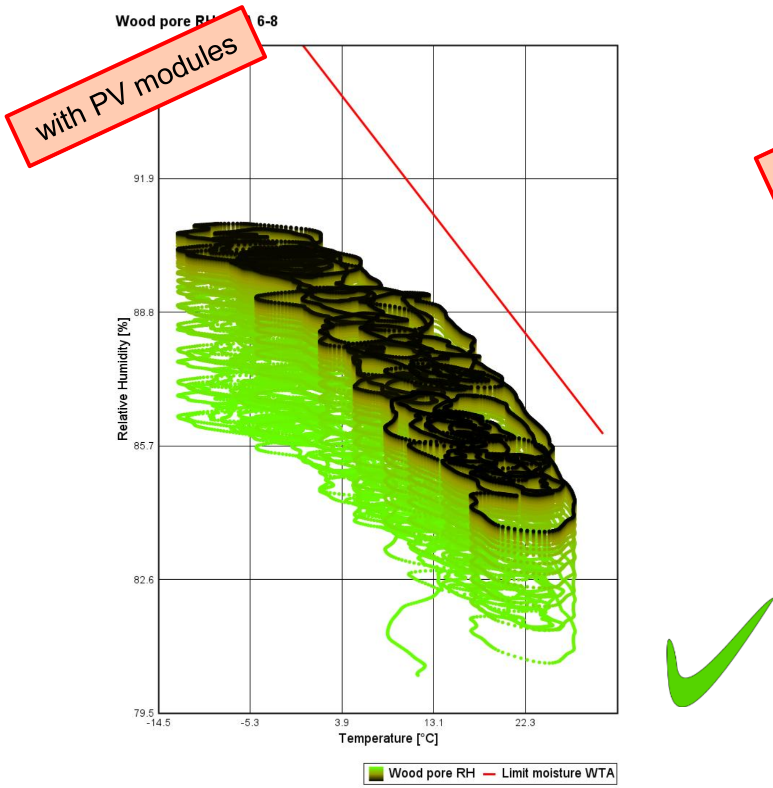


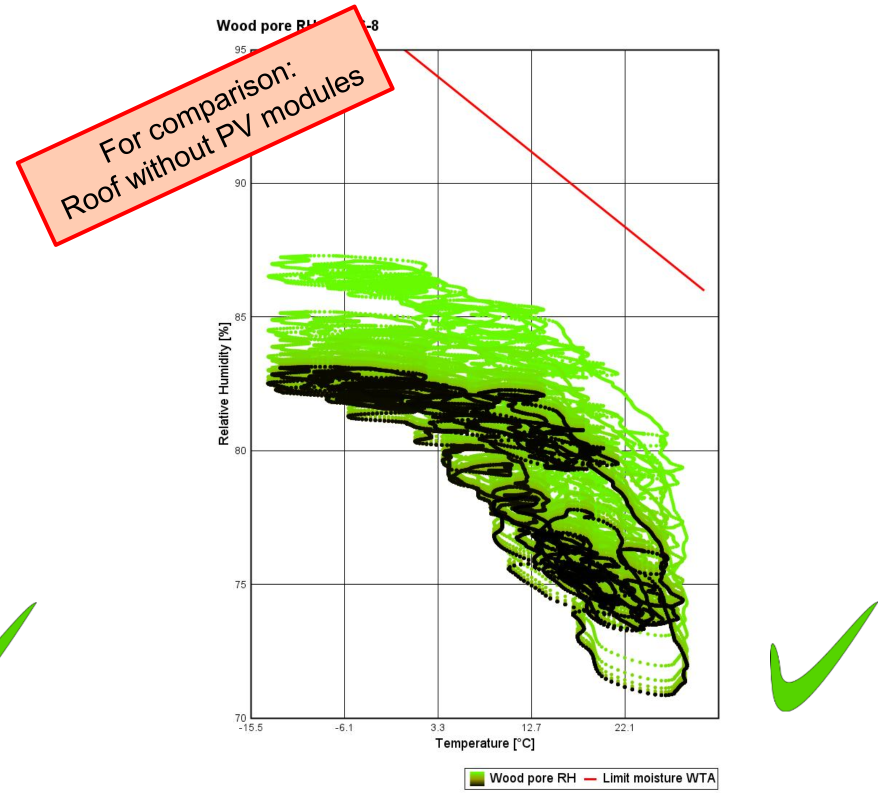
Example B: Evaluation – Wooden Moisture according to WTA

Evaluation with WUFI® Graph:

Wood moisture in the wooden sheathing according to WTA 6-8

→ Evaluation of the water content in the interior centimetre of the sheathing



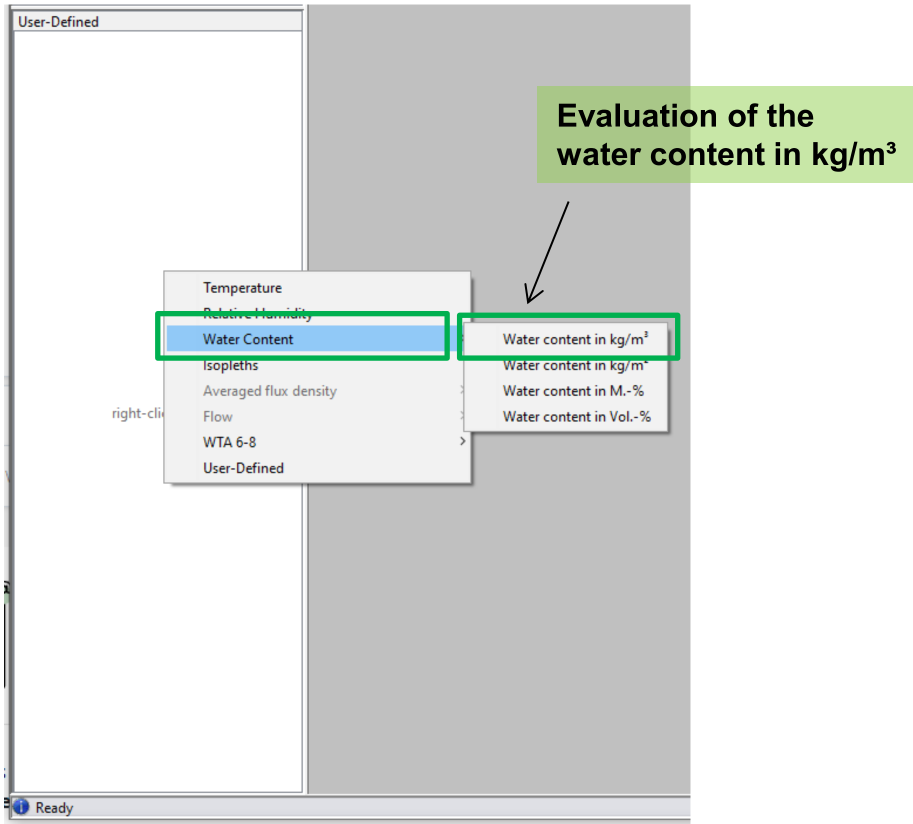


The wood pore RH remains below the limit curve according to WTA 6-8!

Example B: Evaluation – Amount of Condensation

<u>*Evaluation with WUFI® Graph:*</u>
Amount of condensation in the mineral wool insulation

→ Evaluation of the water content in the outer centimetre of the insulation

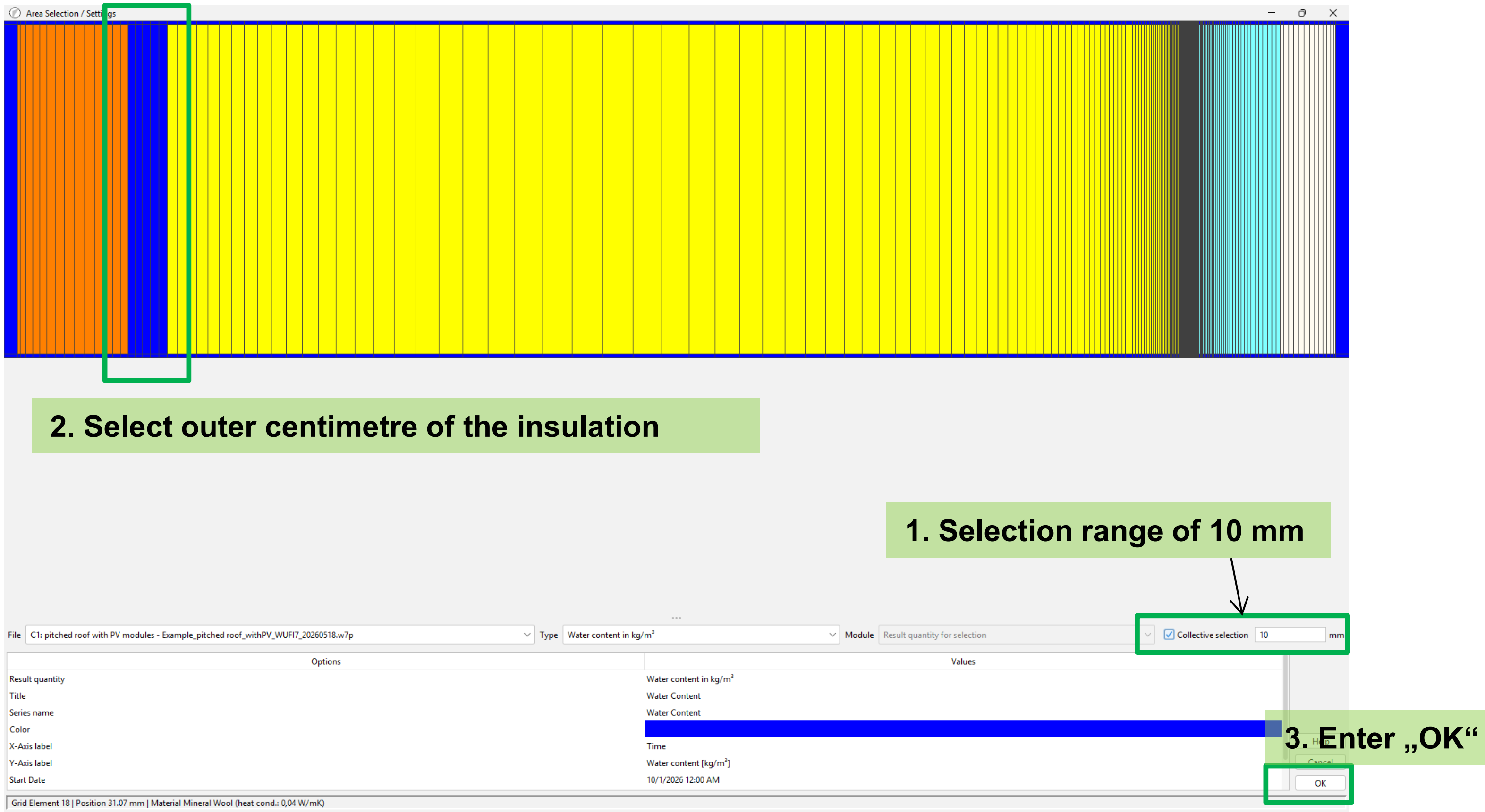


<u>Note:</u>
Further information, including information on inclination-dependent limit values, can be found in the guideline:
[Guideline for assessing the risk of interstitial condensation runoff]

Example B: Evaluation – Amount of Condensation

Evaluation with WUFI® Graph:
Amount of condensation in the mineral wool insulation

→ Evaluation of the water content in the outer centimetre of the insulation

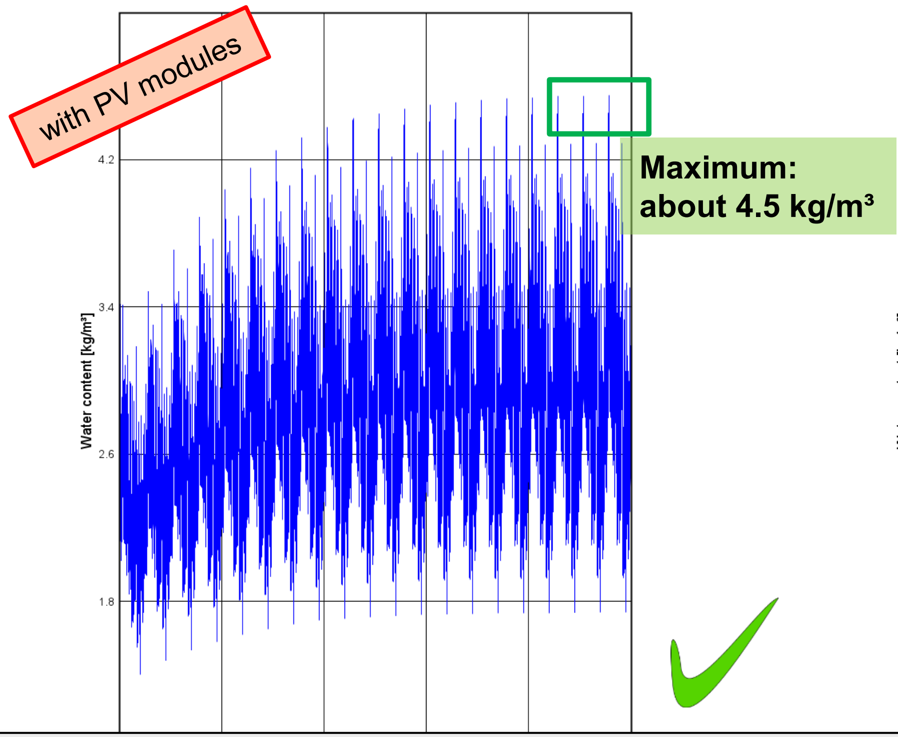


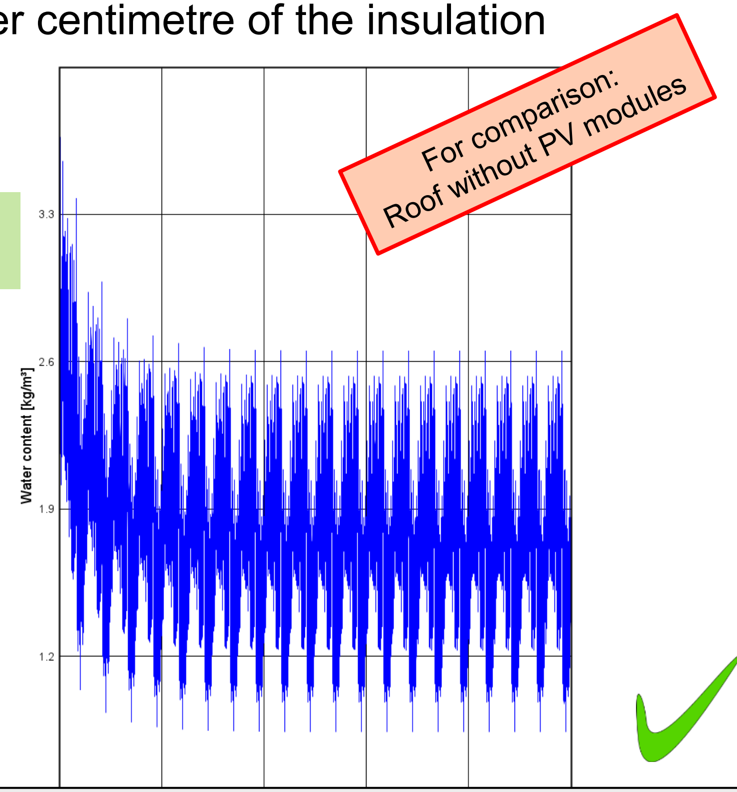
Example B: Evaluation – Amount of Condensation

Evaluation with WUFI® Graph:

Amount of condensation in the mineral wool insulation

→ Evaluation of the water content in the outer centimetre of the insulation





Maximum water content = 4.5 kg/m³ → 4.5 kg/m³ * 0.01 m (layer thickness) = 0.045 kg/m² = 45 g/m²

→ Condensation remains below the minimum limit value of 100 g/m² (≙ minimum retention capacity)

Example B: Evaluation – Final Evaluation

Final Evaluation:

	Criteria	Evaluation
1) Numerics	No or only small differences in balances (especially in the case of convergence failures)?	✓
	Consistent, periodic course of total water content?	✓
2) Evaluation parameters	Total water content reach dynamic equilibrium or decreases?	✓
	Risk of wood decay in the wooden sheathing? (limit values according to DIN 68800 or WTA 6-8)	✓
	Amount of condensation in the insulation layer?	✓

Construction unproblematic from the moisture point of view!