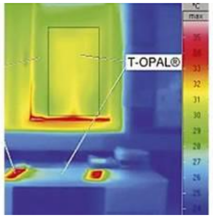
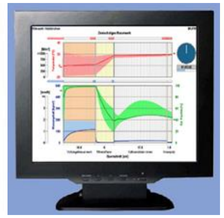
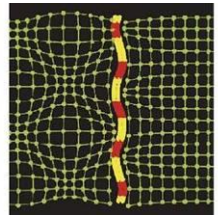




WUFI®

Guideline for the Calculation of Flat Roofs

Date: July 2023

Fraunhofer
IBP

Content

Introduction

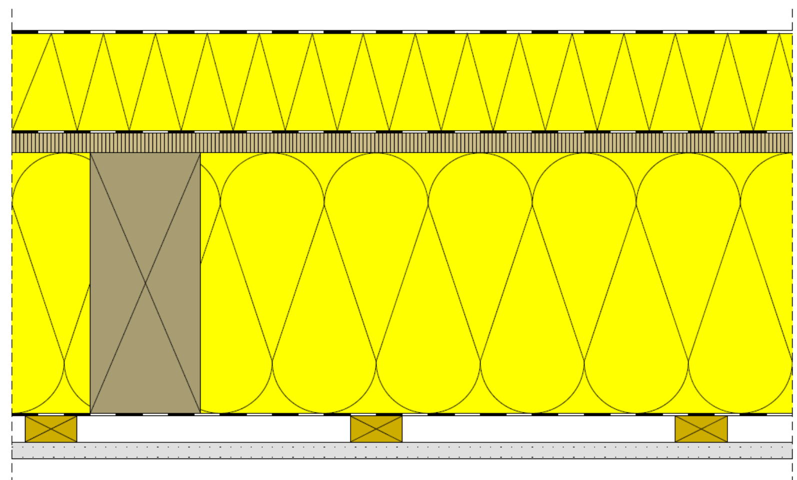
This guideline explains the procedure of the calculation and evaluation of flat roofs in wooden constructions without ballast.

For the assessment of green or gravel flat roof constructions the following guidelines are available:

- Guideline for the calculation of extensive green roofs
- Guideline for the calculation of gravel roofs

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/Monitor Positions

Roofing Membrane

The roofing membrane is not included in the calculation as a component layer, but is taken into account as an s_d-value in the surface transfer parameters.

This leads to practically identical results, but may speed up the calculation considerably compared to considering the roofing membrane in the component assembly.

Underlying Roof Assembly

The underlying layers are to be entered according to the assembly in the cavity axis.

Notes on the Input: Moisture Sources

Component – Assembly/Monitor Positions

Moisture Source – Infiltration (only needed for structures with wooden parts)

According to DIN 68800 [1], the amount of moisture that convectively enters the construction as a function of the air tightness always needs to be assessed for wooden structures and is considered in the simulation using the IBP infiltration model.

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

For roofs 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: Moisture Sources

Component – Assembly/Monitor Positions

Moisture Source – Infiltration (only needed for structures with wooden parts)

The amount of moisture entered in winter is automatically determined in the program 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 [2].

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: Orientation / Inclination

Component - Orientation

Orientation

The relevant orientation is usually North with the lowest radiation gains. However, the orientation is only of minor importance for pitched roofs with an inclination of almost to zero degree.

Roof Inclination

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

Notes on the Input: Surface Transfer Coefficients

Component – Surface Transfer Coefficients

Heat Transfer Coefficient

Exterior Surface

The heat transfer coefficient at the exterior surface is assumed to be 19 W/m²K for flat roofs according to experience values of IBP from numerous field and object investigations. The 25 W/m²K proposed in some standards corresponds to an average wind speed of higher than 6 m/s, which is well above the average value for Germany with about 3.5 m/s and thus too far on the safe side. (If the short-term behavior of the surface temperatures is also to be evaluated, the setting "wind-dependent" may be used).

Interior Surface

The heat transfer coefficient at the interior surface is assumed to be 8 W/m²K according to DIN 4108-3 [3].

Notes on the Input: Surface Transfer Coefficients

Component – Surface Transfer Coefficients

s_d-value on the exterior surface

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

Short-Wave Radiation Absorptivity

The short-wave radiation absorptivity should be selected depending on the colour of the roofing membrane.

Long-Wave Radiation Emissivity

For roofing membranes the long-wave radiation emissivity is usually 0.9.

In order to take into account the (night-time) overcooling, the explicit radiation balance always must switched on for roofs due to its large field of view to the sky,.

Notes on the Input: Surface Transfer Coefficients

Component – Surface Transfer Coefficients

Adhering Fraction of Rain

As the roofing membrane is rain tight, but is not included in the component in WUFI®, rainwater absorption is switched off.

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

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 should be used as a default setting.

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

Notes on the Input: Control

Control

Calculation Period / Profiles:

It is recommended to start the calculation on October 1st, because the component usually moistens up further in the following winter months before drying out 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.

Numerics:

For the numerical settings, the default values can be used.

Notes on the Input: Climate

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 [4], 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 is considered critically representative for Germany for many application fields. However, especially when evaluating roofs, locations with less radiation may cause more unfavorable conditions.

Notes on the Input: Climate

Climate

Indoor Climate:

By default, we recommend to use the indoor climate with medium moisture load + 5% for design purposes according to DIN 4103-3 Appendix D [3] and WTA Guideline 6-2 [5].

Alternatively, depending on the use of the building, the indoor climate according to EN 15026 [6] with medium or high moisture load or other conditions are applicable to the building as well as constant or measured conditions can be applied.

Notes on Ventilated Flat Roofs

Ventilated flat roofs

Requirements for a ventilated cross-section and the openings according to German regulations depending on inclination of the roof

INCLINATION OF THE ROOF	DIN 68800-2		DIN 4108-3	
	max. 15 m ventilation path		max. 10 m for	
	Air-gap height	Openings	Air-gap height	Openings for inclination < 5° up to max. 10 m
< 3°	For roof inclinations below 3°, ventilation is generally not recommended.			
≥ 3° and < 5°	≥ 80 mm resp. ≥ 150 mm 1)	≥ 40%	≥ 50 mm	eaves and monopitch roof connection for inclination < 5°: 2 ‰ of the roof area, min. 200 cm²/m
≥ 5° and < 15°	≥ 80 mm	≥ 40 %	(≥ 20 mm)	ridge and hip for inclination ≥ 5°:
≥ 15°	≥ 80 mm	≥ 40 %	(≥ 20 mm)	0.5 ‰ of the roof area, min. 50 cm²/m

1) Specification valid for greened, flat pitched and pitched roofs according to DIN 68800-2, Annex A, Figure A.

Recommendation: The ventilation air-gap height should be larger than the specified minimum dimension.

Source: Informationsdienst Holz - Flachdächer in Holzbauweise, 01-2019

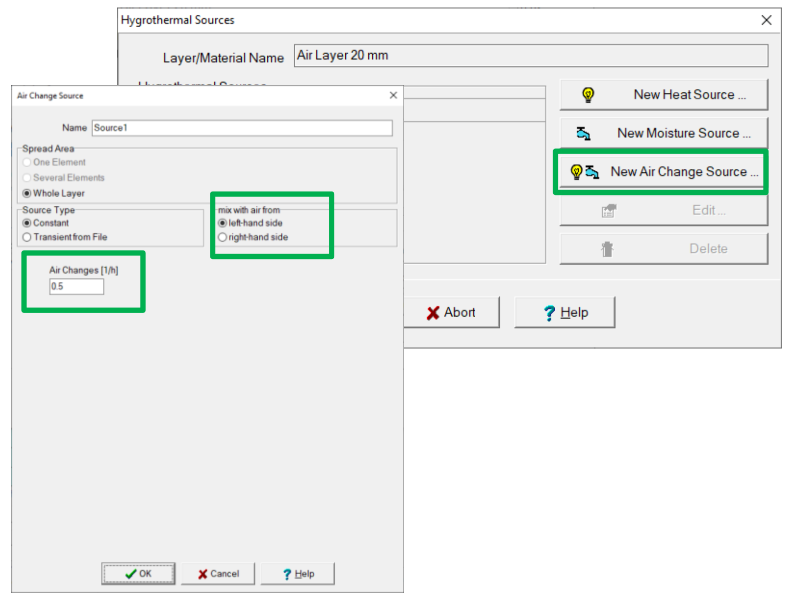
Ventilated flat roofs

Air Change Source in WUFI®

Guided by set air change rate, an air change source exchanges a certain amount of air at the source's location in the component with outdoor air. Depending on the temperature and humidity conditions in the component and in the outdoor air, this process leads to a transport of heat and humidity into or out of the component.

Procedure:

- Select air layer to be ventilated
- via „Sources, Sinks“
  → create „New Air Change Source“
- Specify constant air change rate in [1/h]; mix with air from „left-hand side“



Notes on Ventilated Flat Roofs

Ventilated flat roofs

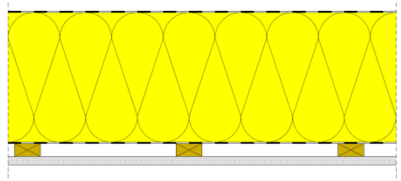
Air change rate in [1/h]

Depending on the design of the ventilated cavity and the inclination of the roof, there may only be a low air change rate.

We recommend varying the air change rate (0/h; 0.5/h; 2/h; 5/h) to check how sensitively the construction reacts to ventilation.

If the construction only works with a high air change rate, pay attention to a very exact design and compliance with the required height of the air gap as well as the ventilation openings given in the standards!

Notes on the Evaluation: Mineral Wool Insulation



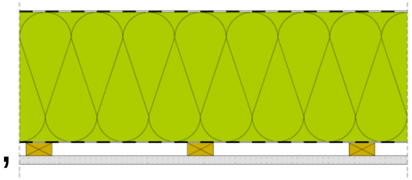
Roofs with mineral wool insulation without wooden sheathing

These assemblies do not have any moisture-sensitive materials in the standard cross-section (in the cavity).
Only at 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 to evaluate the results. For this purpose, the maximum water content in [kg/m³] in the outer area of the mineral wool insulation is evaluated. A distinction is made here between insulation materials with an internal moisture storage function and those with a measured moisture storage function. For more detailed information, please refer to the Guideline for assessing condensation problems in hydrophobic material fiber.

As a general limit value, the condensation water quantity of 200 g/m² specified in EN ISO 13788 [7] is recommended (conversion required). Above this quantity, there is a risk of condensation running off.

Notes on the Evaluation: Wood Fibre Insulation



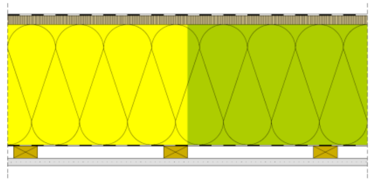
Roofs with wood fibre insulation without wooden sheathing

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 reached if the course of the water content does not change inbetween the years any longer.

For evaluation purposes, the general limit value of 18 % by mass from DIN 68800 [1] 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



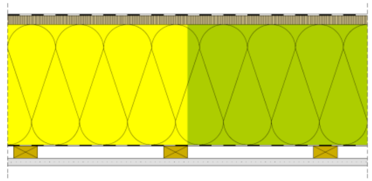
Roofs with insulation and wooden sheathing

For assemblies with exterior wooden sheathing, the insulation between the rafters (mineral wool or wood fibre) is evaluated according to slide 18+19.

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 [1] is recommended as the limit value. If this limit moisture content is not exceeded, no further evaluation is necessary.

If the wood moisture exceeds the limit value according to DIN 68800 [1], an evaluation according to the WTA Guideline 6-8 [8] also can 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

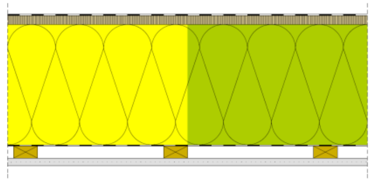
Evaluation according to DIN 68800 [1]

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 specified in DIN 68800 [1] are exceeded over a long period.

However, this limit value includes high safety margins and, in contrast to the WTA guideline, no specifications are made for the evaluation range. 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



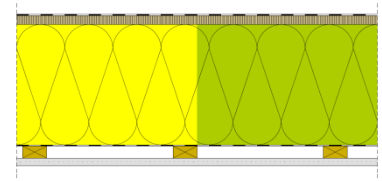
Roofs with insulation and wooden sheathing

Evaluation according to WTA Guideline 6-8 [8]

If the limit value for wood of 20 % by mass according to DIN 68800 [1] is exceeded, also an evaluation according to the WTA 6-8 [8] 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 relevant position of the wood. This allows a more accurate and realistic evaluation.

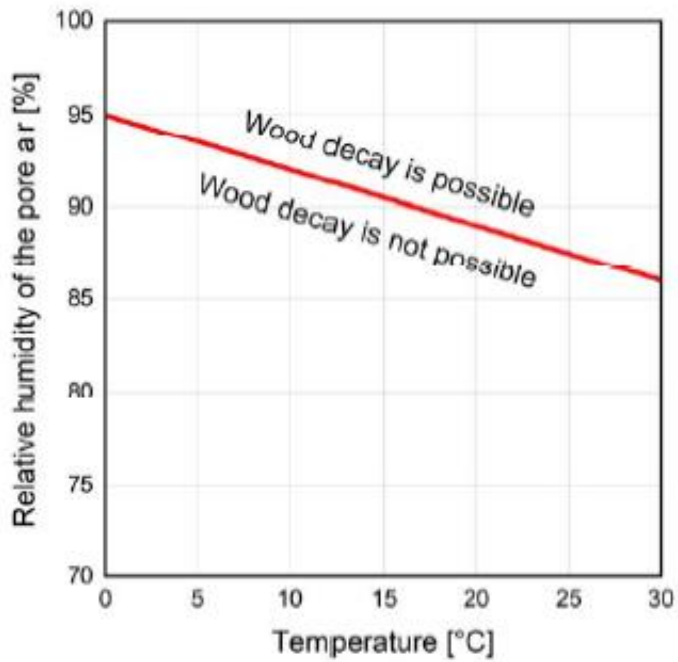
This evaluation is not permissible for wood-based materials, as other limit values for rotting processes may apply here.

Notes on the Evaluation: Wooden Sheathing



<u>Roofs with insulation and wooden sheathing</u>

Limit curve for wood decay depending on temperature (x-axis) and relative humidity (y-axis) according to WTA 6-8 [8].
Below the red limit line, wood decay is not possible in solid wood.



Literature

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

[2] 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.

[3] DIN 4108-3: Wärmeschutz und Energie-Einsparung in Gebäuden - Teil 3: Klimabedingter Feuchteschutz - Anforderungen, Berechnungsverfahren und Hinweise für Planung und Ausführung. Beuth Verlag, October 2018.

[4] Research Report: Energieoptimiertes Bauen: Klima- und Oberflächenübergangsbedingungen für die hygrothermische Bauteilsimulation. IBP-Bericht HTB-021/2016. Carried out on behalf of Project Management Jülich (PTJ UMW). July 2016.

[5] WTA Guideline 6-2/E: Simulation of heat and moisture transfer. December 2014.

[6] EN 15026: Hygrothermal performance of building components and building elements – Assessment of moisture transfer by numerical simulation. July 2007.

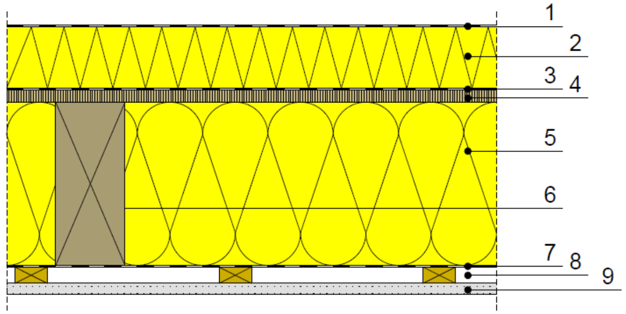
[7] EN ISO 13788: Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods. May 2013.

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

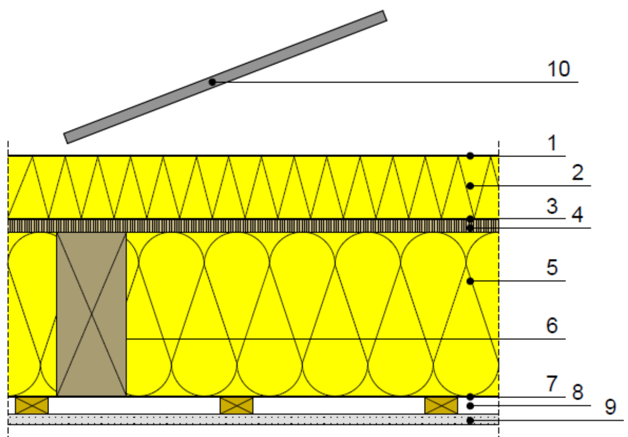
Examples: Flat Roof without and with Shading by PV Modules

Based on the example of a flat roof in timber construction without and with shading by rack-mounted PV modules, the procedure for the input and the evaluation of flat roofs is described.

Example A:



Example B:



1 Roofing Felt
2 EPS Insulation
3 PE Foil
4 Wooden Sheathing
5 Insulation
6 Rafter
7 Vapour Retarder
8 Installation Layer
9 Gypsum Board
10 PV Modules (rack-mounted)

Examples: Assembly

Assembly (from outside to inside):

• Roofing Felt (s_d = 300 m)		
• EPS (heat cond.: 0.04 W/mK – density: 30 kg/m³)	0.1	m
• PE Foil (vapour retarder, s_d = 100 m)		
• Wooden Sheathing (Softwood)	0.025	m
• Mineral Wool (heat cond.: 0.04 W/mK)	0.24	m
• Moisture-Variable Vapour Retarder (PA-Membrane)	0.001	m
• Air Layer	0.02	m
• Gypsum Board	0.0125	m

Examples: Boundary Conditions

Boundary Conditions:

- Flat roof (3° to the North)
- Dark roofing felt (a = 0.8; ε = 0.9)
- Example A: no shading
  Example B: shading by rack-mounted PV modules (WTA 6-8)
- Outdoor Climate: Holzkirchen
- Indoor Climate: Medium Moisture Load + 5 %
  according to DIN 4108-3
- Air Tightness of the Envelope: q_{50} = 3 m³/m³h
- Stack Height: 5 m

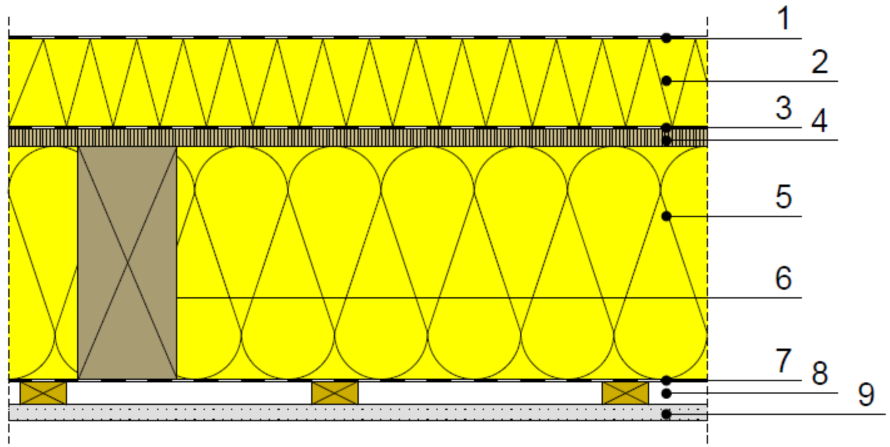
Evaluation Matrix:

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

	Criteria
1) Numerics	Low balance differences?
	Few or no convergence failures?
2) Evaluation parameters	Total water content settled?
	Risk of wood decay in the wooden sheathing? (limit values according to DIN 68800-3 or WTA 6-8)

Example A: Flat Roof without Shading

Example A:
Flat roof in timber construction without shading

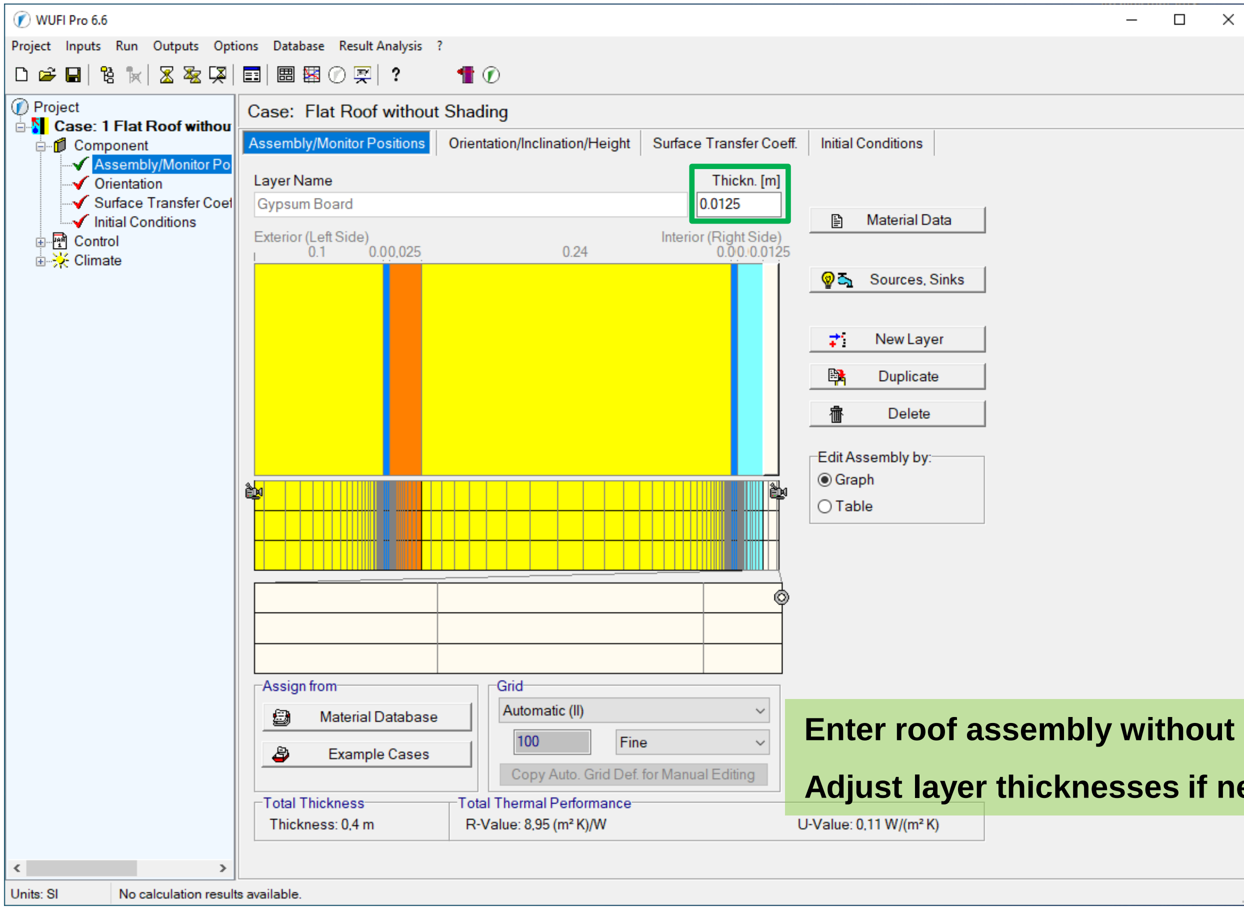


1 Roofing Felt
2 EPS Insulation
3 PE Foil
4 Wooden Sheathing
5 Insulation
6 Rafter
7 Vapour Retarder
8 Installation Layer
9 Gypsum Board

Fraunhofer IBP

Example A: Input - Component Assembly

Input: Component - Assembly / Monitor Positions



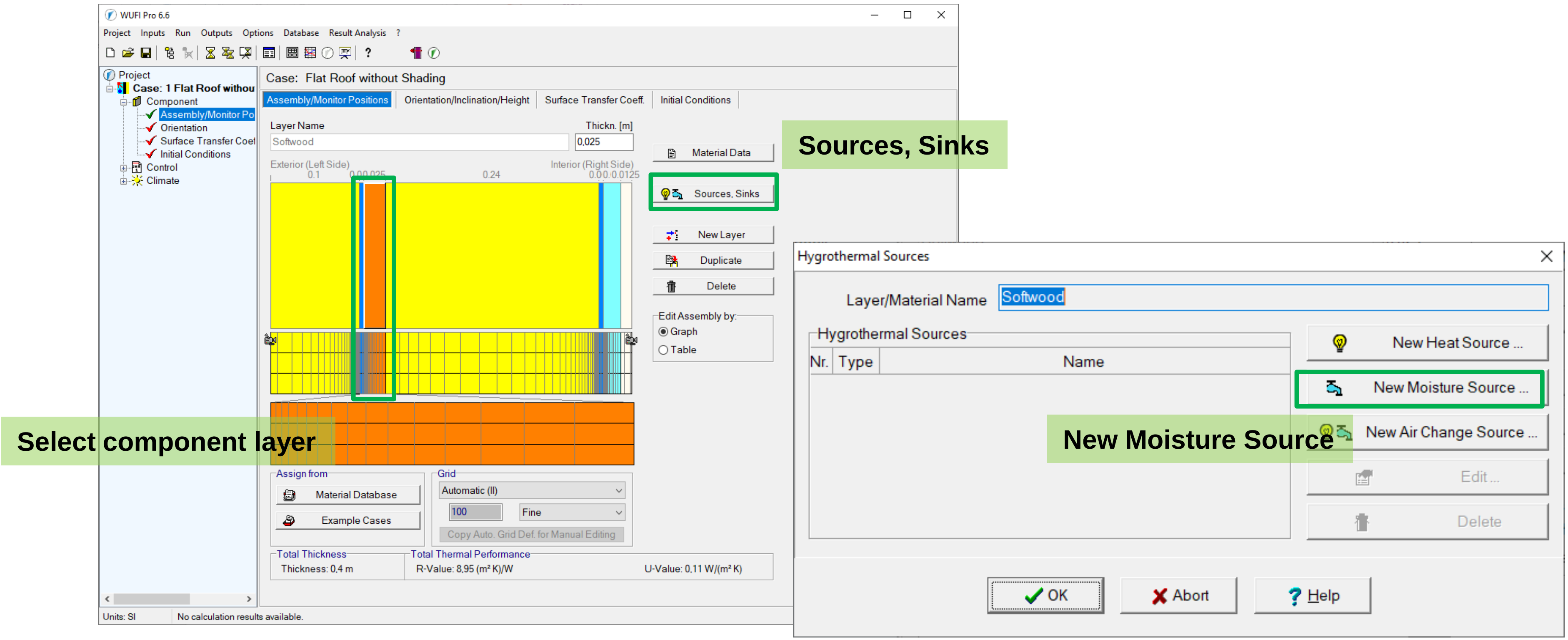
Enter roof assembly without roofing felt

Adjust layer thicknesses if necessary

Example: Input - Infiltration Source

Input: Component - Assembly / Monitor Positions

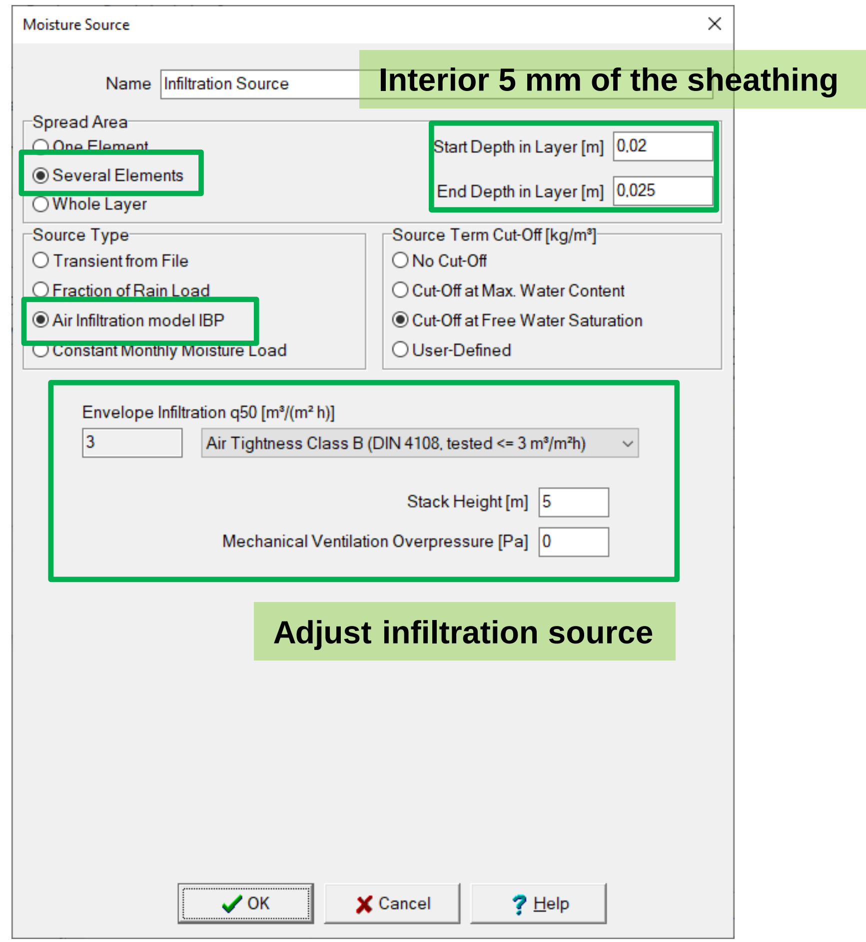
Infiltration source according to DIN 68800 in the wooden sheathing.



Example: Input - Infiltration Source

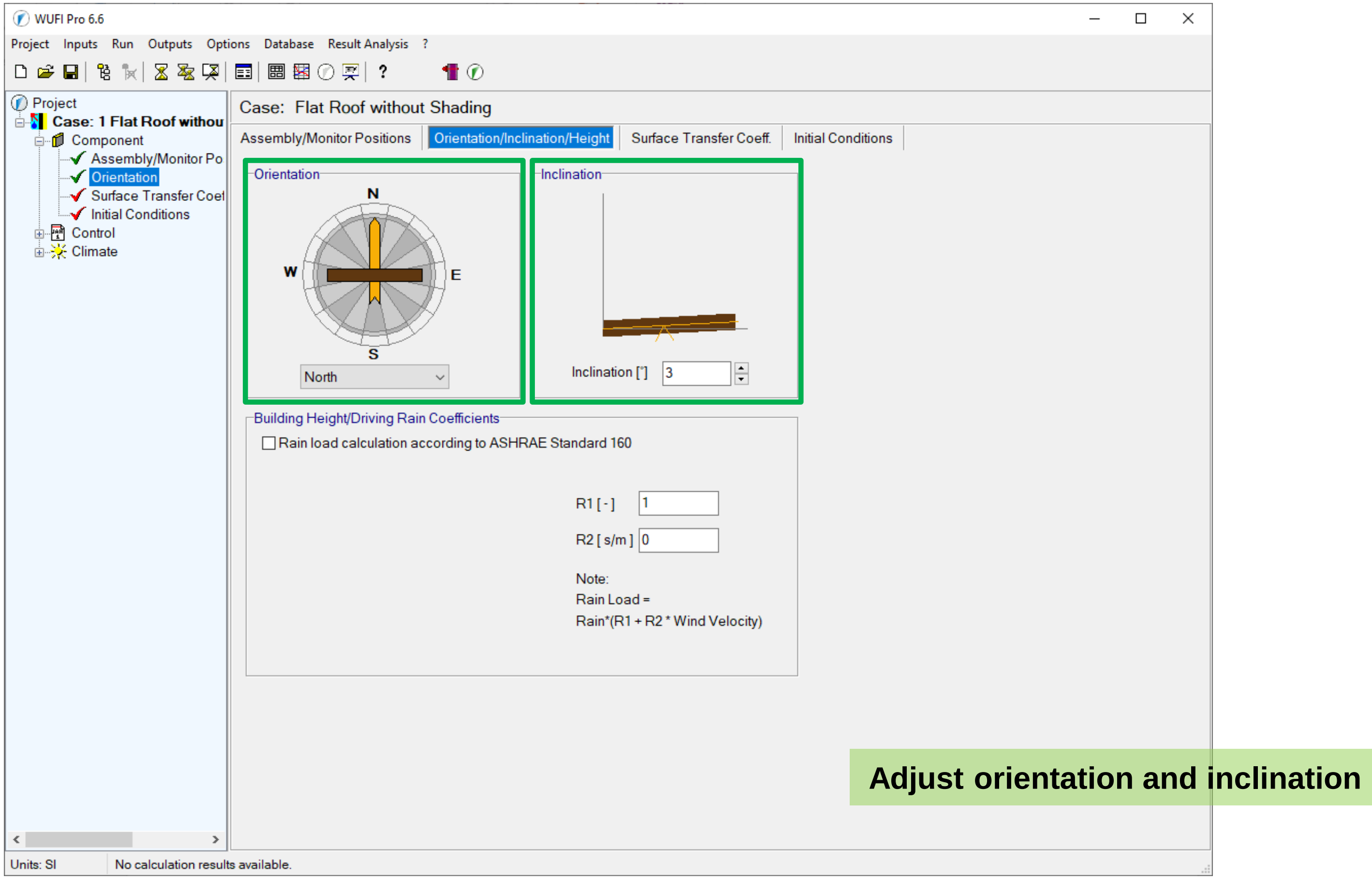
Input: Component - Assembly / Monitor Positions

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



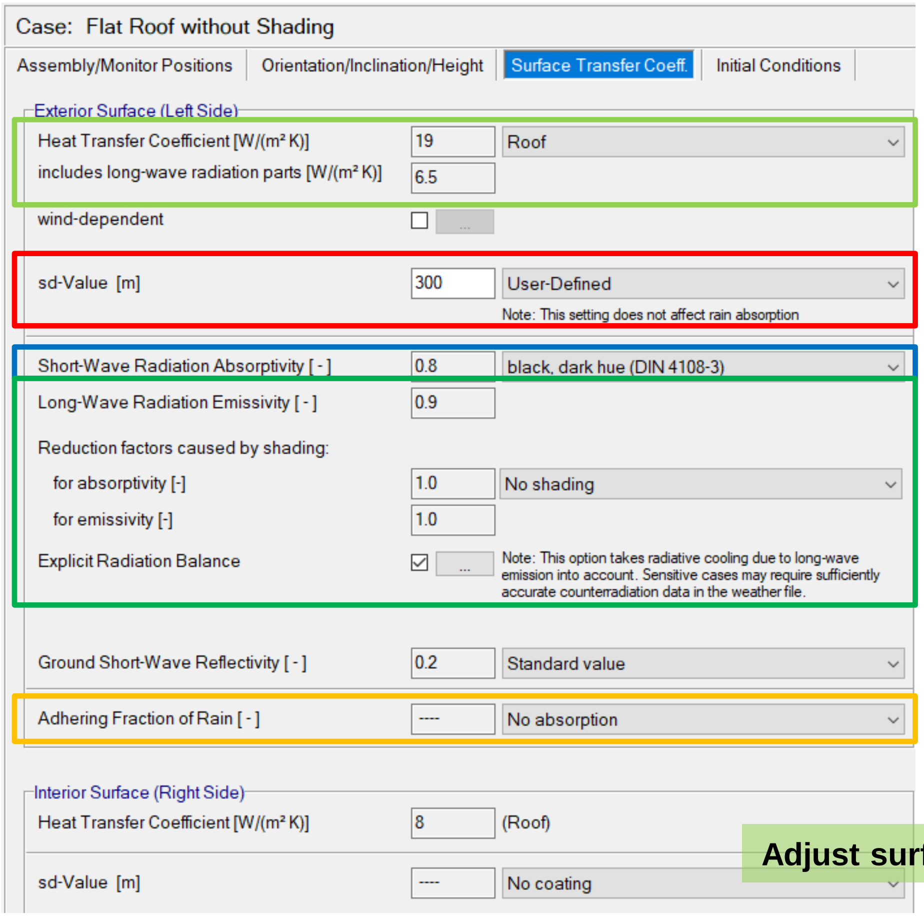
Example: Input - Orientation / Inclination

Input: Component - Orientation



Example: Input - Surface Transfer Coefficients

Input: Component – Surface Transfer Coeff.



Heat Transfer Coefficient for Roof = 19 W/m²K

s_d-value of the roofing membrane = 300 m

Colouring of the roofing felt (here: dark roofing felt with a = 0.8)

Use Explicit Radiation Balance (ε = 0.9)!

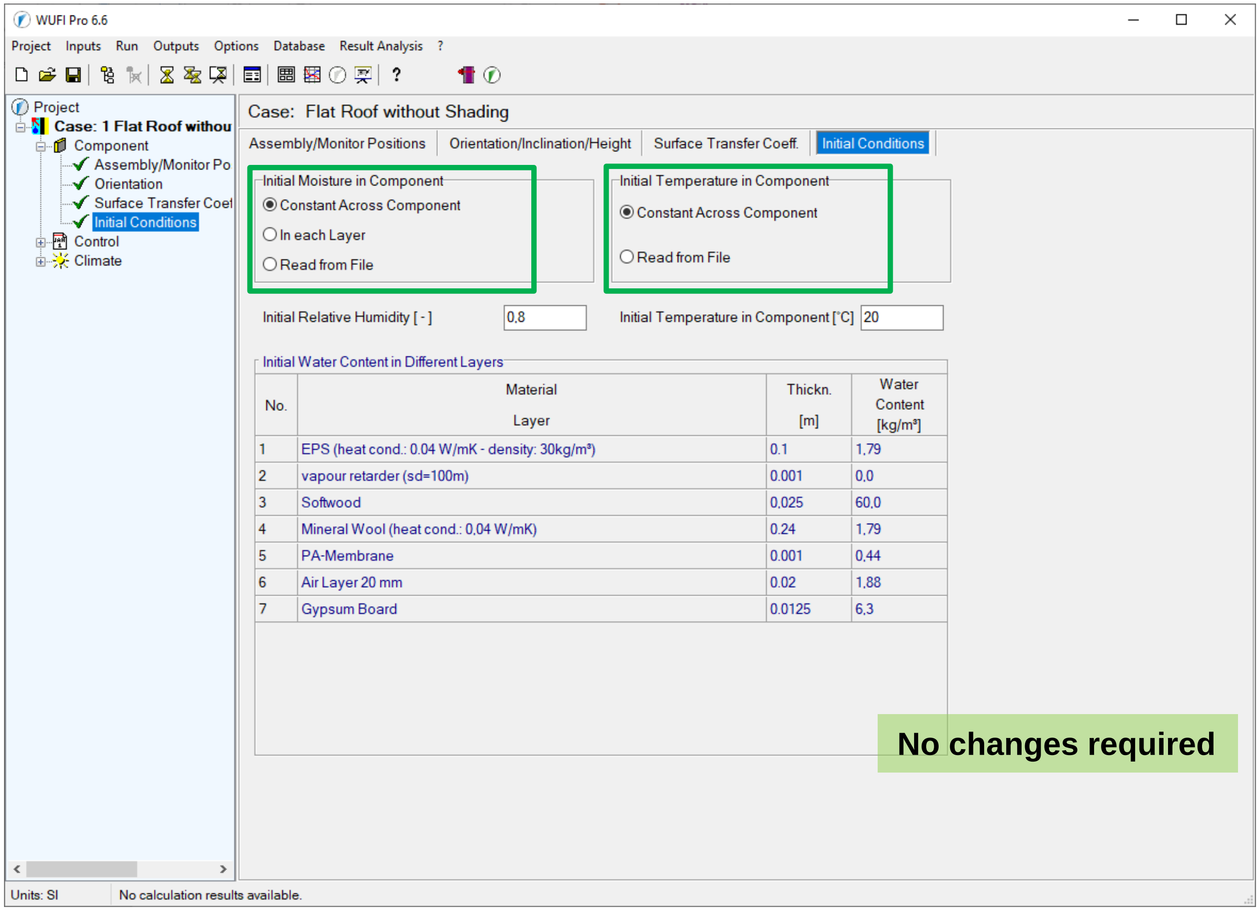
No shading

No Rain Water Absorption!

Adjust surface transfer coefficients!

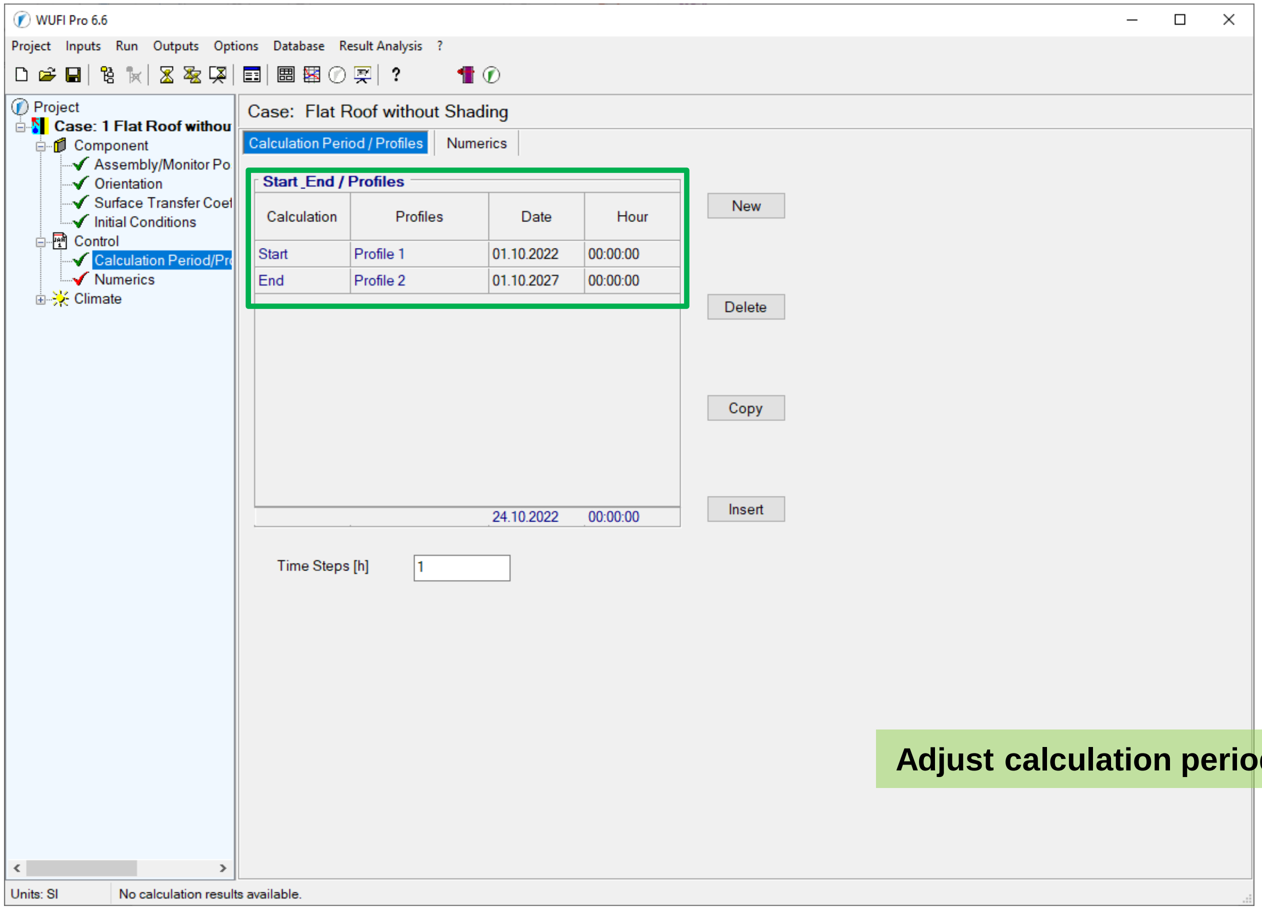
Example: Input - Initial Conditions

Input: Component – Initial Conditions



Example: Input - Calculation Period

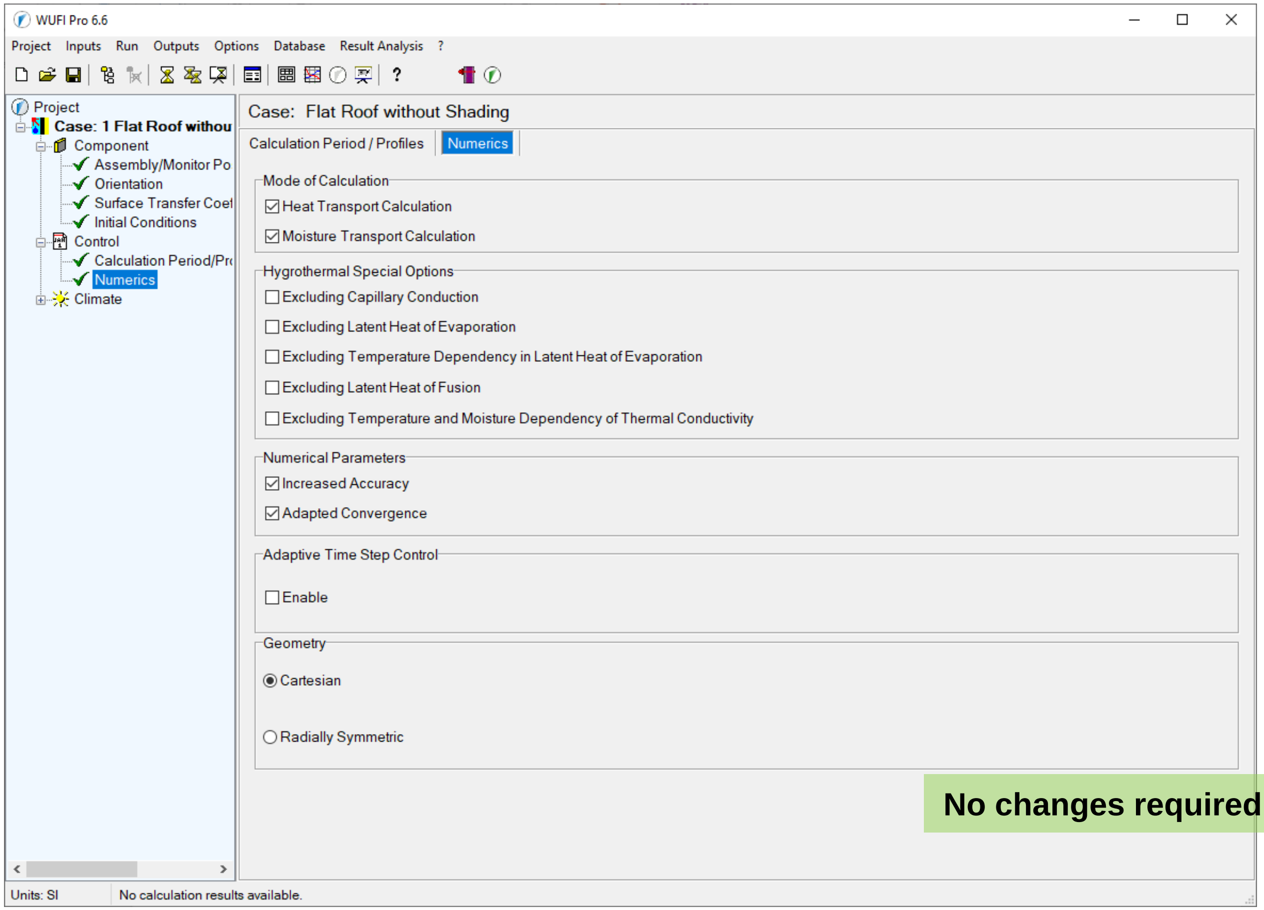
Input: Control – Calculation Period / Profiles



Adjust calculation period

Example: Input - Numerics

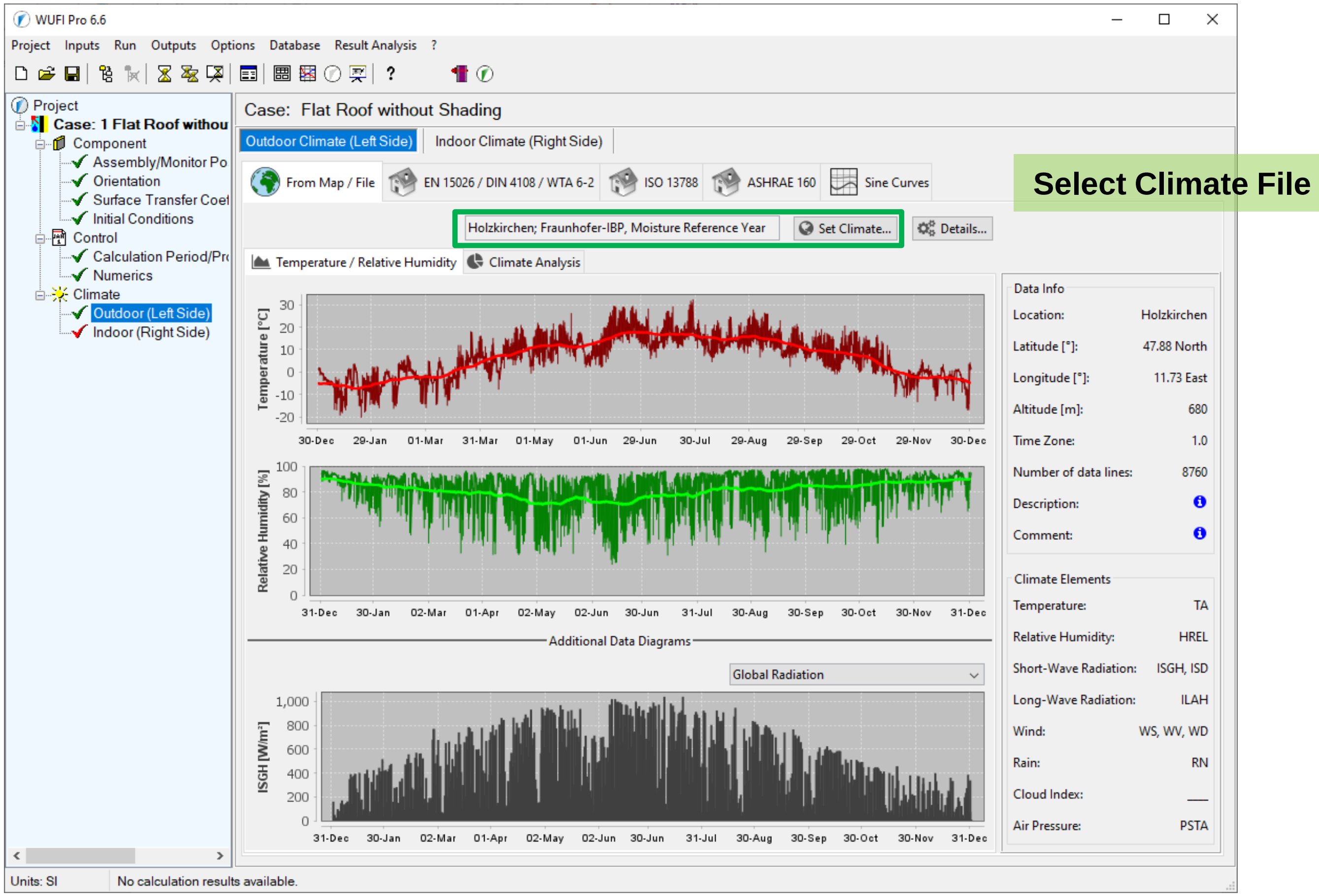
Input: Control – Numerics



No changes required

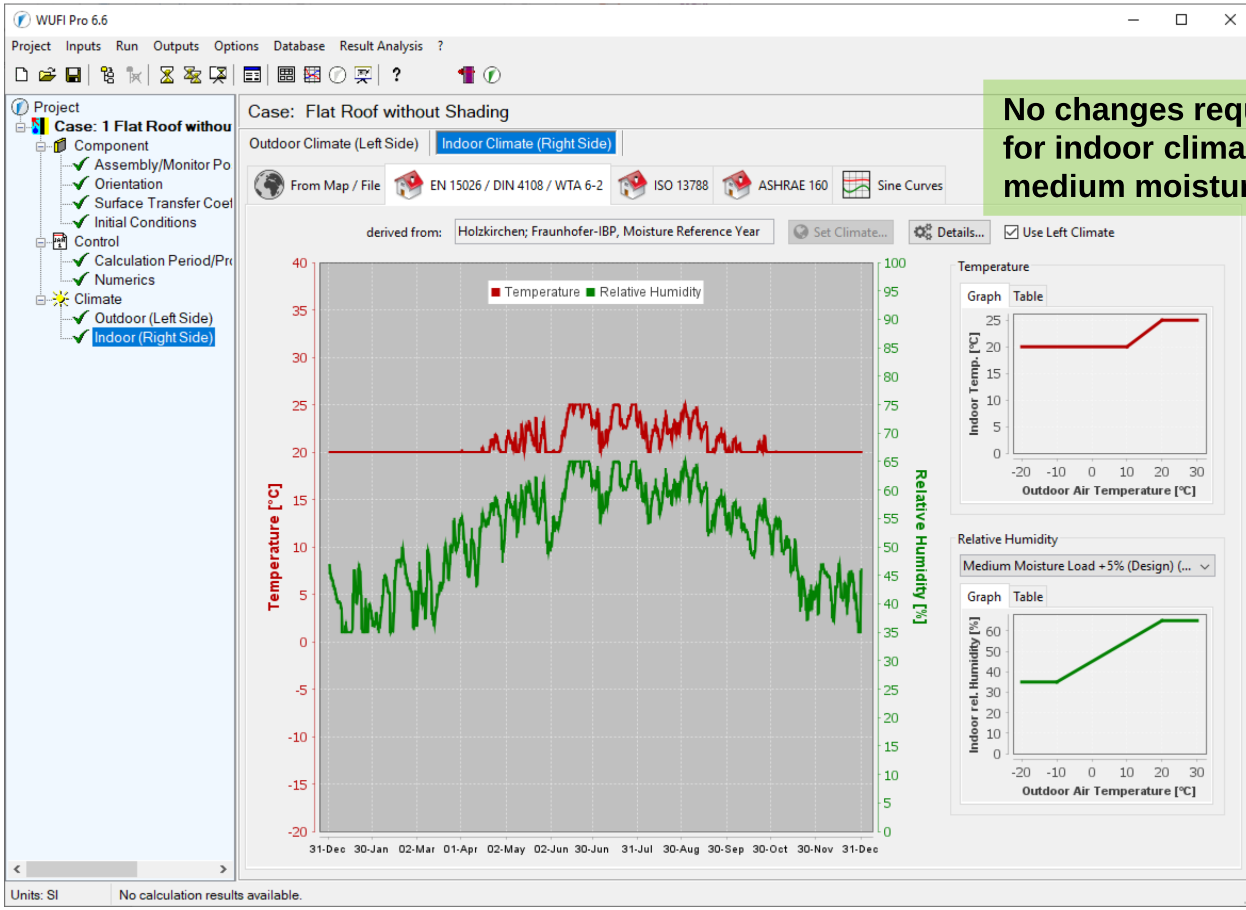
Example: Input - Outdoor Climate

Input: Climate – Outdoor (Left Side)



Example: Input - Indoor Climate

<u>Input:</u> Climate – Indoor (Right Side)



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

Example A: Evaluation – Numerics

__Evaluation:__ Numerics

For more information on the evaluation of the numerical quality, see "Guideline for the Evaluation and Assessment of hygrothermal Calculation Results".

Status of Last Calculation

Status of Calculation

Calculation: Time and Date	24.10.2022 13:48:42
Computing Time	1 min,5 sec.
Begin / End of calculation	01.10.2022 / 01.10.2027
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[kg/m²]	0,0 -0,04
Integral of fluxes, right side (kr,dr)	[kg/m²]	1,2E-7 0,82
Balance 1	[kg/m²]	-0,76
Balance 2	[kg/m²]	-0,76

Water Content [kg/m²]

	Start	End	Min.	Max.
Total Water Content	2,22	1,45	1,42	2,28

Water Content [kg/m³]

Min.	Max.
0,92	1,82

☐ Calculation locked

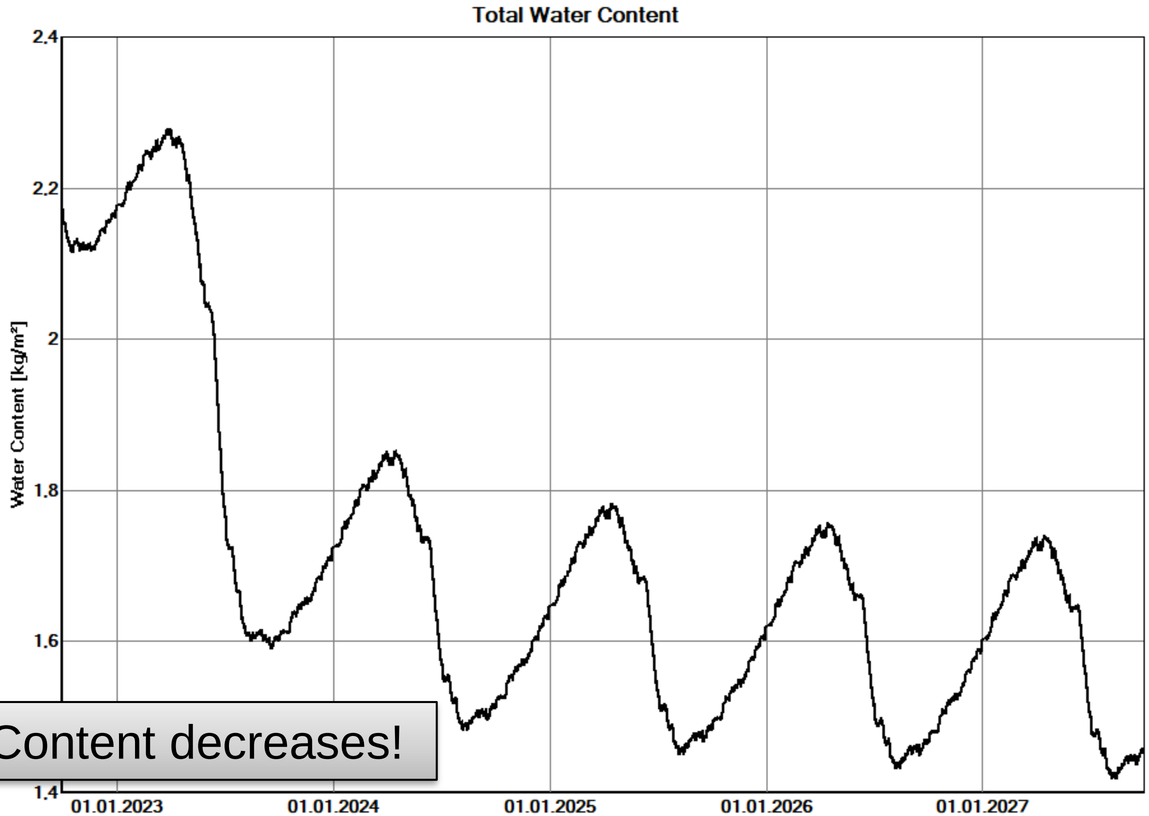
Close Help

No convergence failures and no balance differences!

Fraunhofer IBP

Example A: Evaluation – Total Water Content

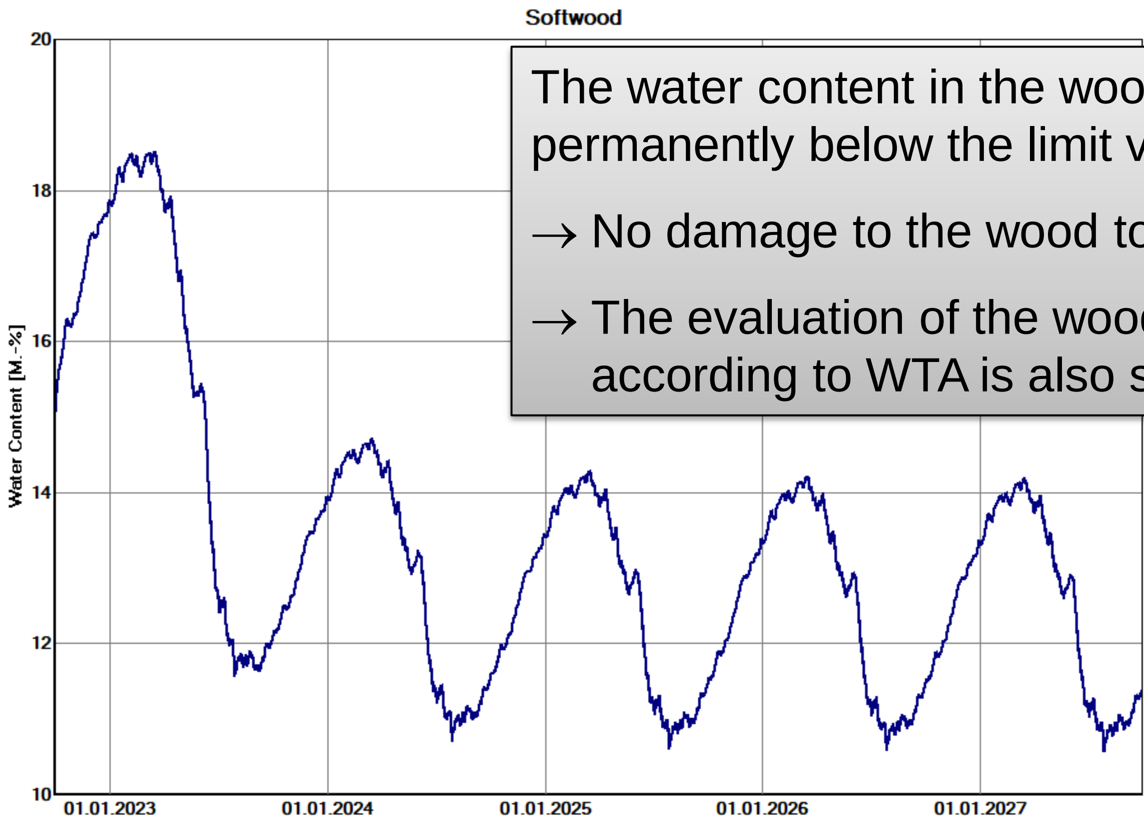
<u>Evaluation:</u> Total Water Content



Total Water Content decreases!

Example A: Evaluation – Wooden Sheathing

Evaluation: Moisture Content in the Wooden Sheathing
– according to DIN 68800



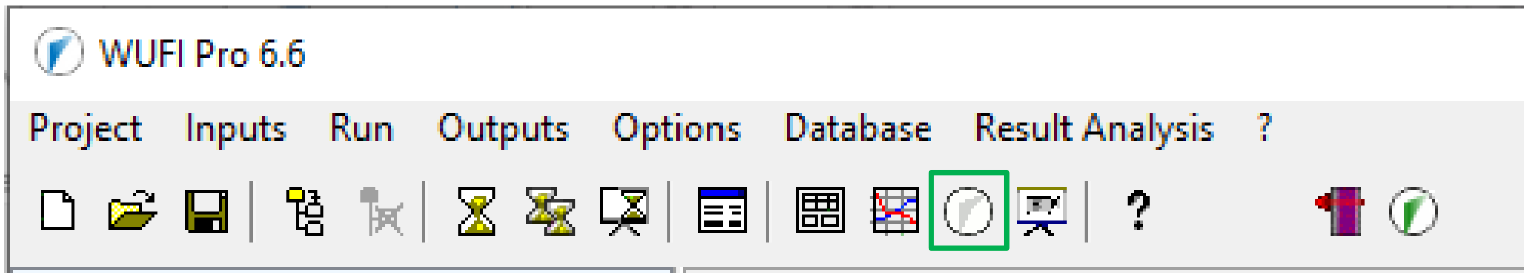
The water content in the wooden sheathing is permanently below the limit value of 20 % by mass.

→ No damage to the wood to be expected

→ The evaluation of the wood moisture content according to WTA is also shown as an example

Example A: Evaluation – Wooden Sheathing

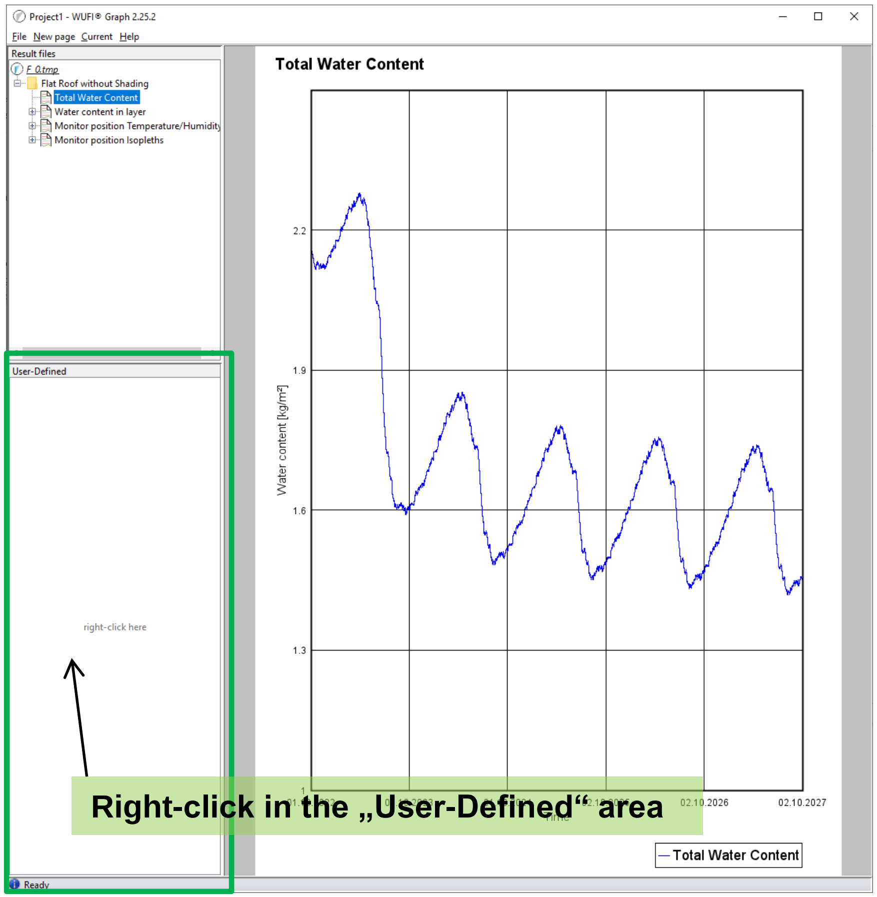
Evaluation: Moisture Content in the Wooden Sheathing
– according to WTA 6-8



Open WUFI Graph

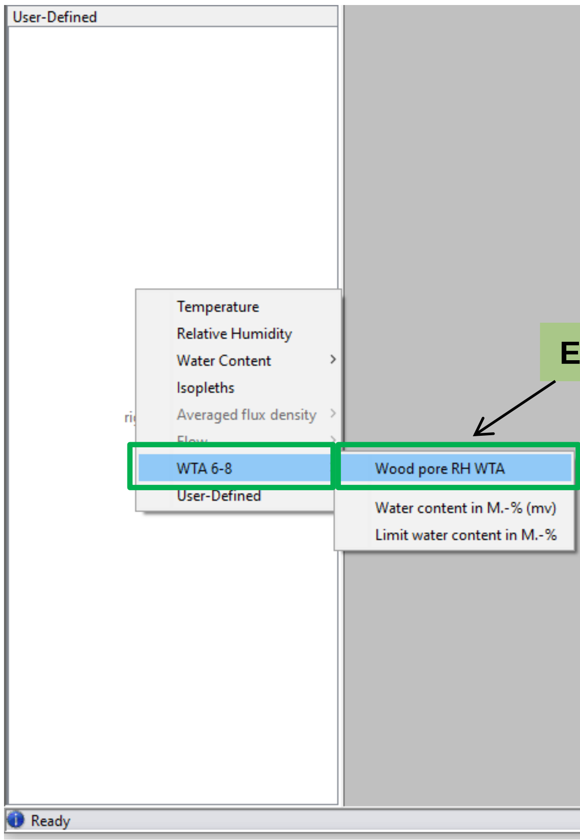
Example A: Evaluation – Wooden Sheathing

Evaluation: Moisture Content in the Wooden Sheathing
– according to WTA 6-8



Example A: Evaluation – Wooden Sheathing

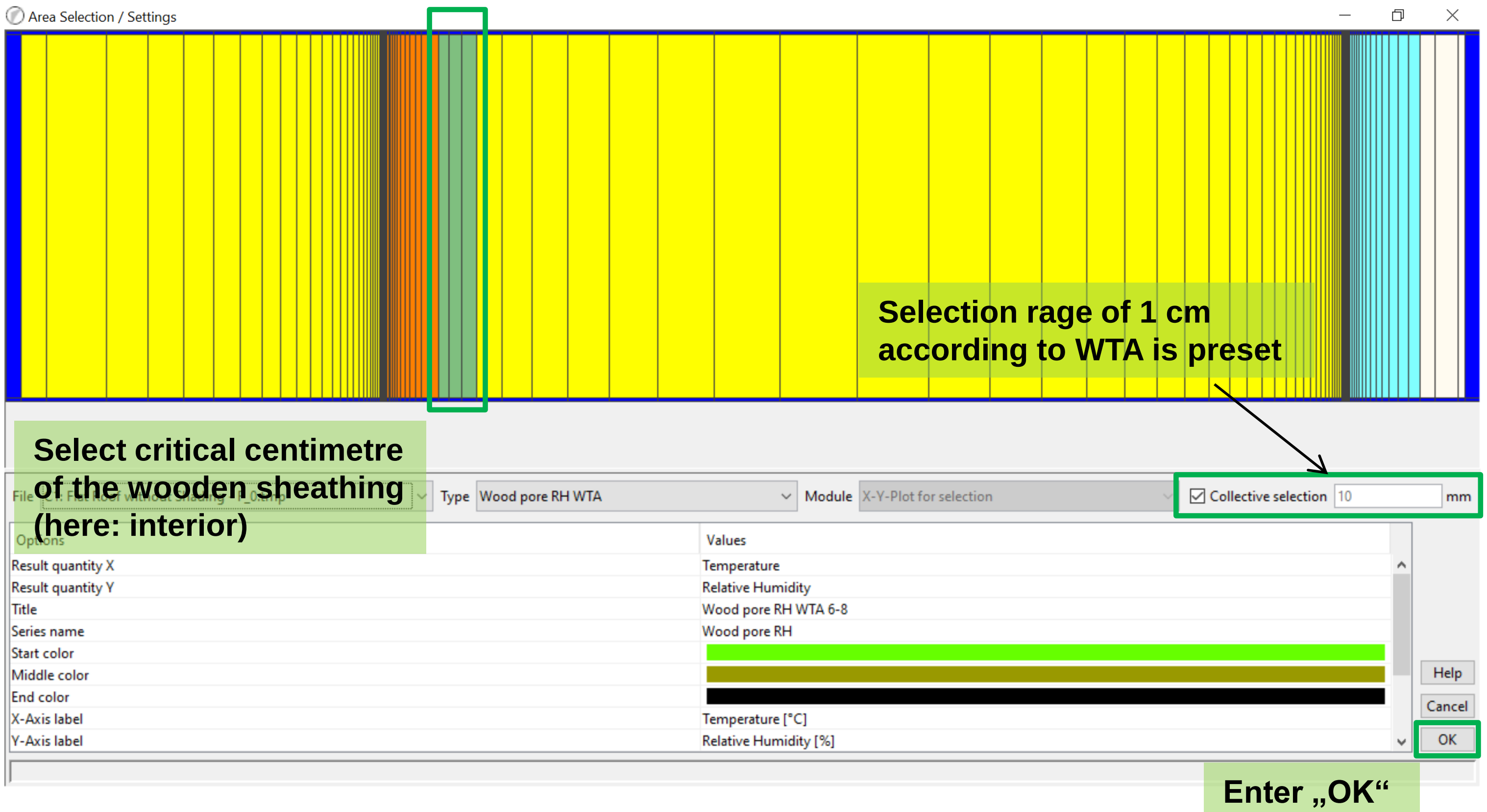
Evaluation: Moisture Content in the Wooden Sheathing
– according to WTA 6-8



Evaluation of the wood pore RH according to WTA

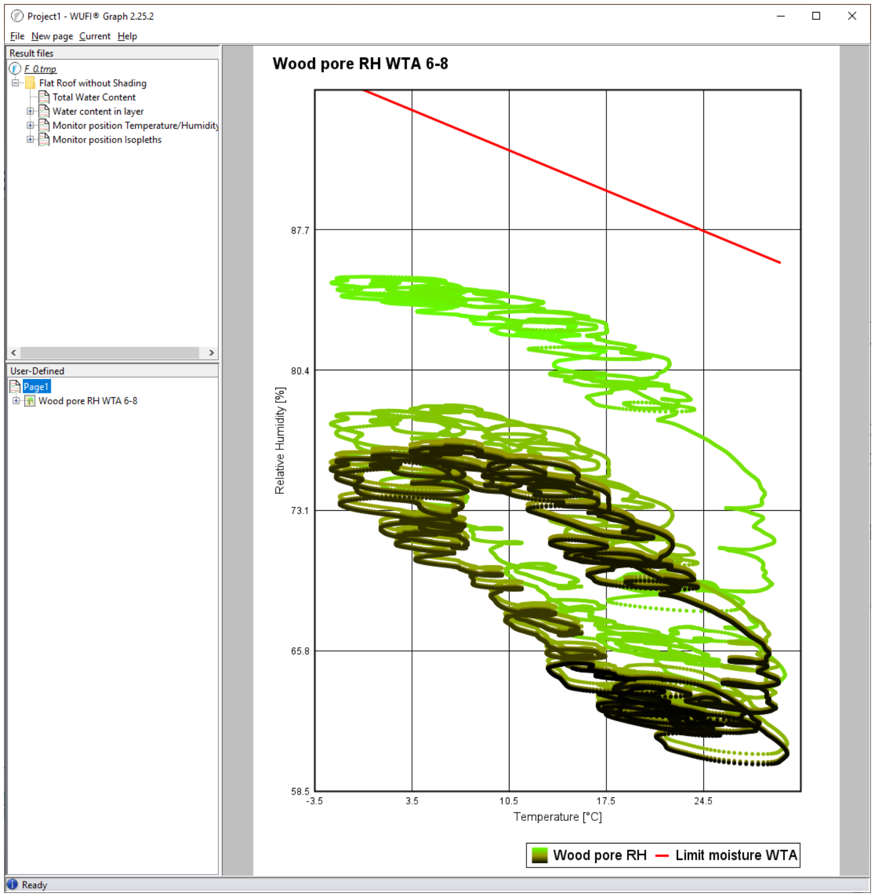
Example A: Evaluation – Wooden Sheathing

Evaluation: Moisture Content in the Wooden Sheathing
– according to WTA 6-8



Example A: Evaluation – Wooden Sheathing

Evaluation: Moisture Content in the Wooden Sheathing
– according to WTA 6-8



The relative pore air moisture in the interior centimetre of the sheathing doesn´t exceed the limits according to WTA.

→ no damage by Wood decay

Example A: Evaluation – final Evaluation

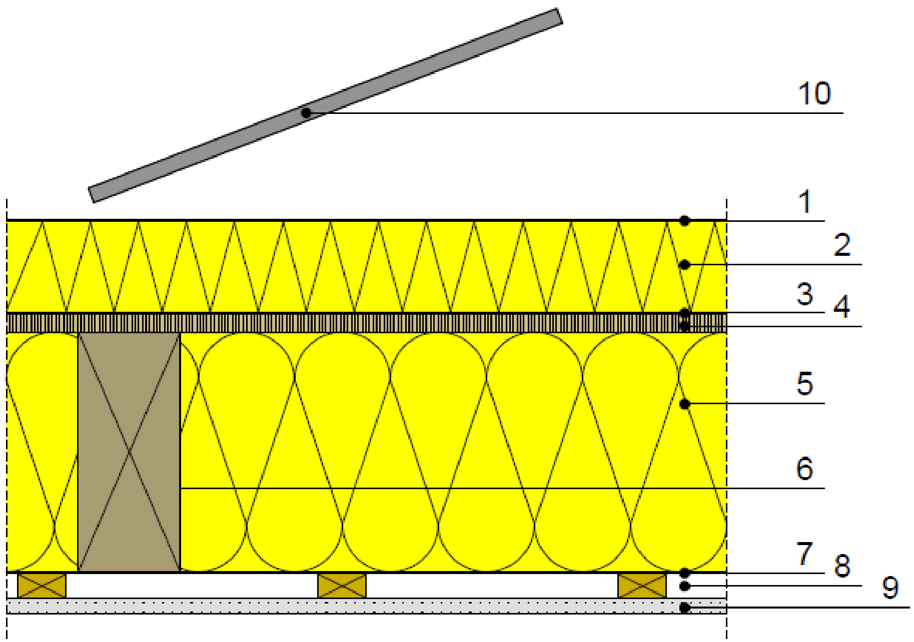
Final Evaluation:

	Criteria	Evaluation
1) Numerical quality	Low balance differences?	✓
	Few or no convergence failures?	✓
2) Evaluation parameters	Total water content steady-state?	✓
	Risk of wood decay in the wooden sheathing? (limit values according to DIN 68800 or WTA 6-8)	✓

Construction unproblematic from the moisture point of view!

Example B: Flat Roof with Shading by PV modules

Example B:
Flat roof in timber construction with shading by rack-mounted PV modules

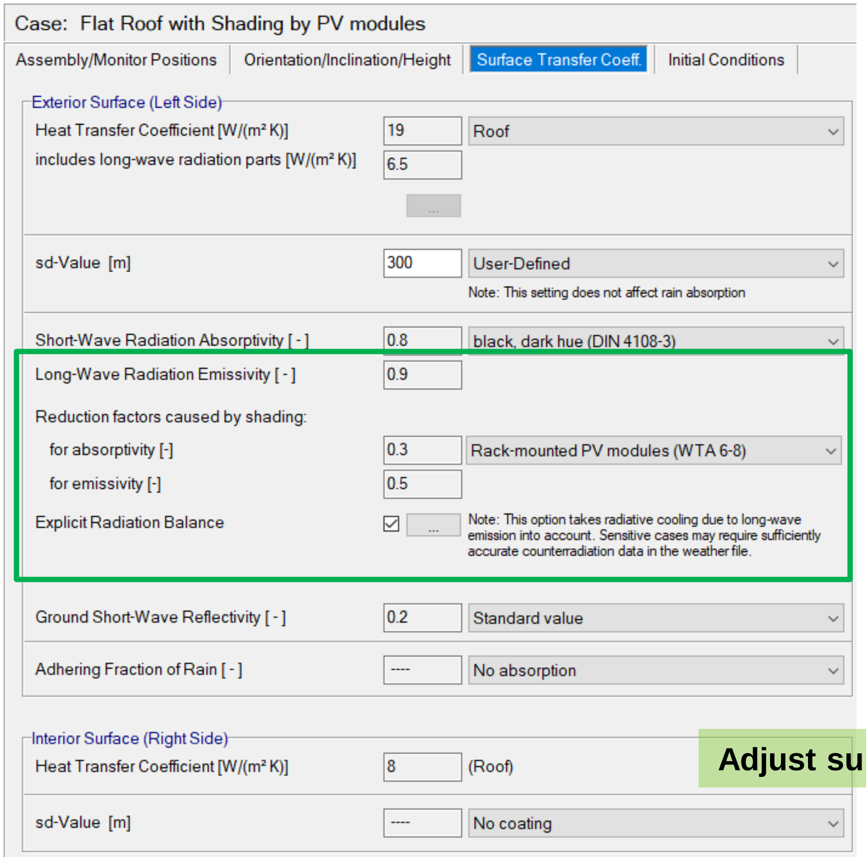


1 Roofing Felt
2 EPS Insulation
3 PE Foil
4 Wooden Sheathing
5 Insulation
6 Rafter
7 Vapour Retarder
8 Installation Layer
9 Gypsum Board
10 PV modules (rack-mounted)

The assembly is identical to example A. The additional shading affects the radiation absorption and emission. Therefore, the reduction factors due to shading are adjusted accordingly!

Example B: Input – Surface Transfer Coefficients

<u>Input:</u> Component – Surface Transfer Coeff.



Use Explicit Radiation Balance (ε = 0.9)!

Shading by rack-mounted PV modules (WTA 6-8)

Adjust surface transfer coefficients!

Fraunhofer IBP

Example B: Evaluation – Numerics

Evaluation: Numerics

For more information on the evaluation of the numerical quality, see "Guideline for the Evaluation and Assessment of hygrothermal Calculation Results".

Status of Last Calculation

Status of Calculation

Calculation: Time and Date	25.10.2022 09:37:09
Computing Time	0 min,57 sec.
Begin / End of calculation	01.10.2022 / 01.10.2027
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[kg/m²]	0,0 -0,03
Integral of fluxes, right side (kr,dr)	[kg/m²]	1,1E-7 0,24
Balance 1	[kg/m²]	-0,13
Balance 2	[kg/m²]	-0,13

Water Content [kg/m²]

	Start	End	Min.	Max.
Total Water Content	2,22	2,1	2,09	2,37

Water Content [kg/m³]

			Min.	Max.
			1,79	1,98

No convergence failures and no balance differences!

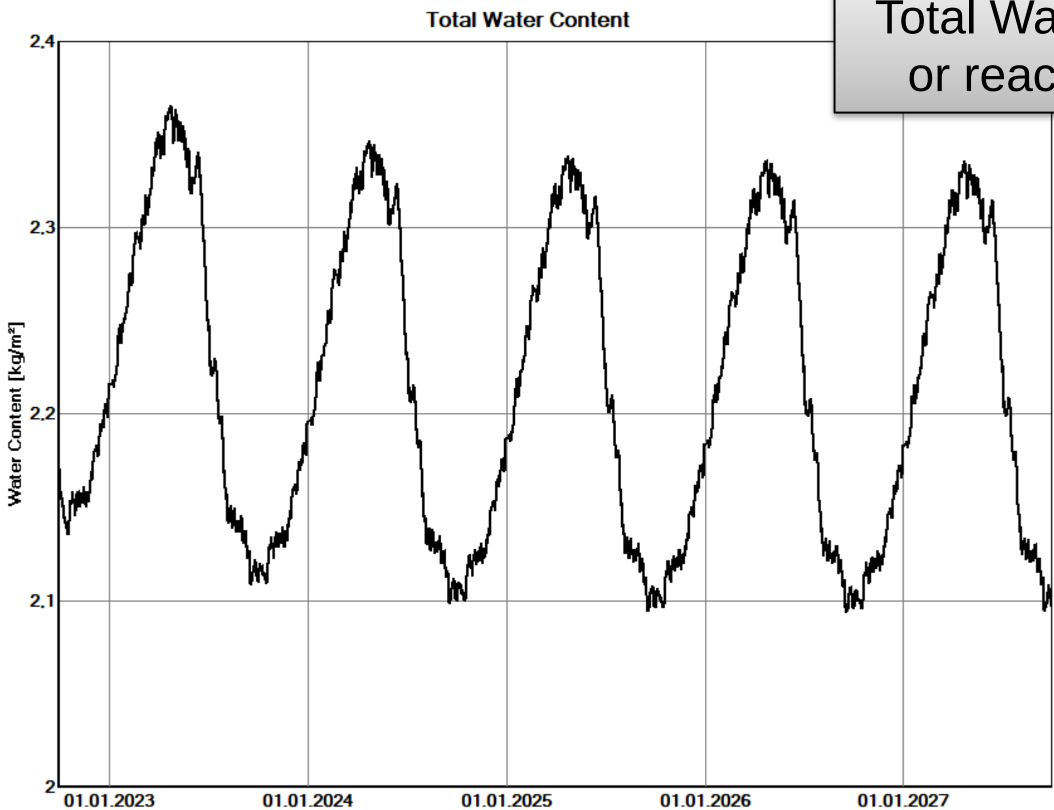
☐ Calculation locked

Close

Help

Example B: Evaluation – Total Water Content

Evaluation: Total Water Content



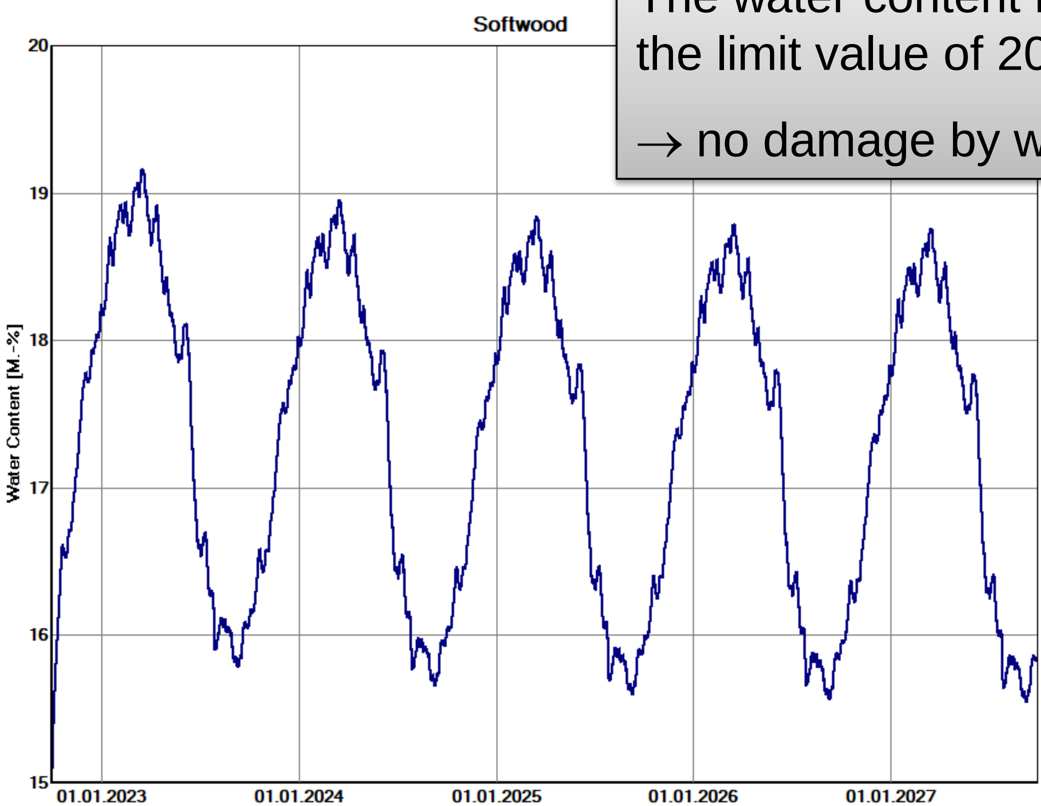
Total Water Content decreases or reaches the settled state!

Example B: Evaluation – Wooden Sheathing

Evaluation: Moisture Content in the Wooden Sheathing
– according to DIN 68800

The water content in the sheathing doesn´t exceed the limit value of 20 % by mass.

→ no damage by wood decay



Example B: Evaluation – final Evaluation

Final Evaluation:

	Criteria	Evaluation
1) Numerical quality	Low balance differences?	✓
	Few or no convergence failures?	✓
2) Evaluation parameters	Total water content steady-state?	✓
	Risk of wood decay in the wooden sheathing? (limit values according to DIN 68800 or WTA 6-8)	✓

⬇

Construction unproblematic from the moisture point of view!