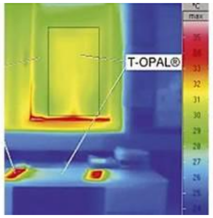
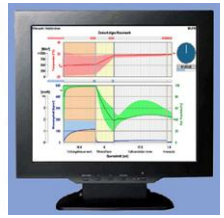
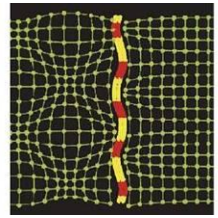




WUFI®

Guideline for the Calculation of Gravel Roofs

Date: July 2026

Fraunhofer
IBP

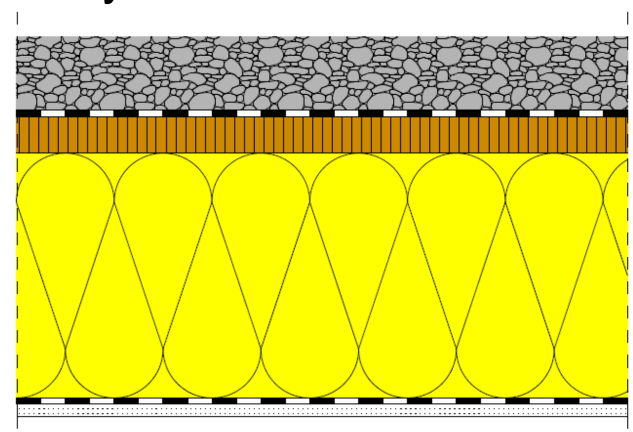
Content

Gravel Roof Material Data in the WUFI® - Material Database

Material Data Set „Generic Gravel":

The **hygrothermal material properties** of a gravel layer have been **adapted by recalculations of field tests and measurements** which were performed on gravel roofs in Holzkirchen, Gräfelfing (both Southern Germany) and Milan (Italy).

In the gravel layer there is **no capillary transport** – the **rainwater** which runs through the gravel layer **has to be modelled by a moisture source**. The moisture source is spread over the whole layer with the exception of the outermost element – by adding the moisture source in the outermost element numerical problems and differences in the balances may be caused.



Fraunhofer IBP

Input: Component Assembly and Grid Setting

Component – Assembly

Generic gravel layer

The generic gravel layer must be specified with the required thickness. The material is available directly in the WUFI® Material Database under *Fraunhofer-IBP* → *Green and Gravel Roofs*.

Underlying Roof Assembly

The underlying layers must be entered according to the structure in the simulation axis (e.g. insulated cavity).

Grid Setting

Recommended grid setting:
Automatic (II) with 200 elements (corresponds to default setting)

Input: Moisture Source in the Gravel

Component – Assembly

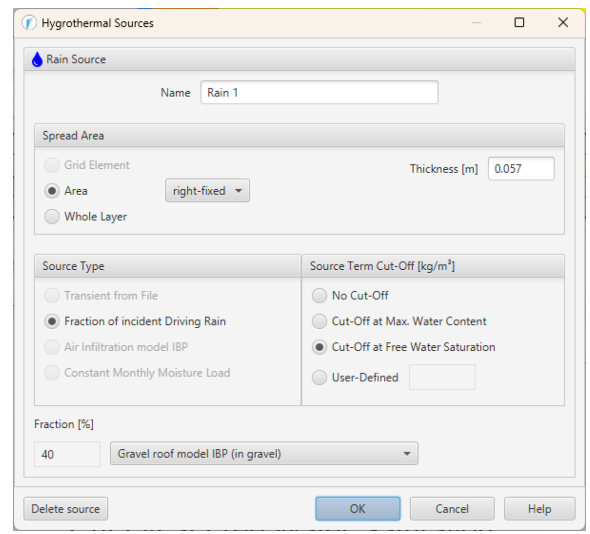
Moisture Source in the Gravel Layer

To account for the water passing through the gravel layer, a moisture source must be applied throughout the whole layer with the exception of the outermost element.

Note: Applying the moisture source to the outermost element may result in numerical problems and balance differences.

Settings:

- Spread Area: Area – right-fixed
  Thickness: Gravel layer thickness minus approx. 0.003 m
- Source Type: Fraction of incident Driving Rain
- Source Term Cut-Off:
  Cut-Off at Free Water Saturation
- Fraction: 40% (Gravel roof model IBP)



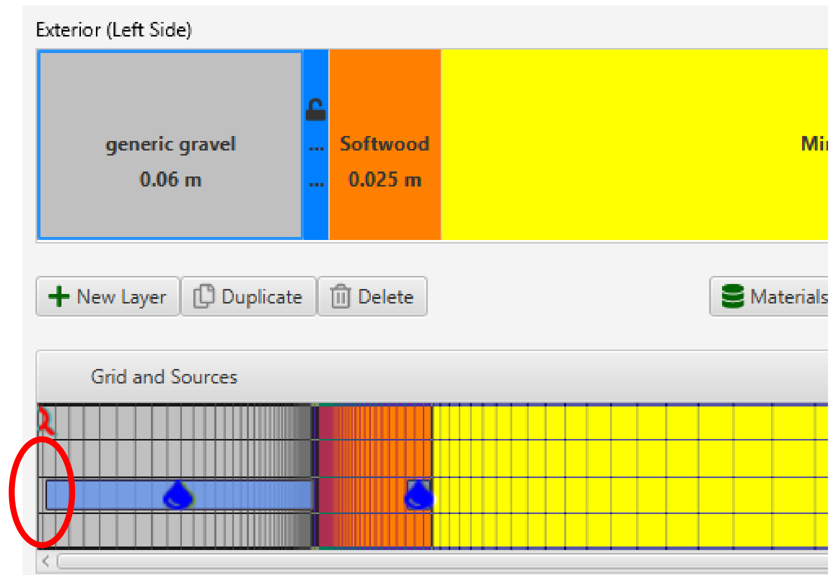
Input: Moisture Source in the Gravel

Component – Assembly

Moisture Source in the Gravel Layer

Note on entering the thickness of the moisture source:

- The distribution of the grid elements varies depending on the component assembly.
- The thickness of the source should be selected so that the moisture source is not located in the outer element of the gravel layer.
- This can be checked visually in the component assembly.



Input: Infiltration Source

Component – Assembly

Moisture Source – Infiltration (only for wooden structures)

According to DIN 68800 [2], the amount of moisture that convectively enters the construction as a function of the air tightness must always be assessed for wooden structures and can be taken into account in the simulation using the infiltration model of the IBP.

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

Recommended settings for roofs:

- 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

Input: Infiltration Source

Component – Assembly

Moisture Source – Infiltration (only for wooden structures)

The amount of moisture entered during cold periods is automatically determined in the program from the overpressure due to the thermal buoyancy in the building (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®

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 construction moisture contents are known, these can be specified separately for each individual layer.

Input: Outdoor Climate

Boundary Conditions (exterior) – Climate

Outdoor Climate:

An outdoor climate appropriate for the building location must 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, with 20% reduced radiation, is considered critically representative of German locations up to altitudes of 700 m. This can be set 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 [8].

Input: Orientation / Inclination

Boundary Conditions (exterior) – Orientation

Orientation

The relevant orientation for the Northern hemisphere is usually North, as here the lowest radiation gains occur. However, the orientation is only of minor importance for very low roof pitches.

Roof Inclination

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

Input: Surface Transfer Coefficients (exterior)

Boundary Conditions (exterior) – Surface

Heat transfer

The heat transfer coefficient at the exterior surface of gravel roofs is assumed to be 19 W/m²K.

Radiation

Selection (drop-down menu): Roof → Gravel roof, generic model

According to the gravel roof model, the short-wave radiation absorption coefficient is 0.5. The long-wave radiation emission is 0.93. For roofs, the radiative overcooling must always be switched on due to the large field of view to the sky in order to take into account overcooling as a result of long-wave radiation.

Rain

Rain must be taken into account when simulating gravel roofs.

Input: Indoor Climate

Boundary Conditions (interior) – Climate / Surface

Indoor Climate:

For design purposes, an indoor climate with medium moisture load + 5% (according to DIN 4108-3 [3] and EN 15026 [6]) is recommended.

Alternatively, depending on the use of the building, the indoor climate with low moisture load (according to EN 15026 [6]) or with medium or high moisture load (according to DIN 4108-3 [3] and EN 15026 [6]) can be applied. For example, constant or measured conditions can also be applied.

Heat Transfer:

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

Control

Period of Calculation:

It is recommended to start the calculation on October 1, 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 the time the construction needs to reach steady state conditions. Gravel roofs usually require a calculation time of about 10-15 years.

Notes on the Evaluation of Gravel Roofs

Calculation Quality

Status of Calculation

Calculation: Time and Date	Mar 19, 2026, 4:04 PM
Start / end of the computed time period	Oct 1, 2025 / Oct 1, 2035
Calculation Period	0:03:06.913
Currently simulated time step	Oct 1, 2035, 12:00 AM

Check for numerical quality

No. of Convergence Failures		**135**	
Sum of diffusive fluxes (left/right)	[kg/m²]	-1109.836	0.469
Sum of capillary fluxes (left/right)	[kg/m²]	0.000	0.000
Balance (mass vs. sum of surface-fluxes)	**[kg/m²]**	**2.787**	**2.776**

- The differences in the balances should remain as small as possible.

- The number of convergence failures is not a decisive factor, but a high number indicates difficult convergence.
  However, in the case of gravel roofs, the large amounts of moisture in the gravel roof structure (driving rain source) can lead to a higher number of convergence failures. These usually occur in the gravel layer and often have no or only a marginal effect on the underlay construction.

- If the water content curves in the layers of the underlay construction do not show any abnormalities (e.g. abrupt jumps, peaks, etc.), the result is usually acceptable.

Notes on the Evaluation of Gravel Roofs

Gravelled lightweight constructions

The evaluation procedure and the evaluation criteria are almost identical to those for normal flat roofs and can be found in the Guideline for the calculation of flat roofs

The evaluation of the moisture conditions in a possibly existing additional insulation of the outer sheathing is explained on the following slides.

Notes on the Evaluation of Gravel Roofs

Additional evaluation in the case of an additional insulation

A slow accumulation of moisture is often observed in the additional insulation of the exterior sheathing, therefore moisture-insensitive materials should preferably be used in this area.

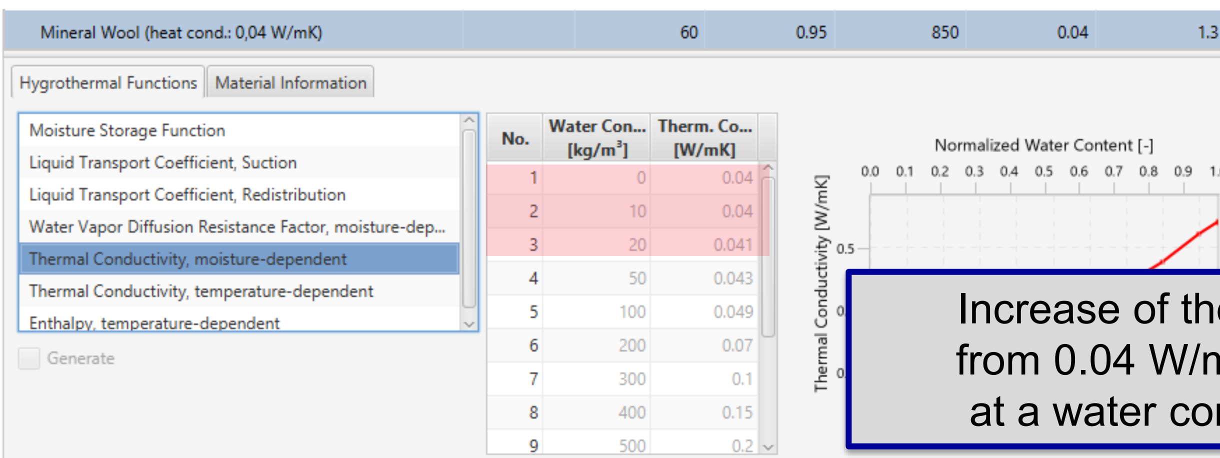
- Moisture leads to an increase in thermal conductivity - but this increase usually remains so small (see next slide) that it appears negligible even for typical service lives of 25 years.
- In rigid-foam insulation, moisture remains in the pore structure of the material - i.e. usually without any further consequences for the material or construction.
- In fibre insulation, dew water can possibly run off into other component layers and damage them - this effect must be considered separately!

Notes on the Evaluation of Gravel Roofs

<u>Additional evaluation in the case of an additional insulation</u>

The example shows the water content of a mineral wool insulation, which increases to about 20 kg/m³ over the service life of the roof (converted to a thickness of 6 cm, this corresponds to about 1.2 kg/m²).

The effect on the thermal conductivity can be taken from the material data. In this case, it increases by about 2.5 % from 0.04 to 0.041 W/mK. If the additional insulation is relevant for the U-value of the component, the effect could be compensated by using insulation that is about 1.5 mm thicker.



Increase of thermal conductivity from 0.04 W/mK to 0.041 W/mK at a water content of 20 kg/m³.

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, March 2024.

[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.

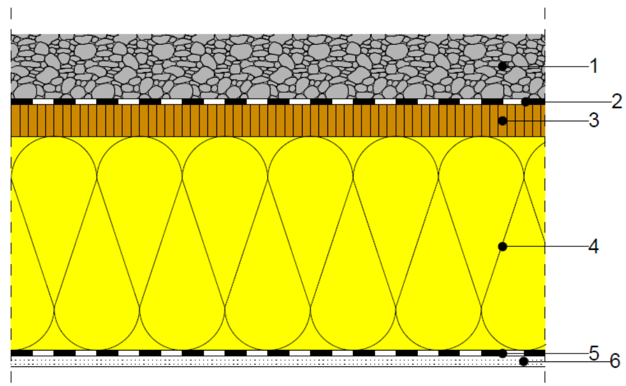
[5] WTA Guideline 6-2: Simulation of heat and moisture transfer. October 2025.

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

Examples: Gravel roof on lightweight construction

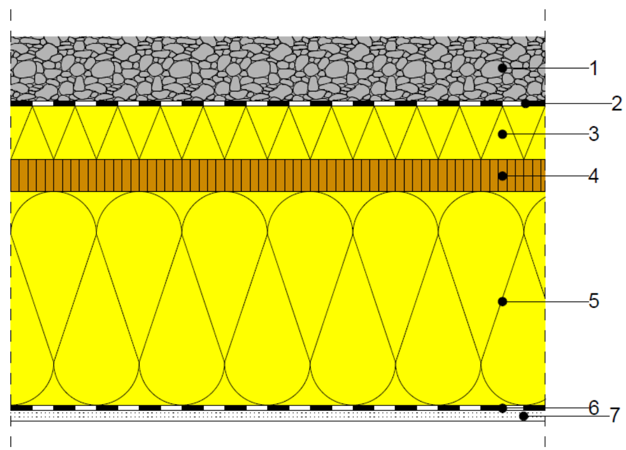
The following section describes the evaluation procedure for gravel roofs on lightweight constructions using two example cases. It presents the required material data, moisture sources, boundary conditions, and the evaluation procedure for the roof assembly.

<u>Example A:</u>
Gravel roof on a lightweight construction without additional insulation



1 Gravel Layer
2 Roofing Membrane (s_d = 300 m)
3 Wooden Sheathing
4 Mineral Wool
5 Moisture-variable vapour retarder
6 Gypsum Board

<u>Example B:</u>
Gravel roof on a lightweight construction with additional insulation



1 Gravel Layer
2 Roofing Membrane (s_d = 300 m)
3 EPS Insulation
4 Woden Sheathing
5 Mineral Wool
6 Moisture-variable vapour retarder
7 Gypsum Board

Example A: Assembly

Assembly (from outside to inside):

• Generic Gravel	0.06	m
• Roofing Membrane (s_d = 300m)	0.001	m
• Wooden Sheathing (Softwood)	0.025	m
• Mineral Wool (heat cond.: 0.04 W/mK)	0.24	m
• Moisture-variable vapour retarder (Vario KM Duplex)	0.001	m
• Gypsum Board	0.0125	m

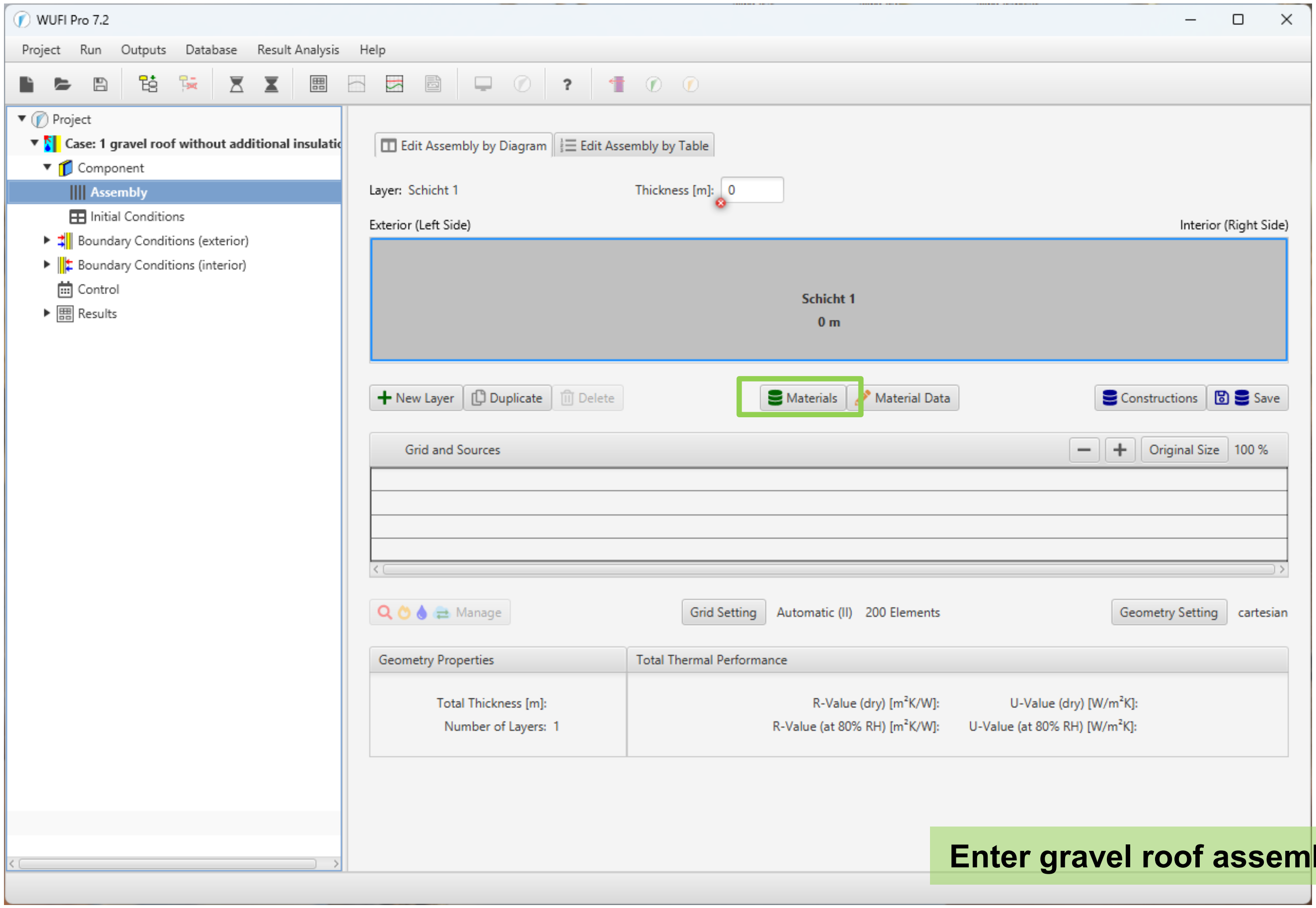
Example A: Boundary conditions

Boundary Conditions:

- Flat roof (3° to the North)
- Short-Wave Radiation Absorptivity / Long-Wave Radiation Emissivity: according to the generic gravel roof model
- 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

Example A: Component Assembly

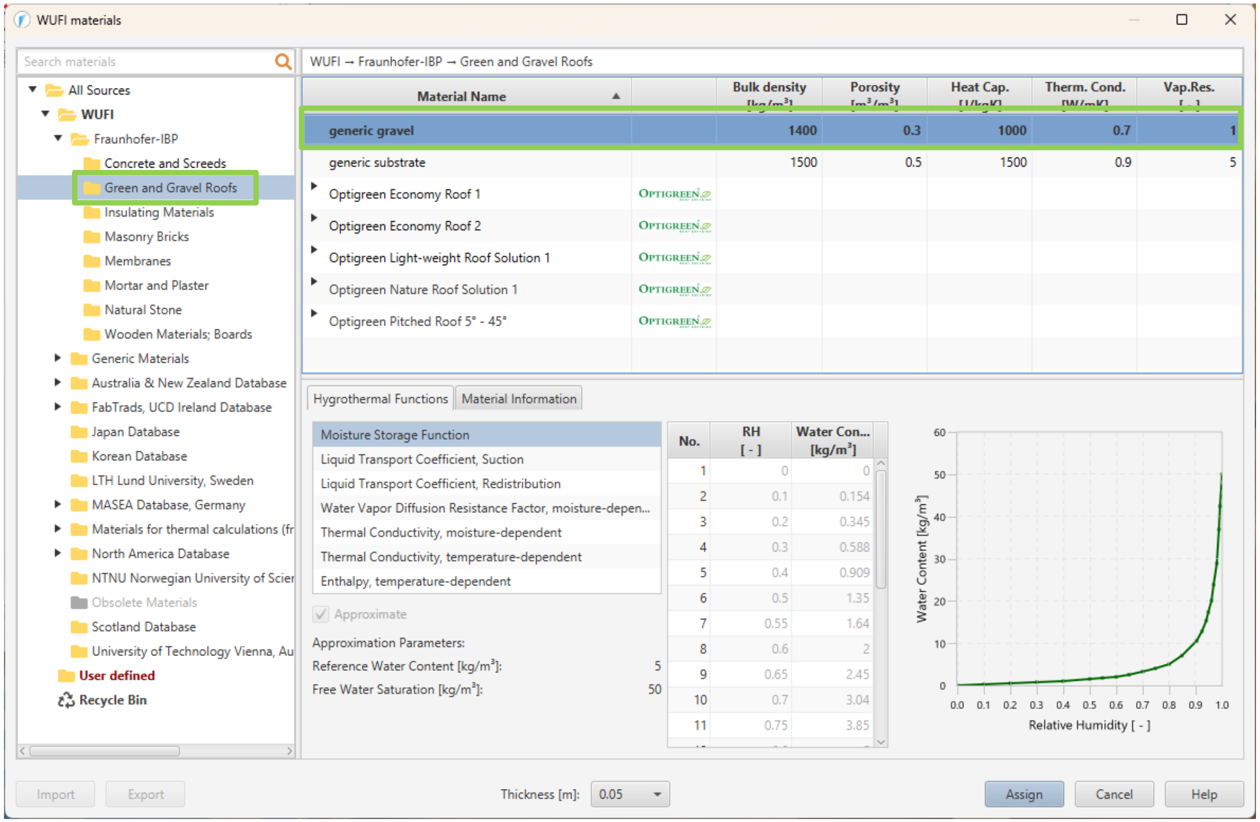
__Input:__ Component – Assembly



Enter gravel roof assembly in single layers

Example A: Component Assembly

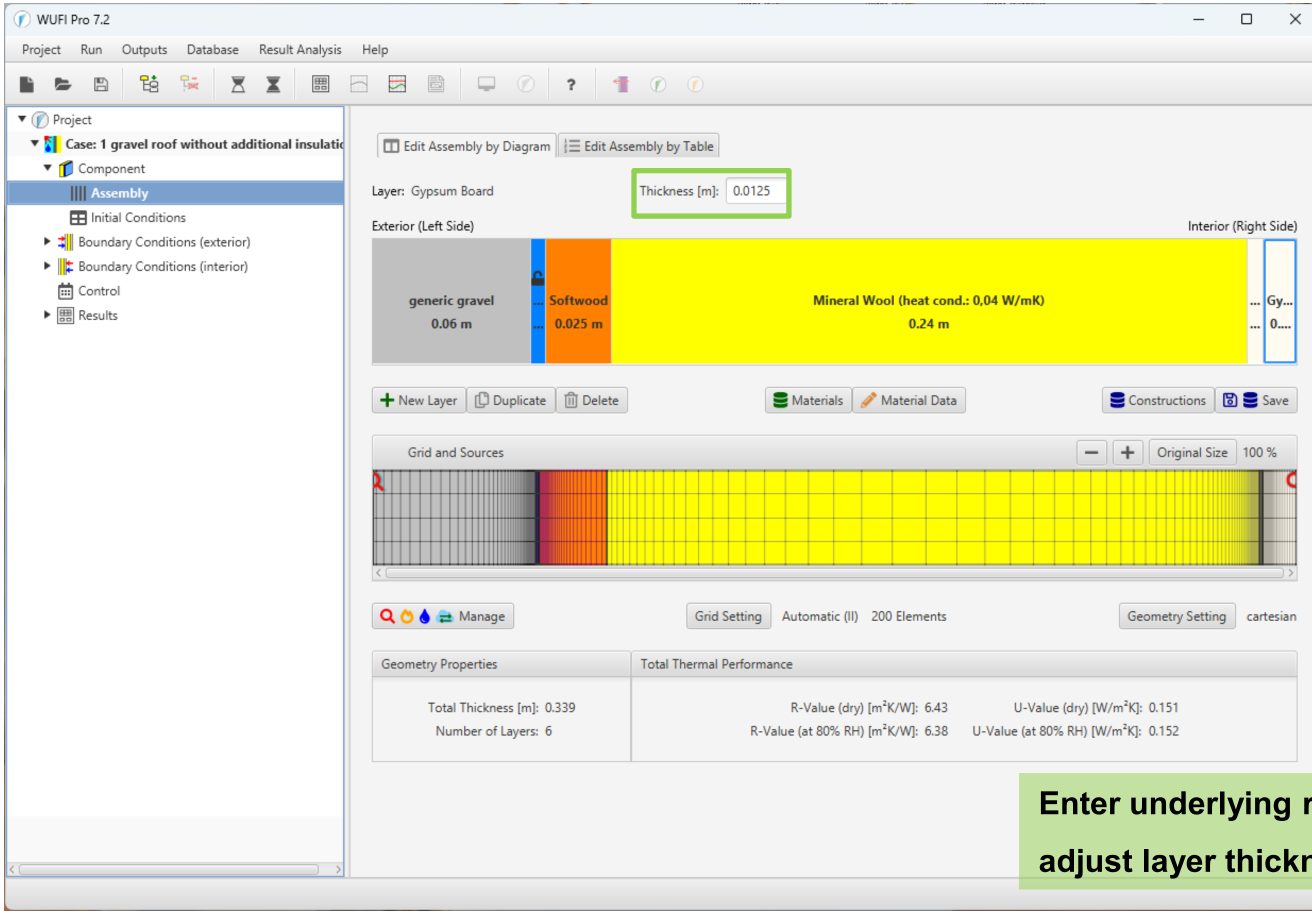
<u>Input:</u> Component – Assembly



Green and gravel roofs → Generic gravel

Example A: Component Assembly

Input: Component – Assembly

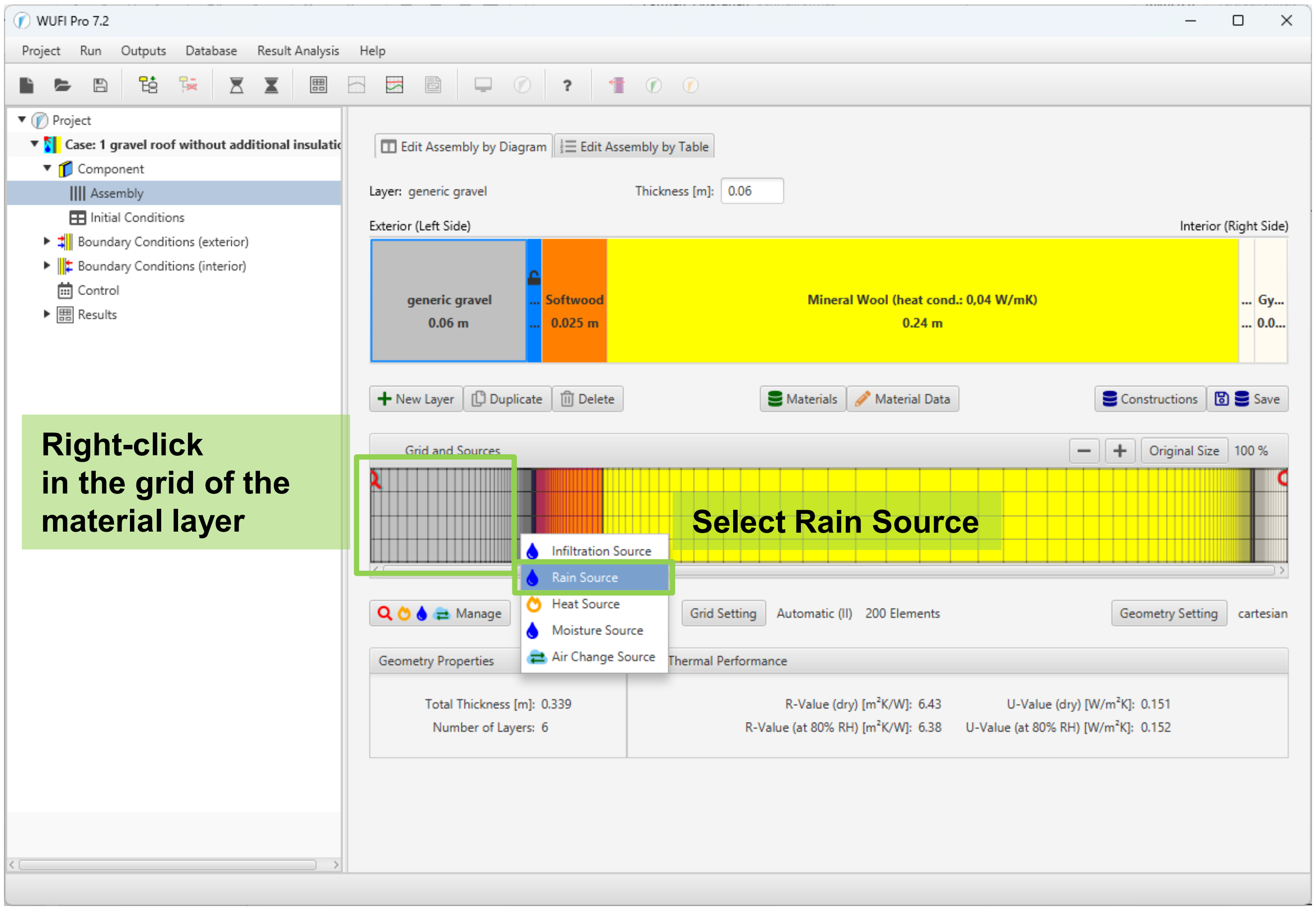


Enter underlying roof construction; adjust layer thicknesses if necessary

Example A: Moisture Source in the Gravel Layer

<u>Input:</u> Component – Assembly

Insert moisture source in the layer "Generic Gravel"



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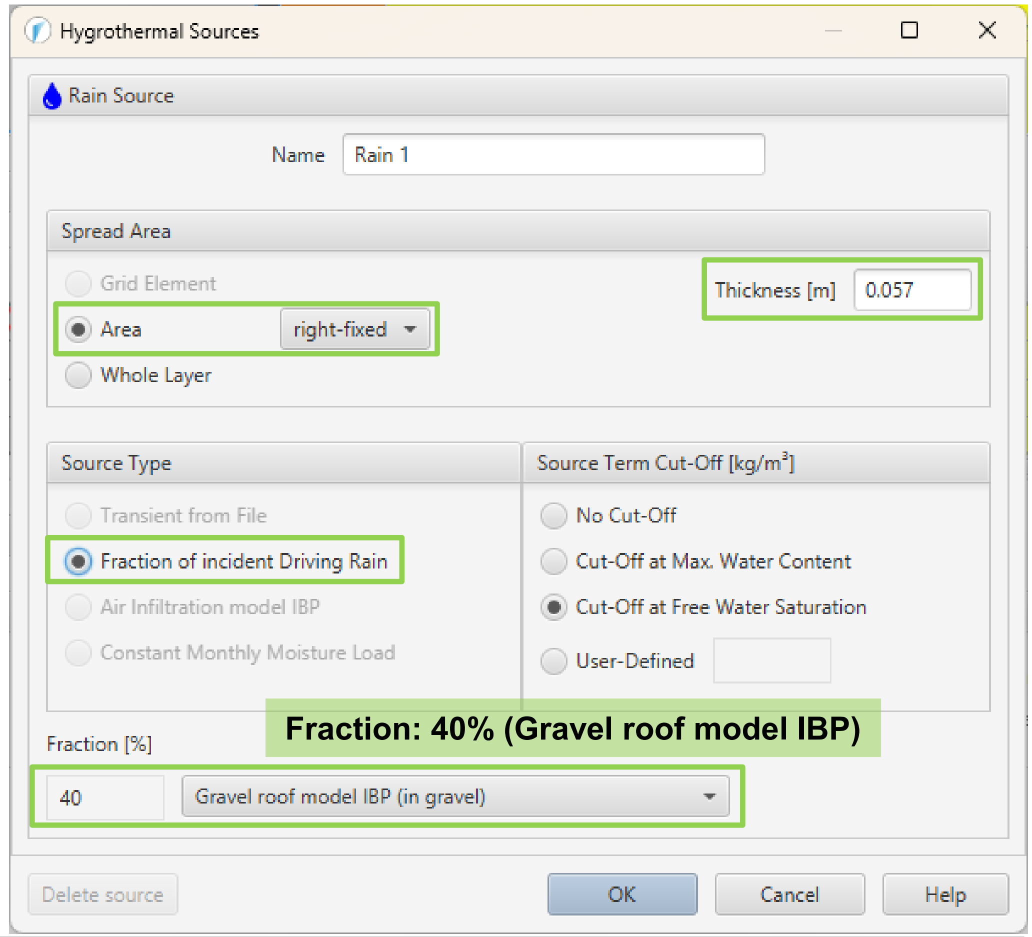
Example A: Moisture Source in the Gravel Layer

<u>Input:</u> Component – Assembly

Moisture source in the whole gravel layer with the exception of the outermost element.

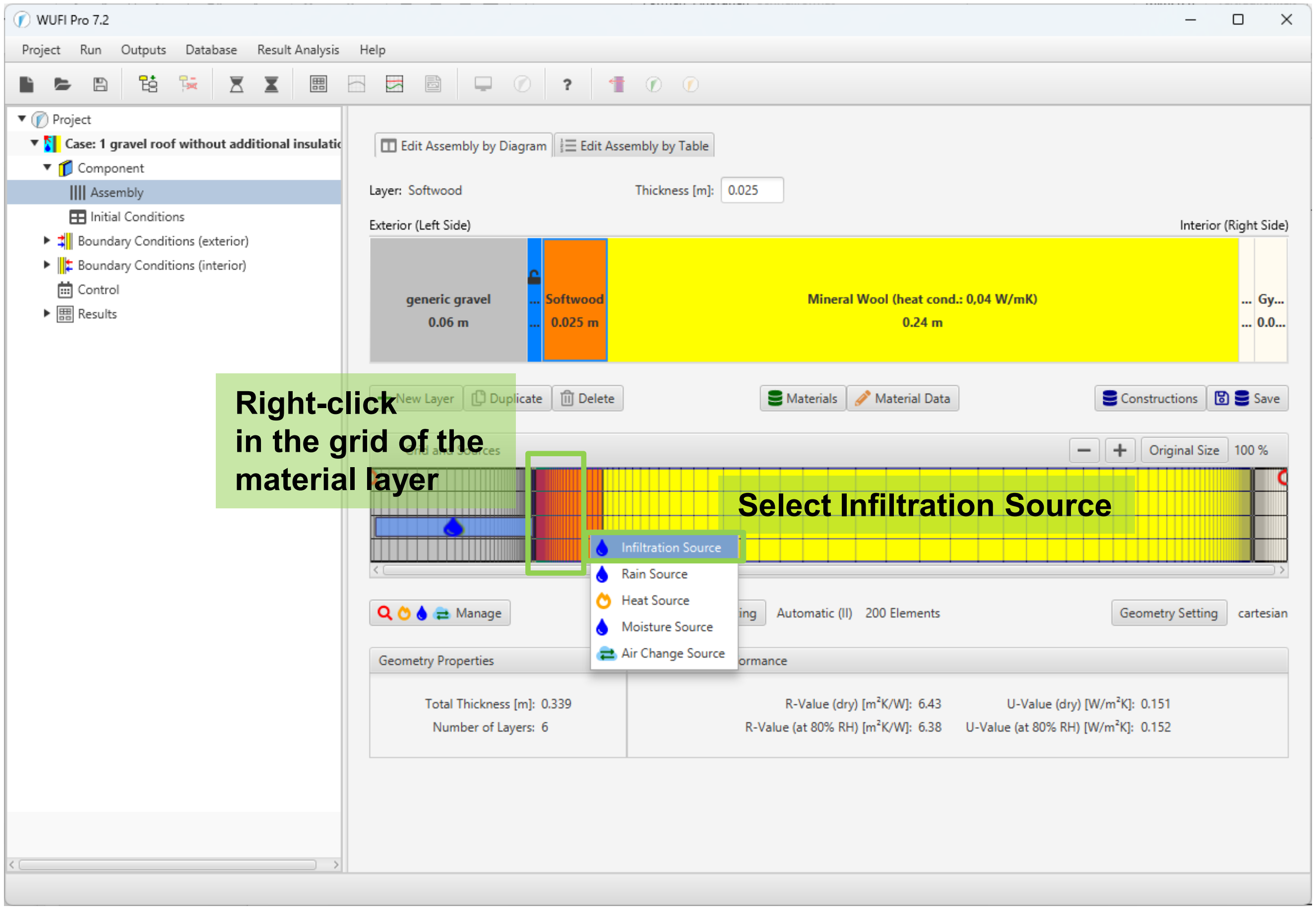
<u>Note:</u>
By adding the moisture source in the outermost element numerical problems and differences in the balances may be caused.



Example A: Infiltration Source

Input: Component – Assembly

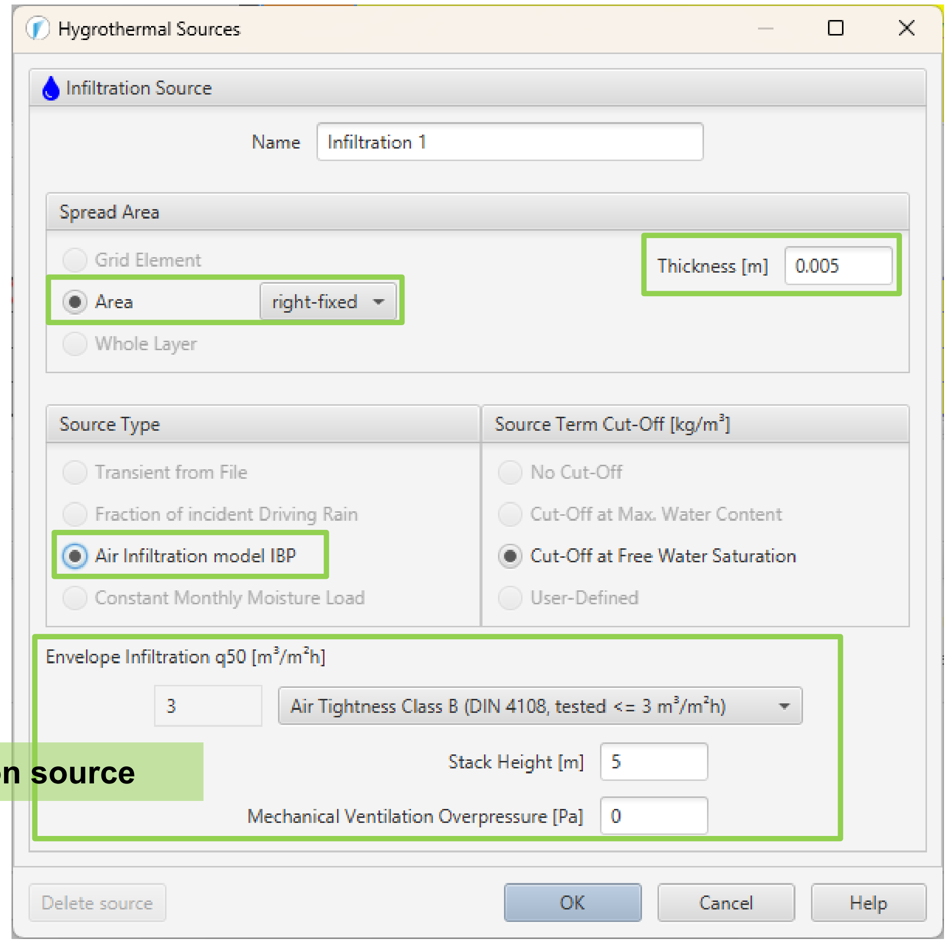
Infiltration source according to DIN 68800 in the wooden sheathing



Example A: Infiltration Source

Input: Component – Assembly

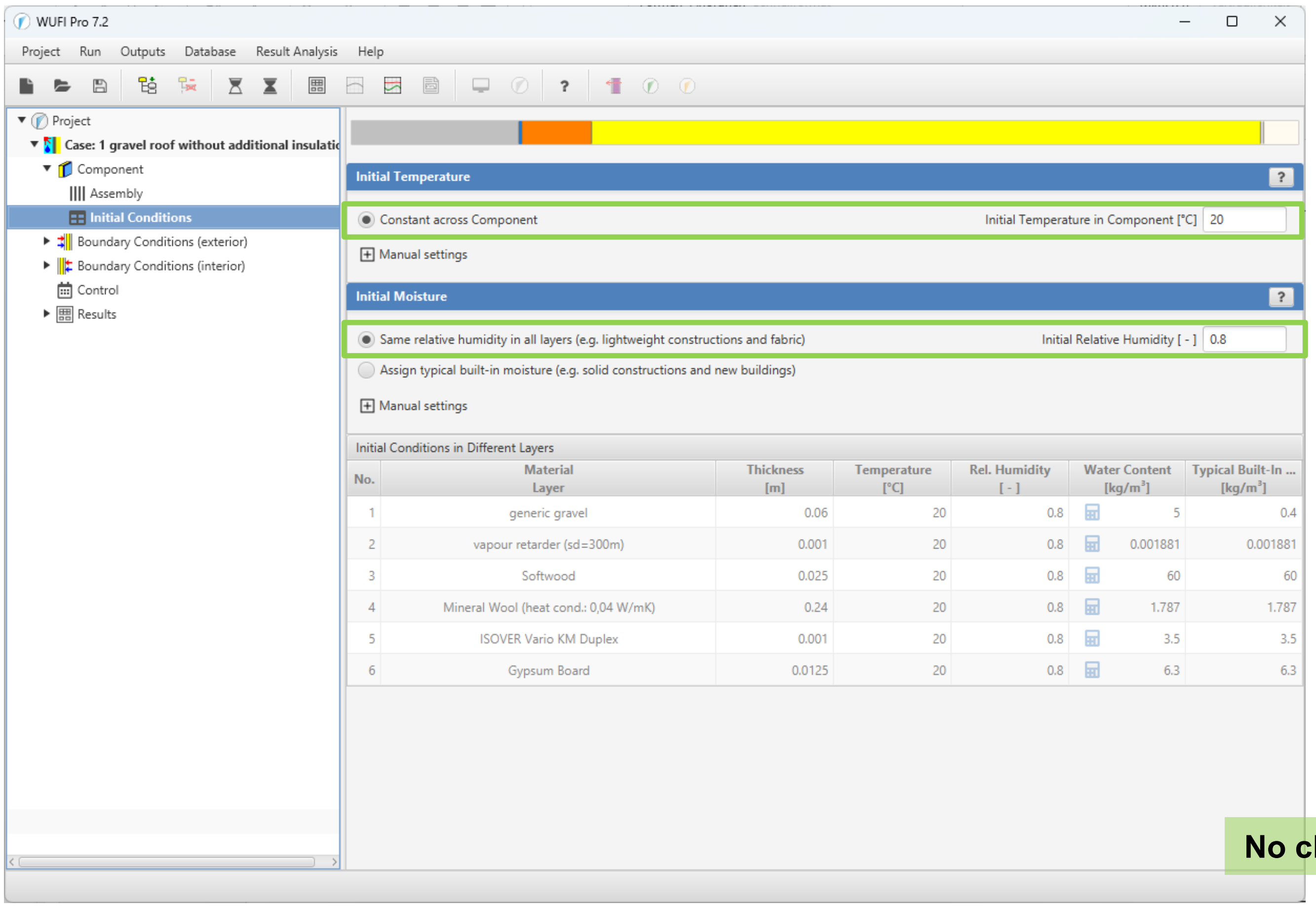
Moisture Source in the interior 5 mm of the wooden sheathing.



Adjust infiltration source

Example A: Initial Conditions

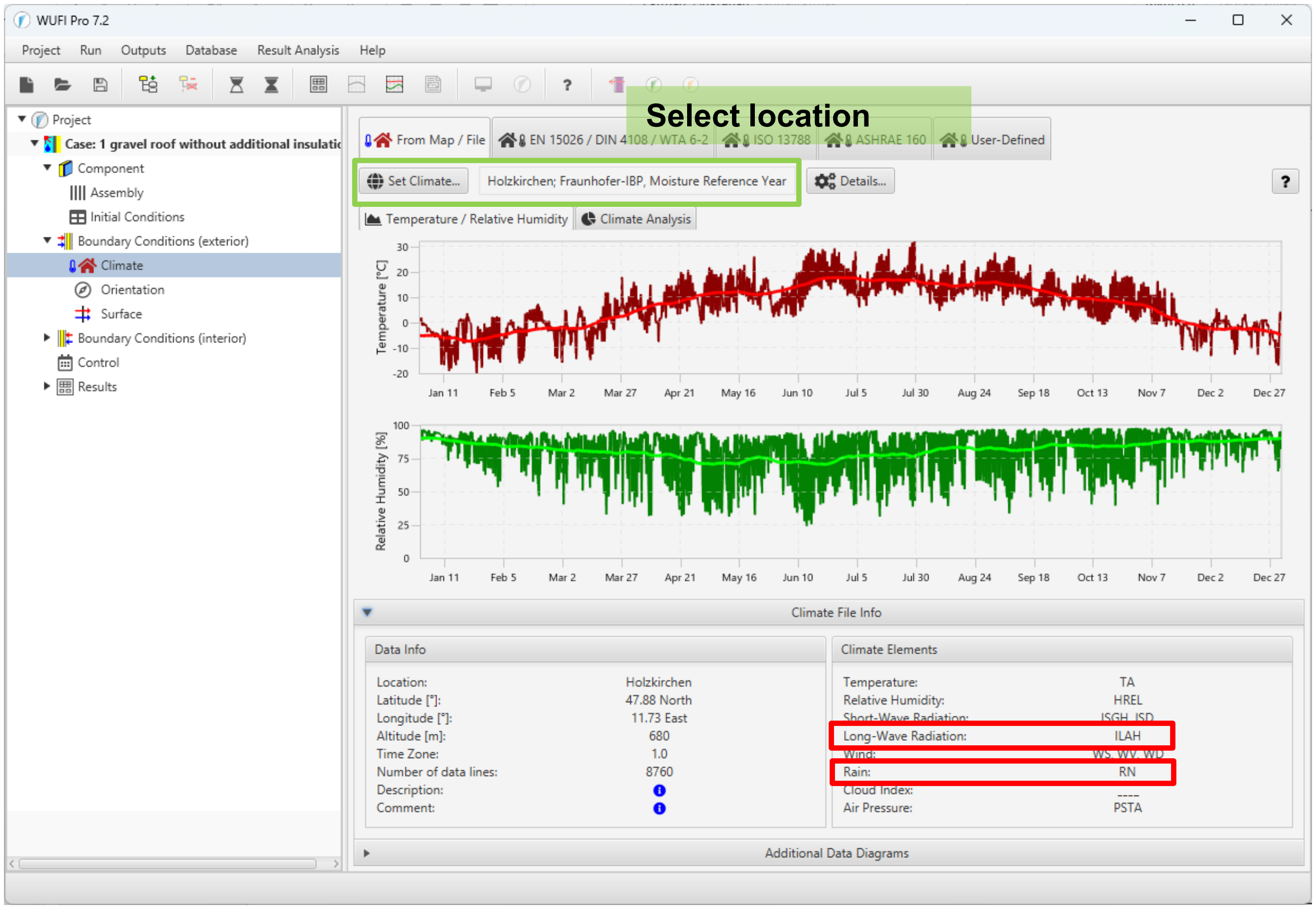
__Input:__ Component – Initial Conditions



No changes required

Example A: Outdoor Climate

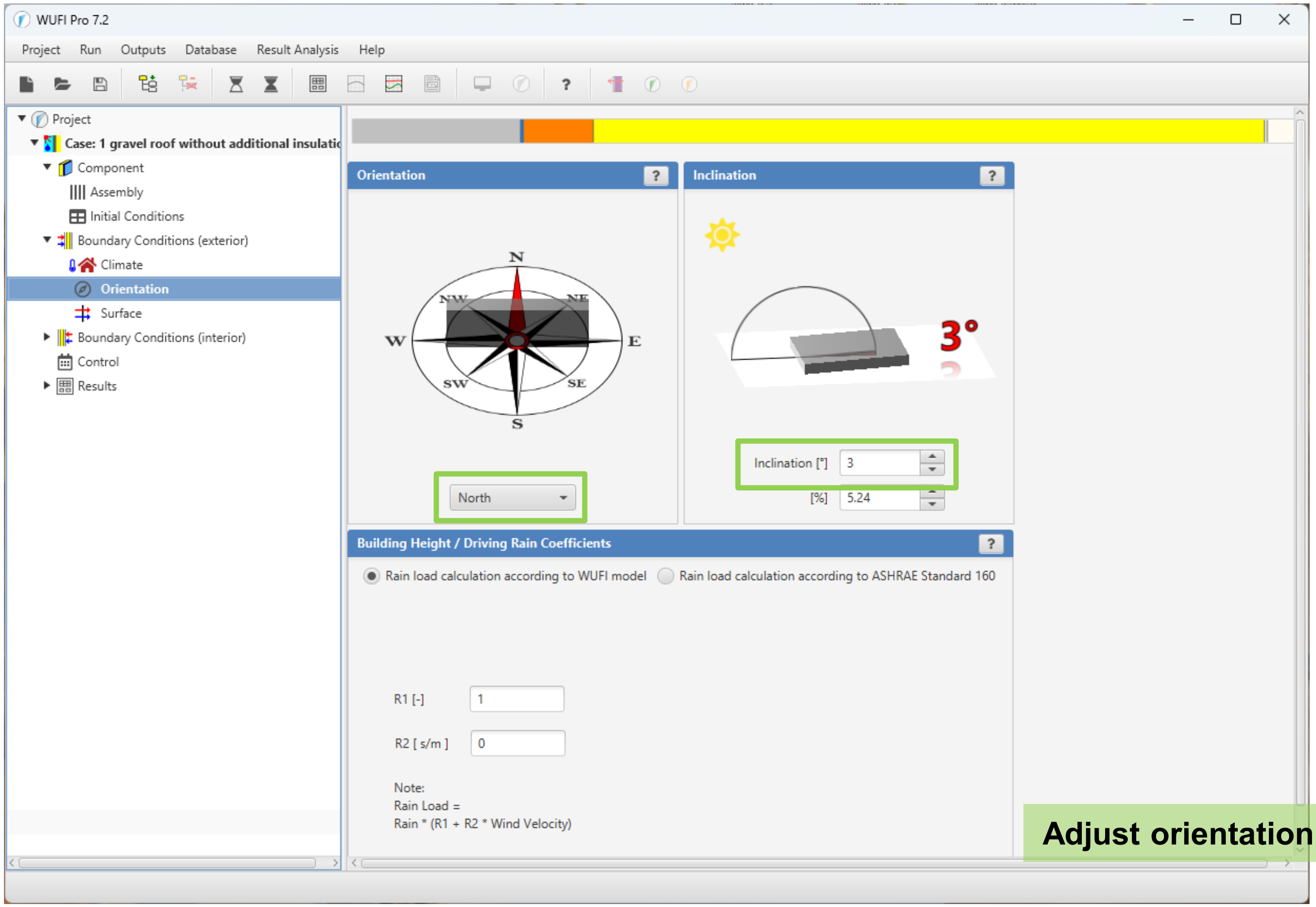
Input: Boundary Conditions (exterior) – Climate



Note:
For the application of the generic gravel roof model, climate data with long-wave radiation and rain data are necessary!

Example A: Orientation / Inclination

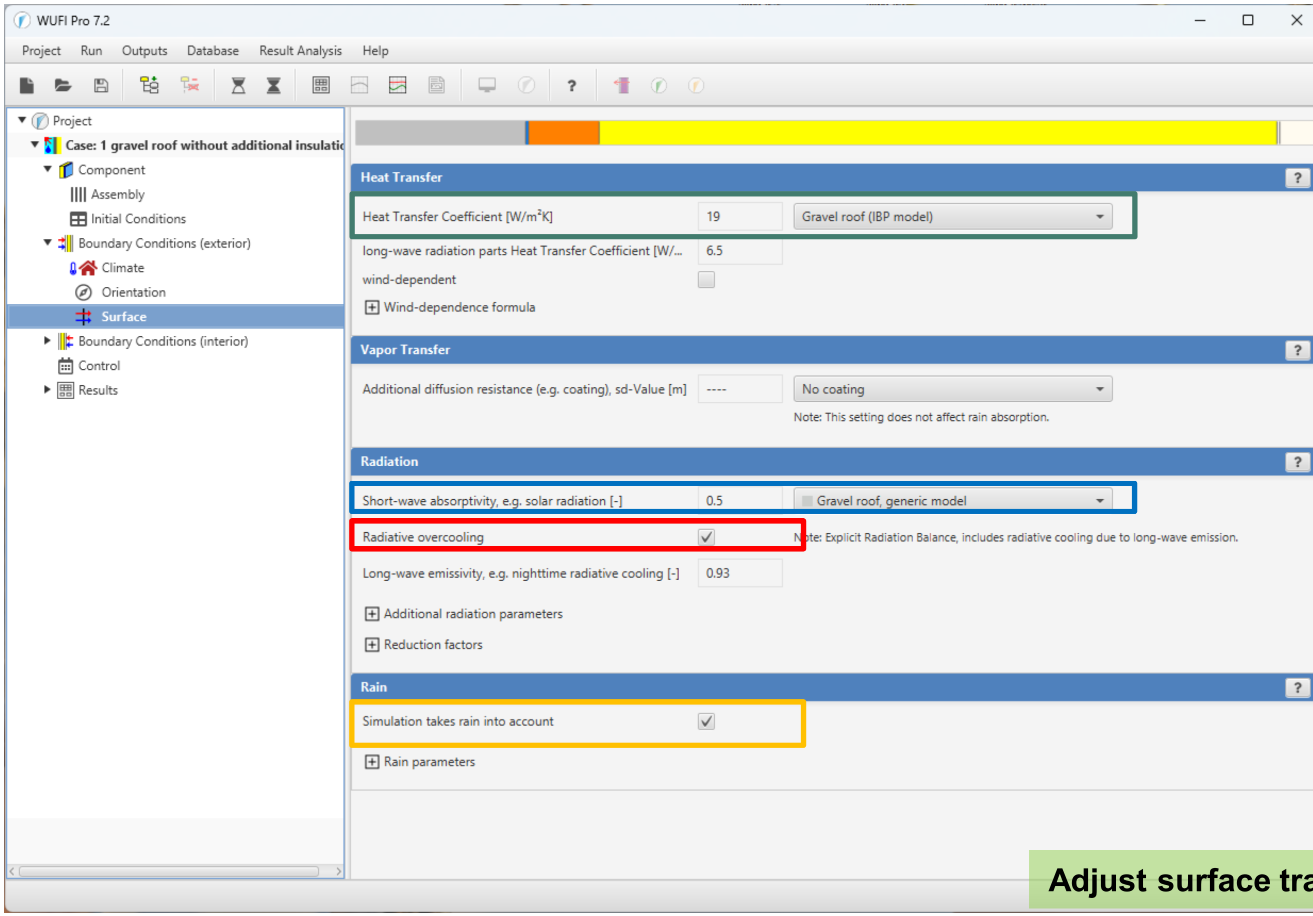
Input: Boundary Conditions (exterior) – Orientation



Adjust orientation and inclination

Example A: Surface Transfer Coefficients (exterior)

Input: Boundary Conditions (exterior) – Surface



Heat transfer coefficient (from list: gravel roof)

Absorption (from list: gravel roof, generic model)

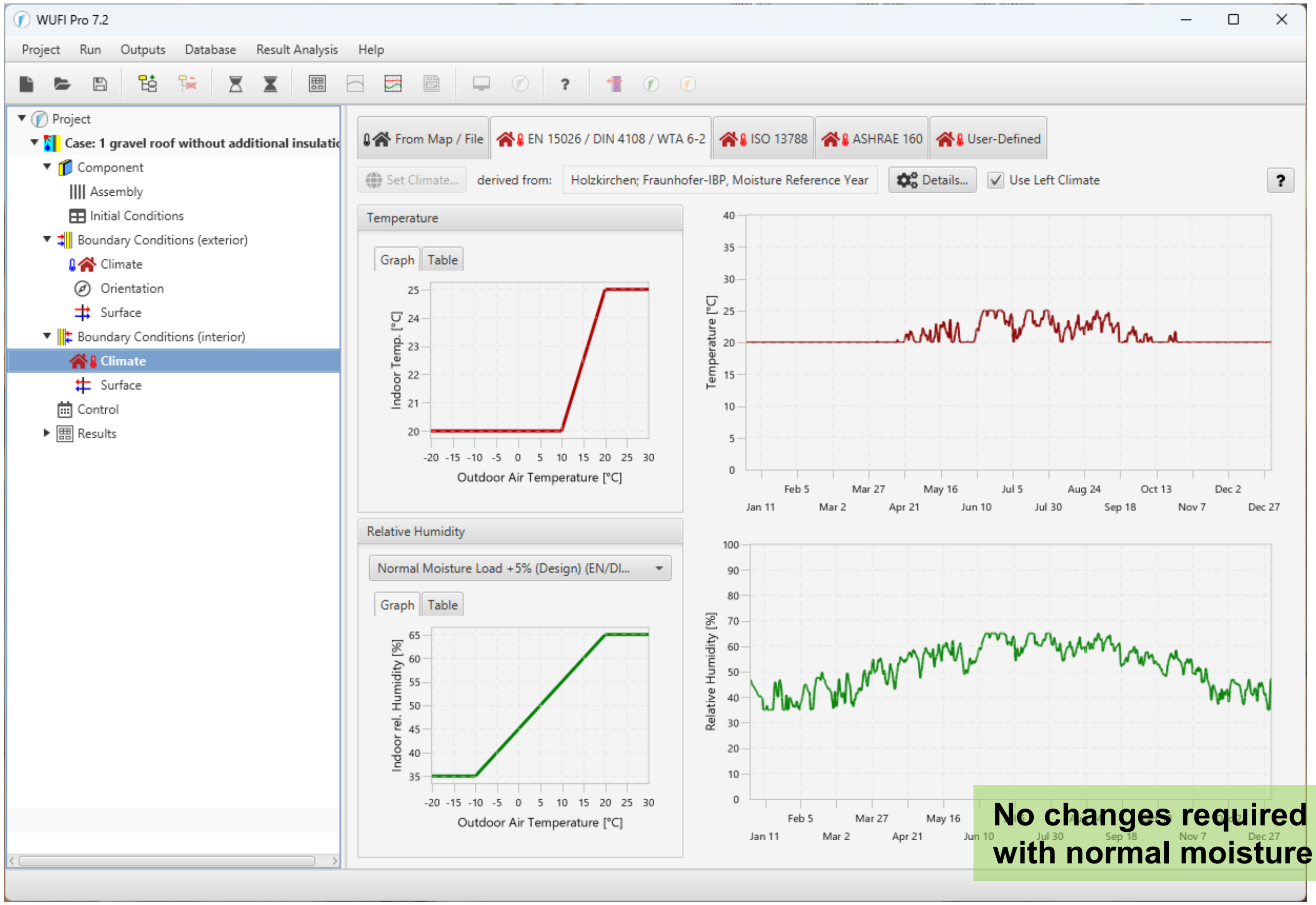
Use the radiative overcooling!

Rain is taken into account

Adjust surface transfer coefficients!

Example A: Indoor Climate

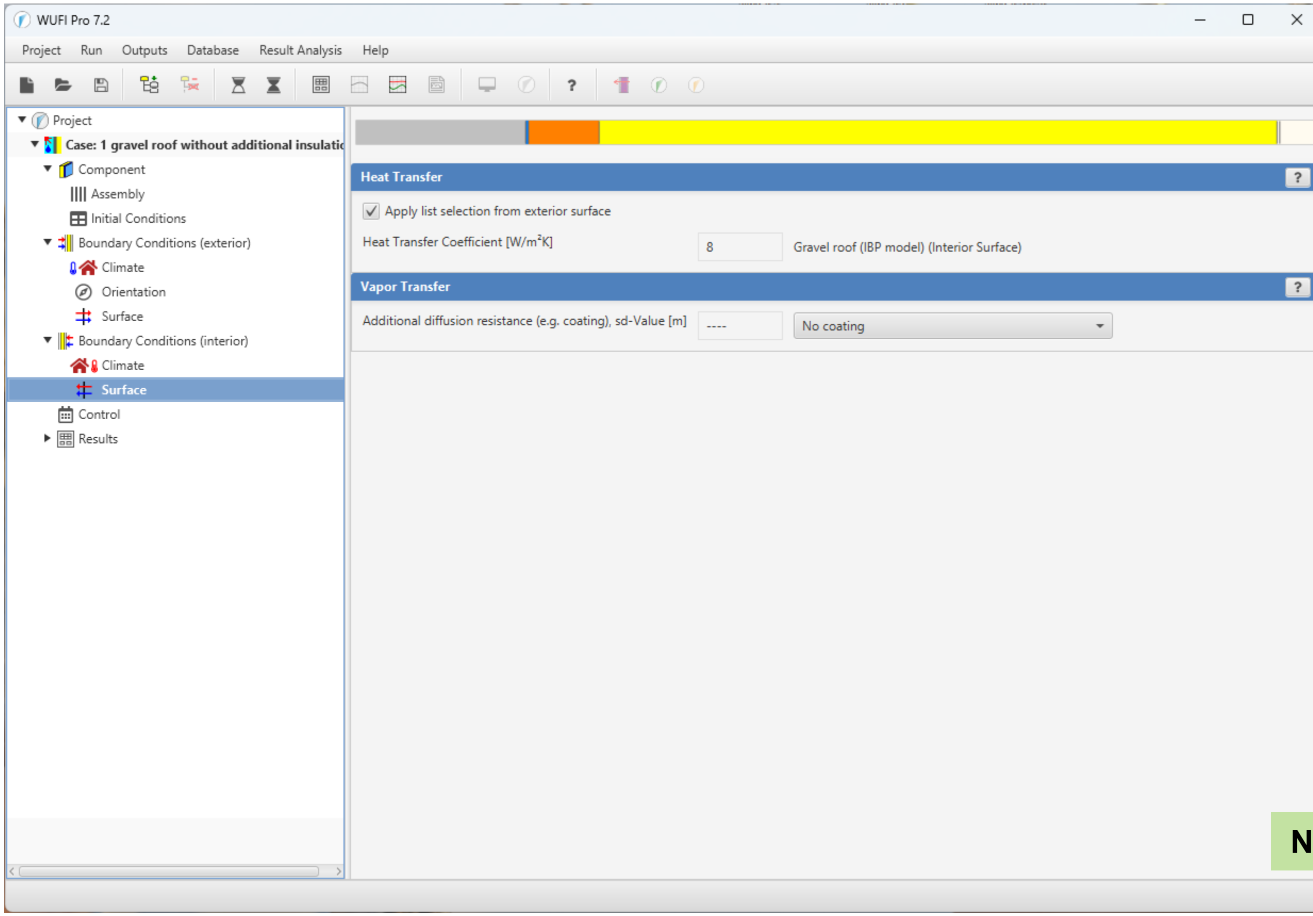
Input: Boundary Conditions (interior) – Climate



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

Example A: Surface Transfer Coefficients (interior)

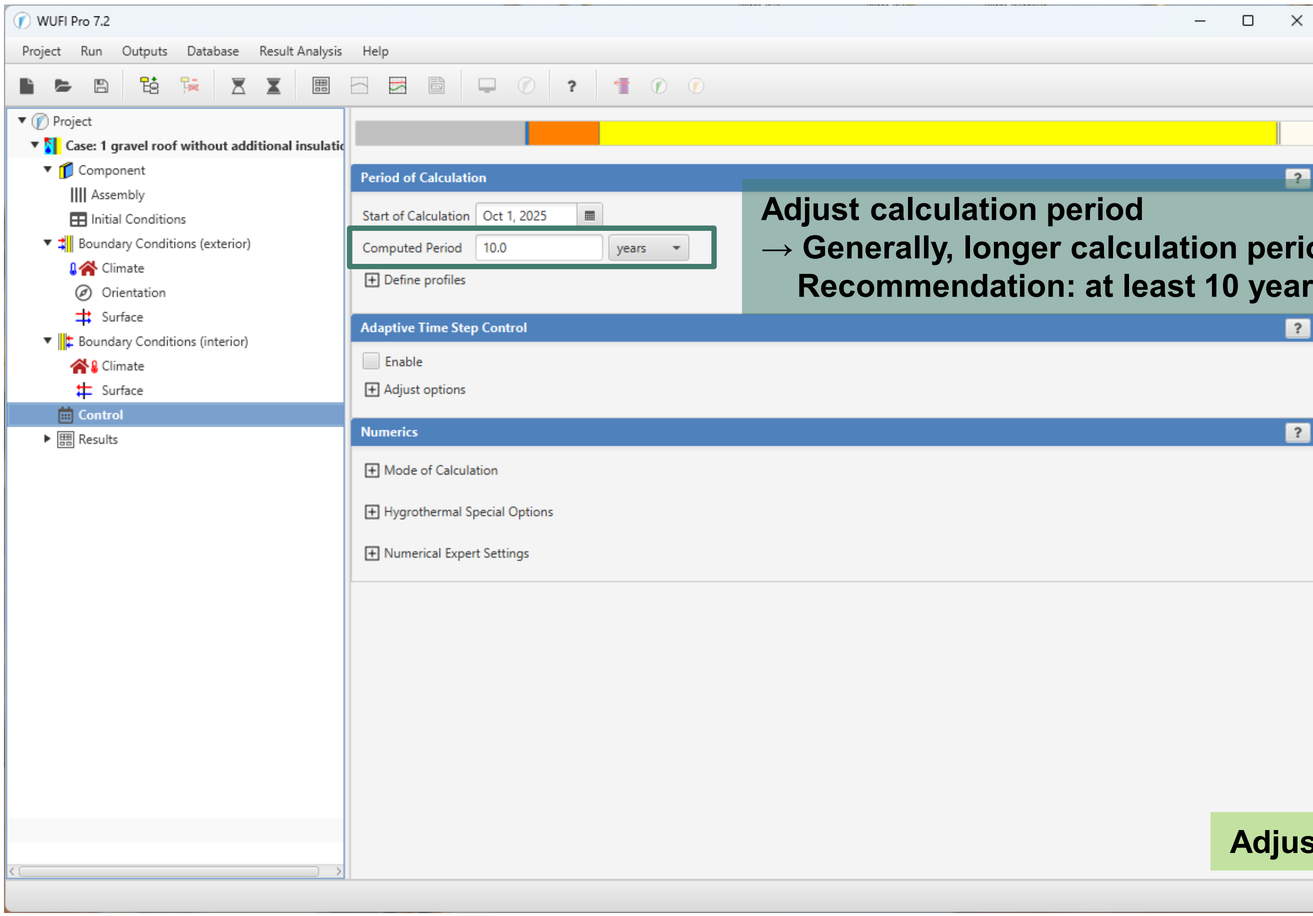
<u>Input:</u> Boundary Conditions (interior) – Surface



No changes required

Example A: Period of Calculation and Numerics

Input: Control

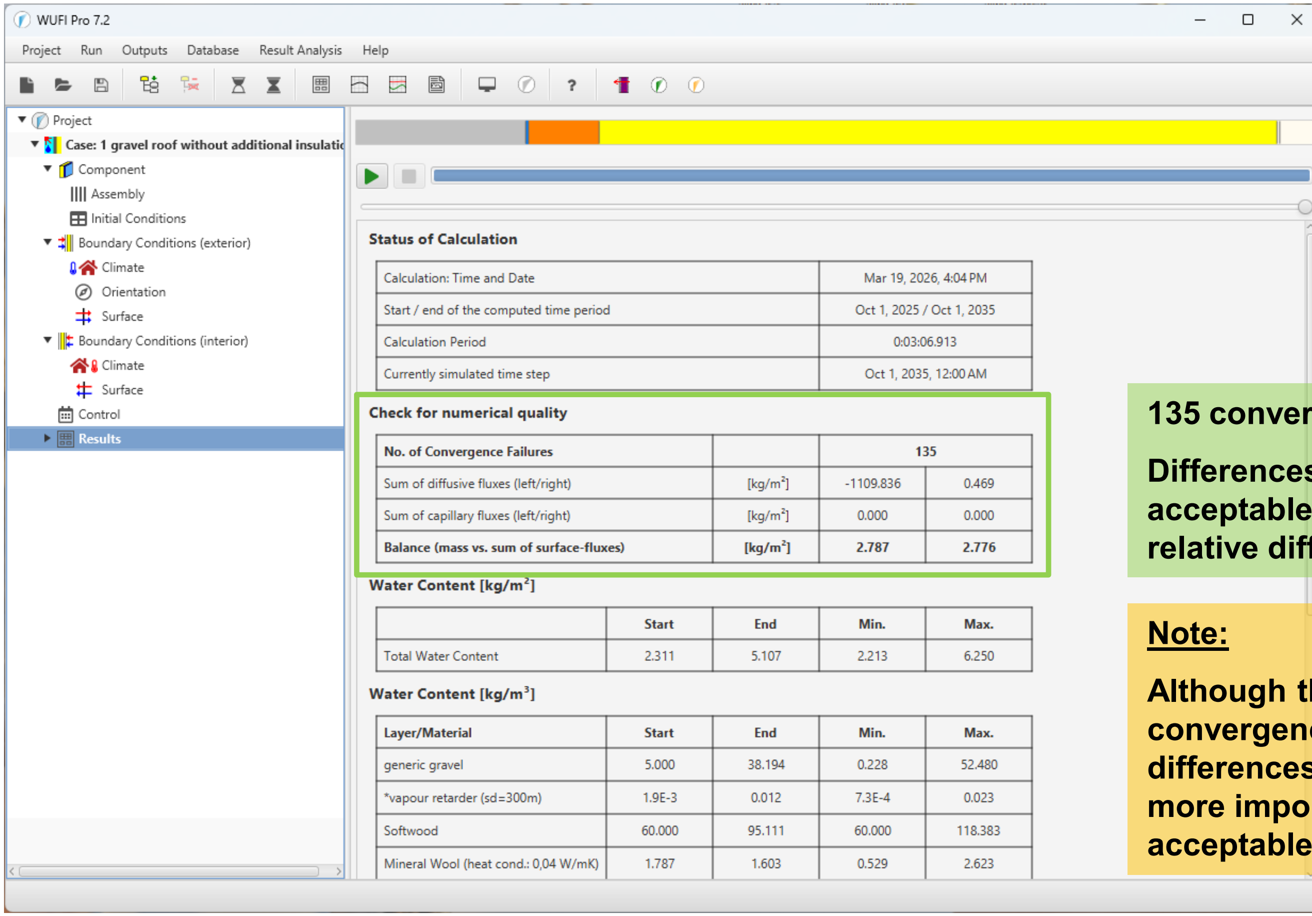


Adjust calculation period
→ Generally, longer calculation periods are required
Recommendation: at least 10 years

Adjust calculation period

Example A: Check for Numerical Quality

Results:



135 convergence failures

Differences in balance acceptable due to small relative differences!

Note:

Although there are many convergence failures, the differences in balance are more important and are acceptable in this case.

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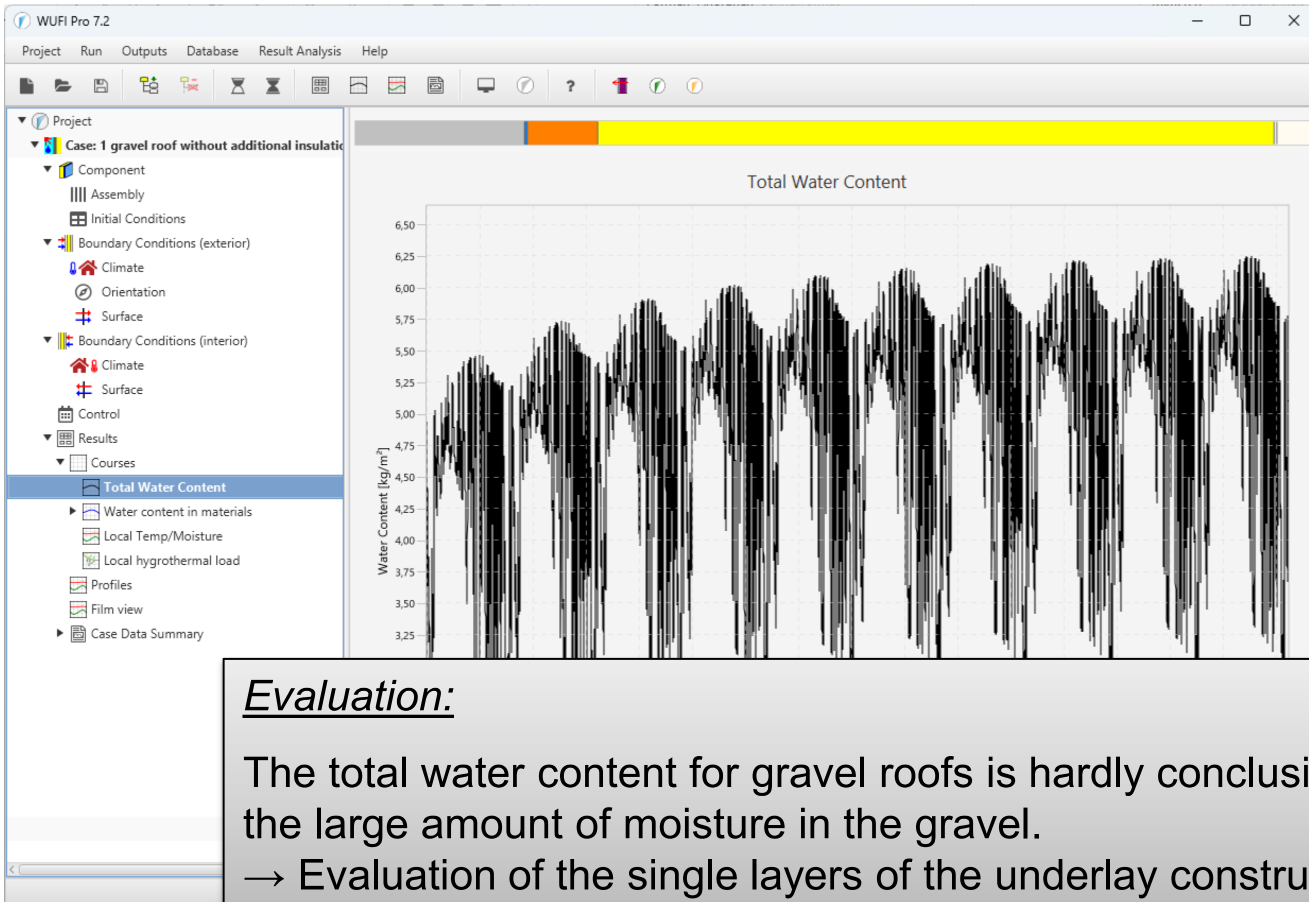
Example A: Evaluation of Total Water Content

Evaluation:
Total water content

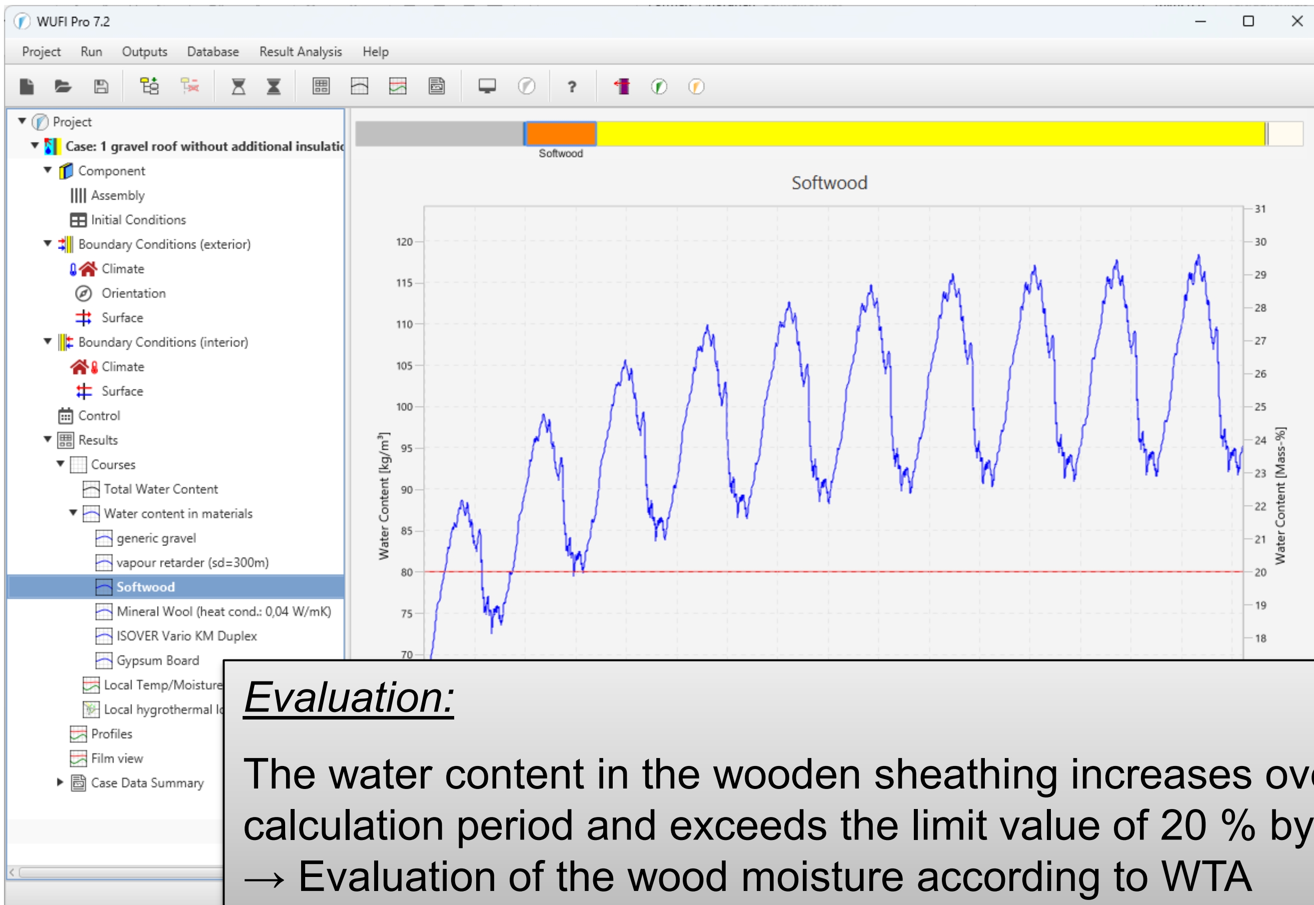


Evaluation:

The total water content for gravel roofs is hardly conclusive because of the large amount of moisture in the gravel.
→ Evaluation of the single layers of the underlay construction

Example A: Evaluation of Wood Moisture

<u>Evaluation:</u>
Water content in the wooden sheathing



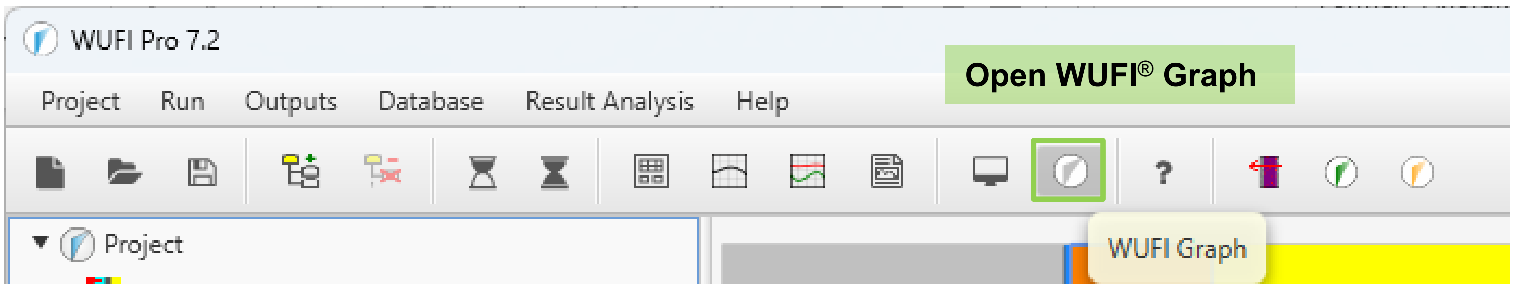
<u>Evaluation:</u>

The water content in the wooden sheathing increases over the calculation period and exceeds the limit value of 20 % by mass clearly.
→ Evaluation of the wood moisture according to WTA

Example A: Evaluation of Wood Moisture with WUFI® Graph

Evaluation with WUFI® Graph:
Wood moisture in the wooden sheathing according to WTA 6-8

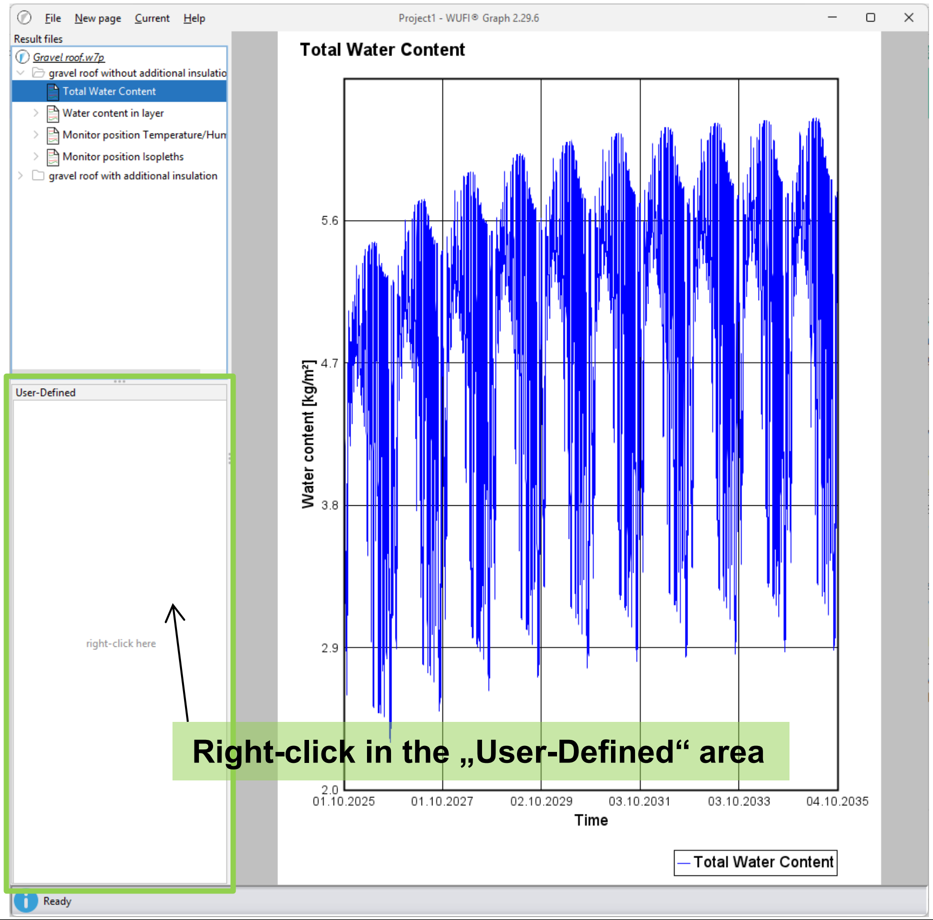
Note:
To open WUFI® Graph, the WUFI® project must first be saved!



Example A: Evaluation of Wood Moisture with WUFI® Graph

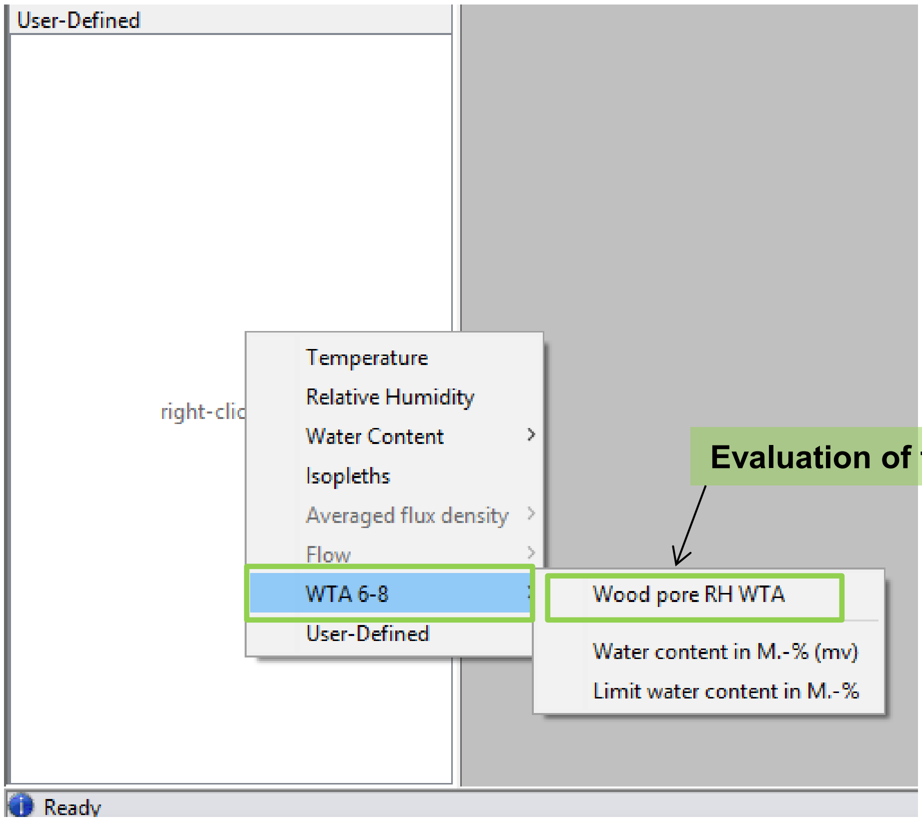
<u>Evaluation with WUFI® Graph:</u>

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



Example A: Evaluation of Wood Moisture with WUFI® Graph

Evaluation with WUFI® Graph:
Wood moisture in the wooden sheathing according to WTA 6-8



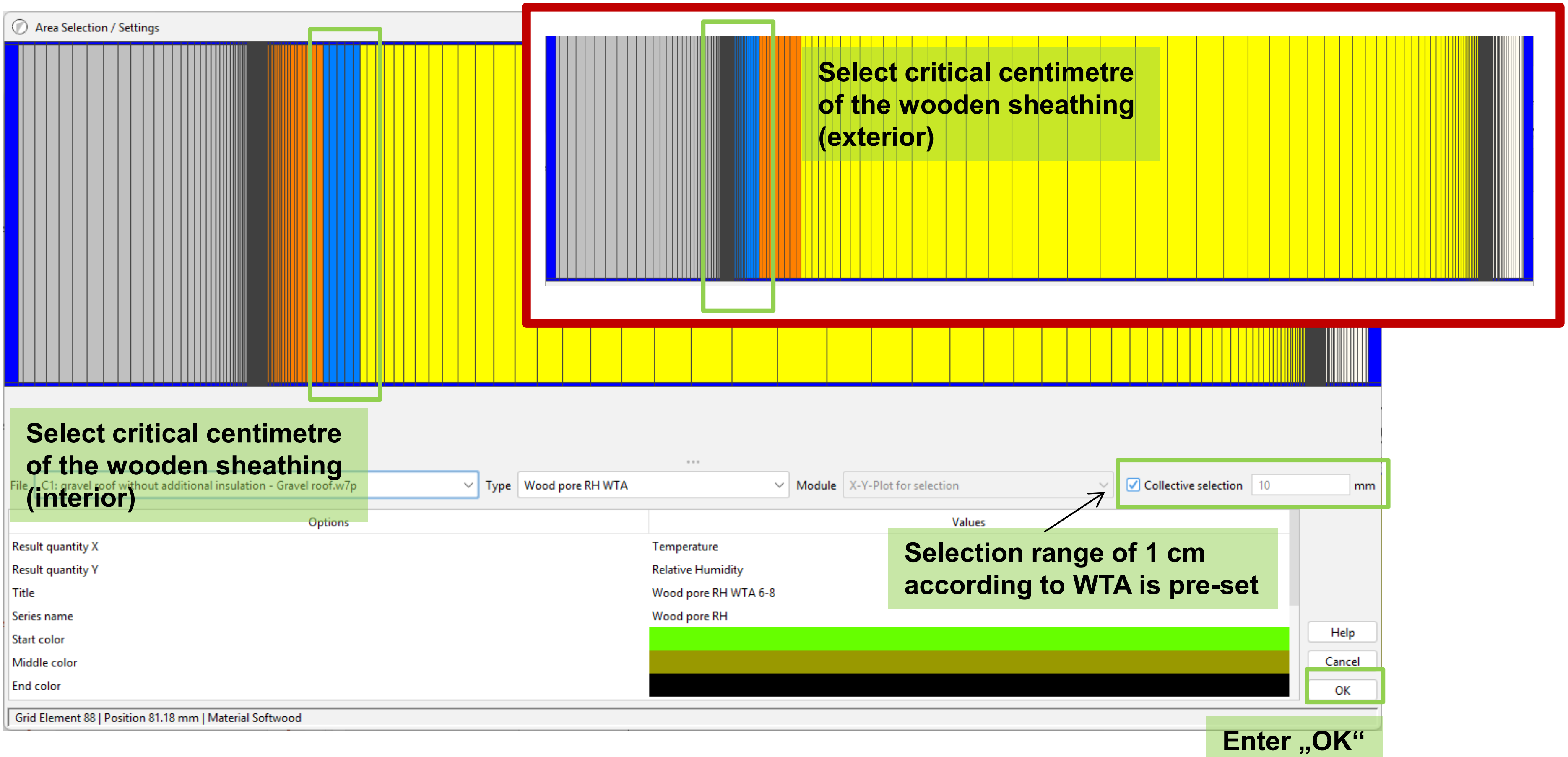
Evaluation of the wood pore RH according to WTA

Example A: Evaluation of Wood Moisture with WUFI® Graph

Evaluation with WUFI® Graph:

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

Evaluation in the most critical centimetre (in case of doubt, consider both sides)

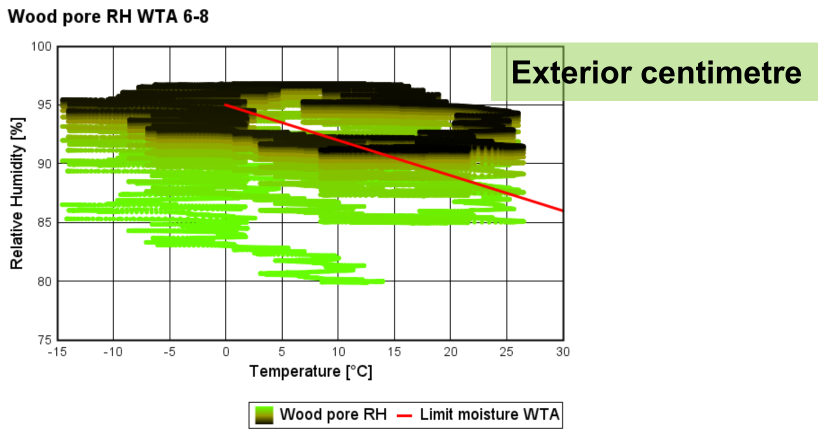


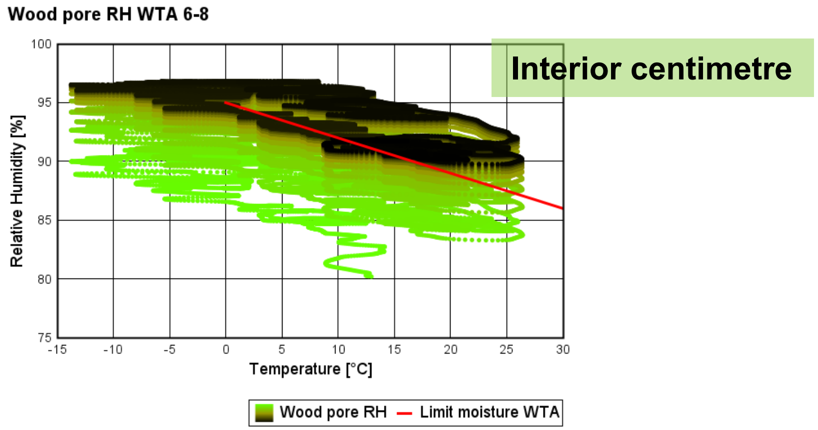
Example A: Evaluation of Wood Moisture with WUFI® Graph

Evaluation with WUFI® Graph:

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

Evaluation in the most critical centimetre (in case of doubt, consider both sides)





Evaluation:

The relative pore air moisture in the interior and the exterior centimetre of the sheathing exceeds the limit moisture according to WTA also clearly.

→ High risk regarding damage of the wood

Example B: Assembly

Assembly (from outside to inside):

• Generic Gravel	0.06	m
• Roofing Membrane (s_d = 300 m)	0.001	m
• EPS (heat cond.: 0.04 W/mK – density: 30 kg/m³)	0.1	m
• Wooden sheathing (Softwood)	0.025	m
• Mineral Wool (heat cond.: 0.04 W/mK)	0.24	m
• Moisture-variable vapour retarder (Vario KM Duplex)	0.001	m
• Gypsum Board	0.0125	m

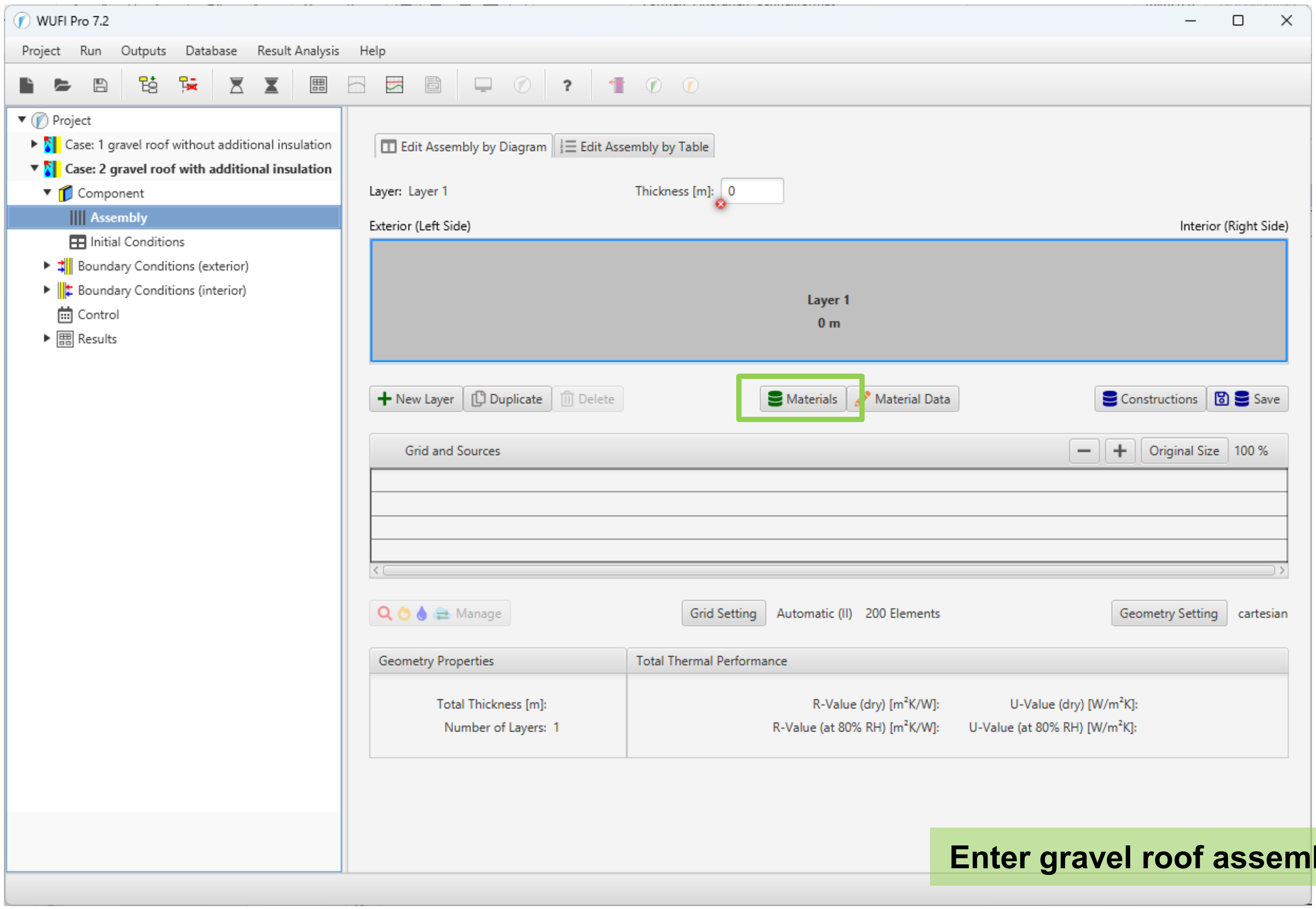
Example B: Boundary Conditions

Boundary conditions:

- Flat roof (3° to the North)
- Short-Wave Radiation Absorptivity / Long-Wave Radiation Emissivity: according to the generic gravel roof model
- Outdoor Climate: Holzkirchen
- Indoor Climate: Medium Moisture Load + 5 %
  according to DIN 4108-3
- Air Tightness of the Envelope: q_{50} = 3 m^3/m^3h
- Stack Height: 5 m

Example B: Component Assembly

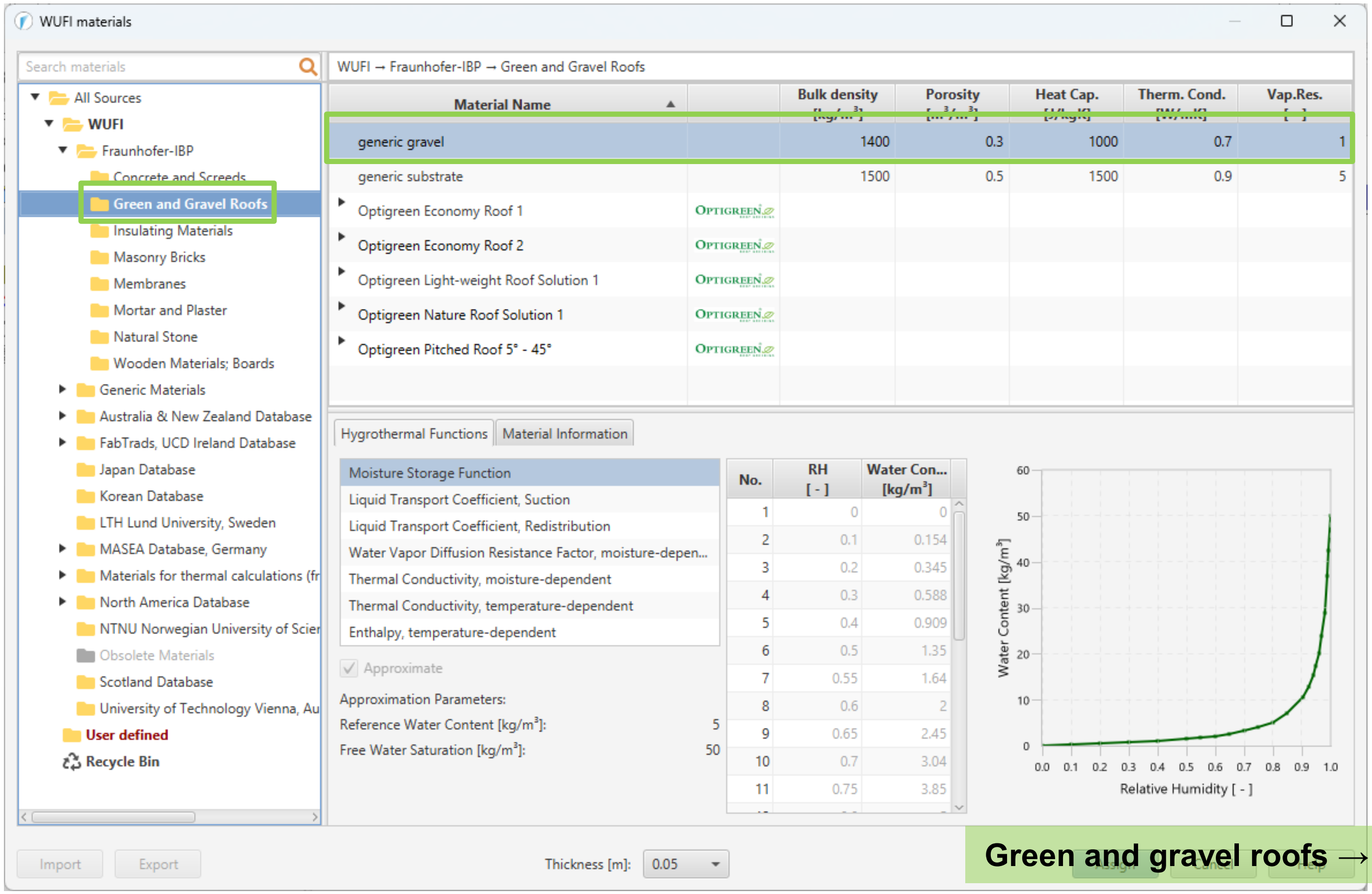
<u>Input:</u> Component – Assembly



Enter gravel roof assembly in single layers

Example B: Component Assembly

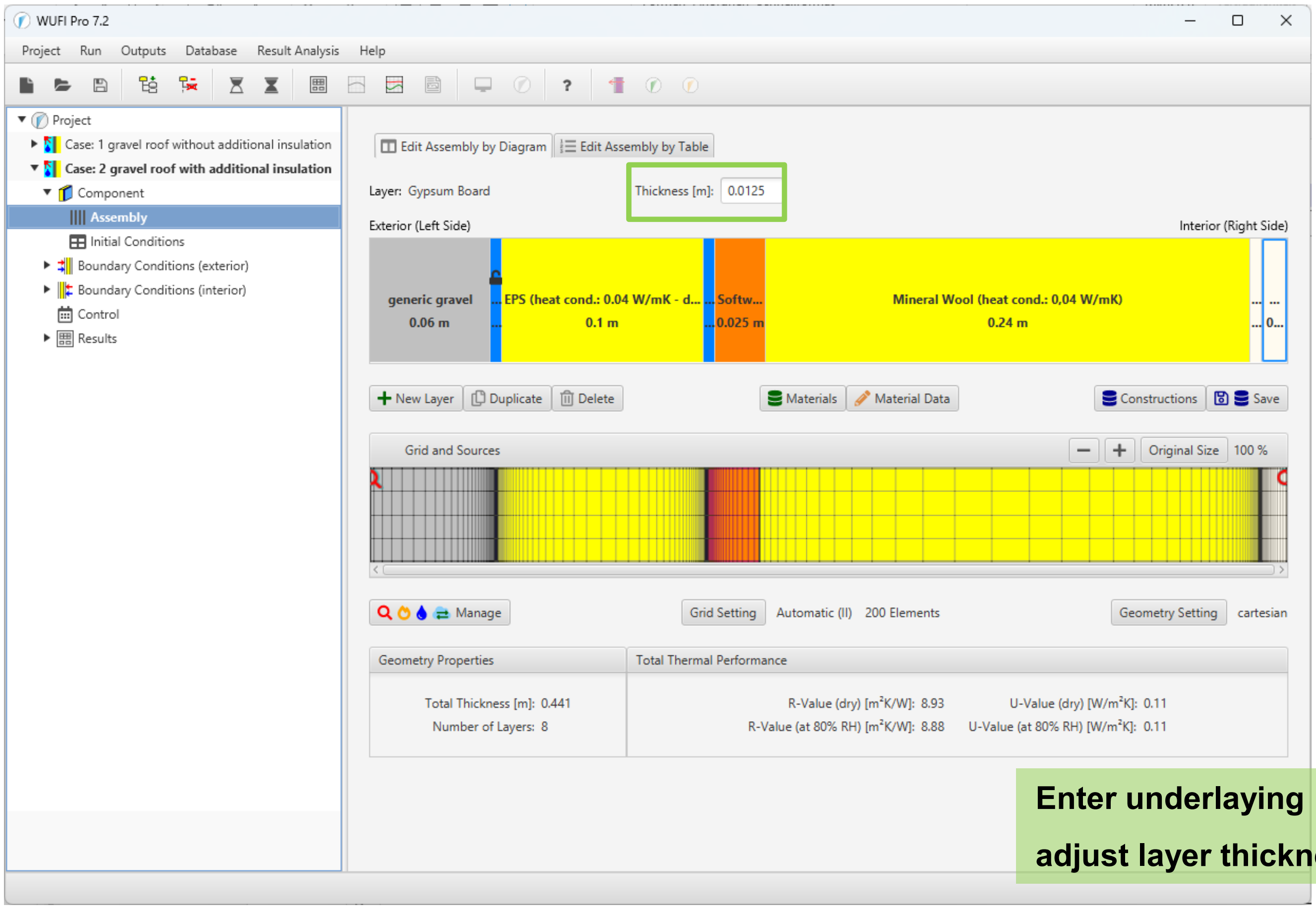
Input: Component – Assembly



Green and gravel roofs → Generic gravel

Example B: Component Assembly

<u>Input:</u> Component – Assembly



Enter underlaying roof construction; adjust layer thicknesses if necessary

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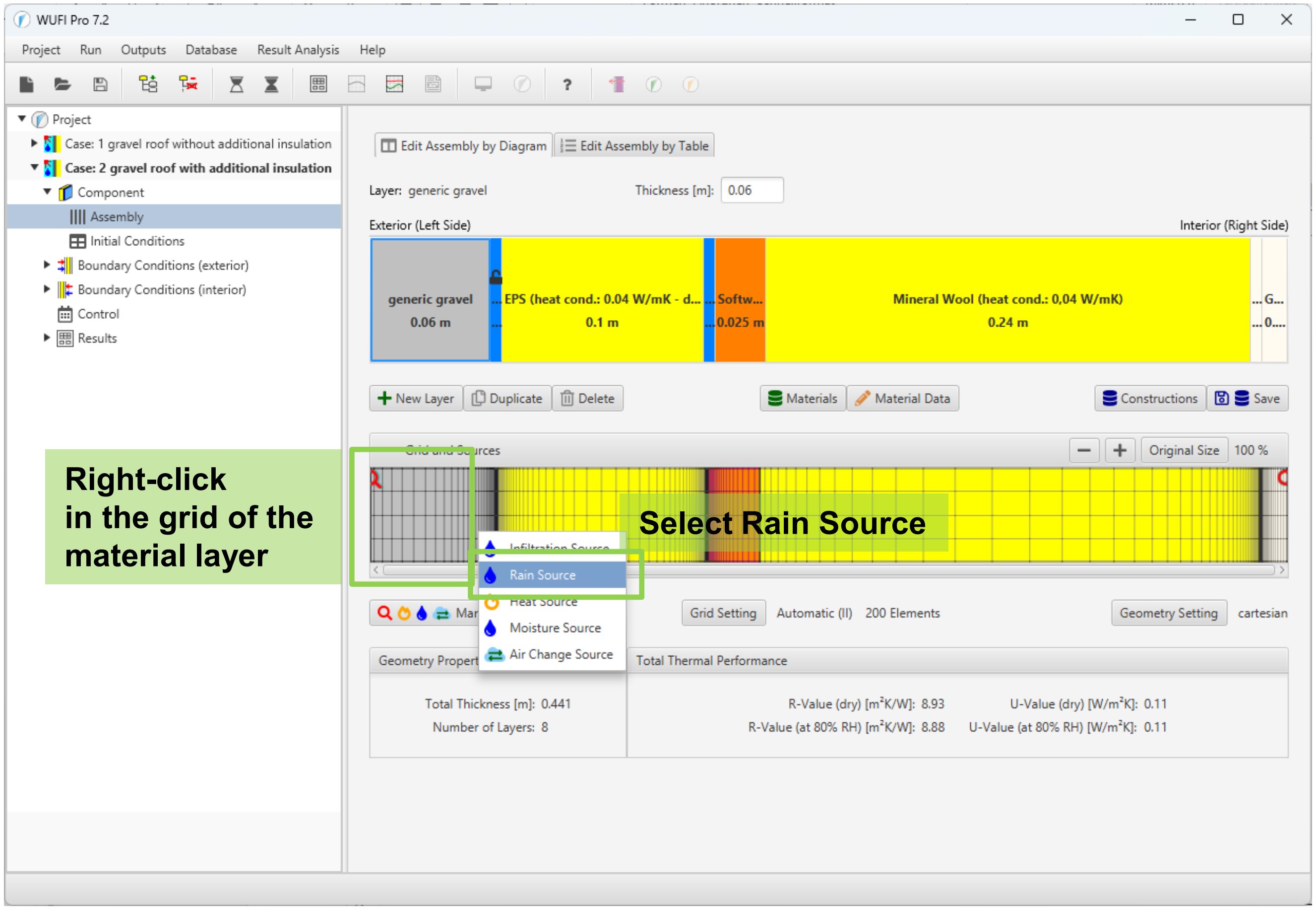
Example B: Moisture Source in the Gravel Layer

Input: Component – Assembly

Insert moisture source in the layer "Generic Gravel"

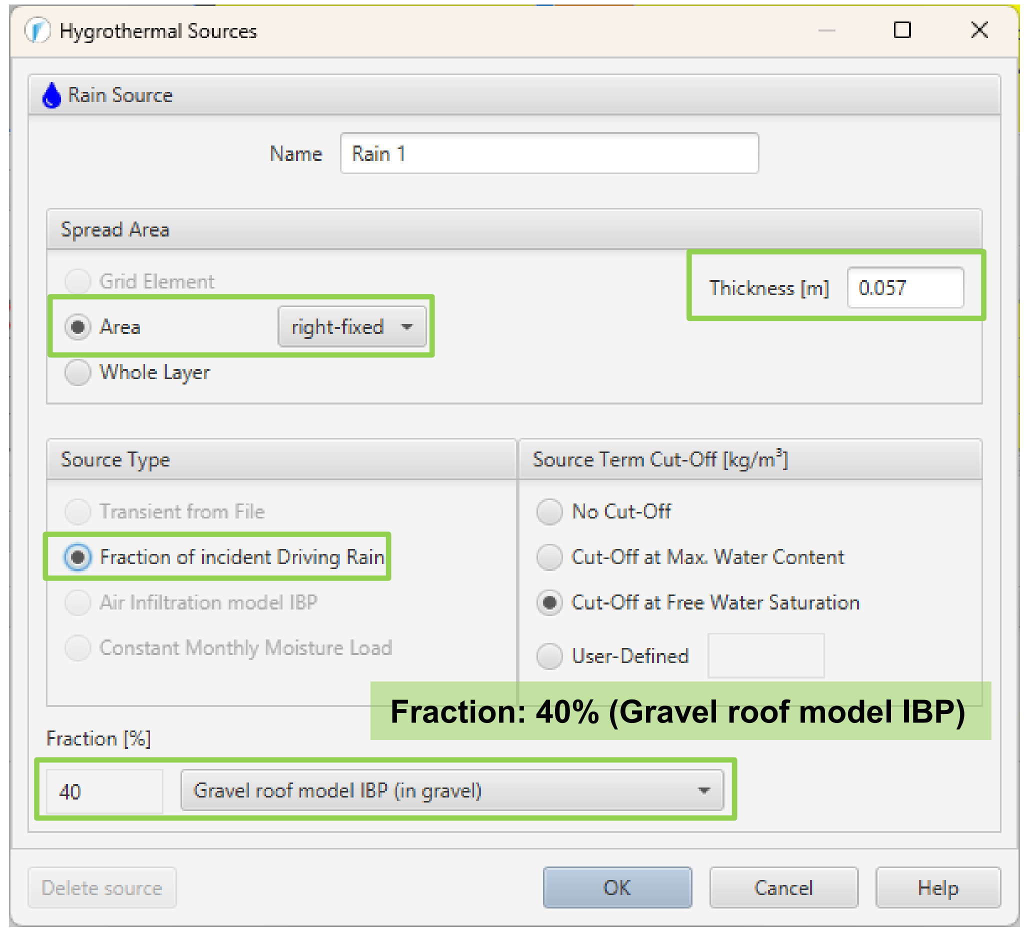


Example B: Moisture Source in the Gravel Layer

Input: Component – Assembly

Moisture source in the whole gravel layer with the exception of the outermost element.

Note:
By adding the moisture source in the outermost element numerical problems and differences in the balances may be caused.



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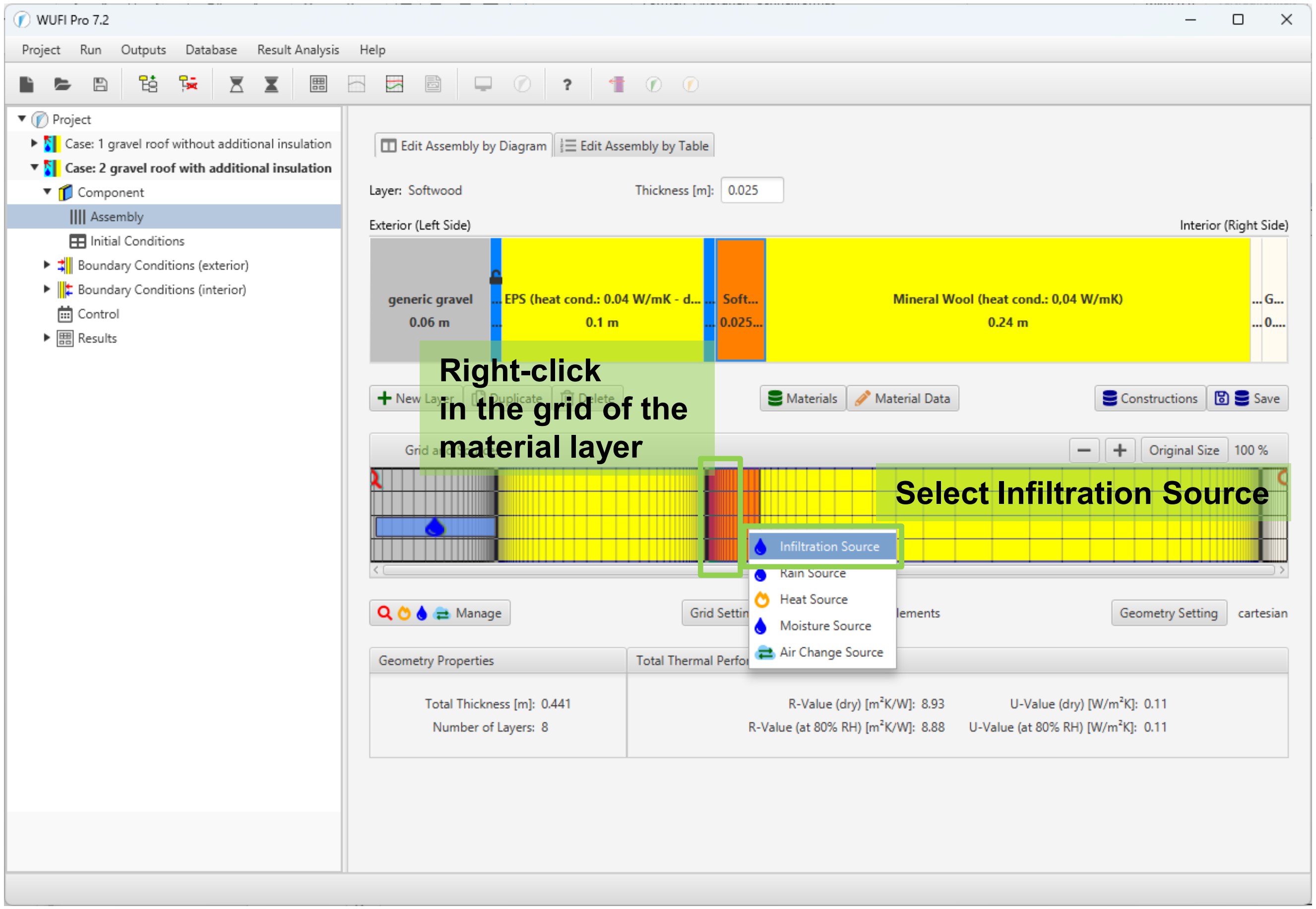
Example B: Infiltration Source

Input: Component – Assembly

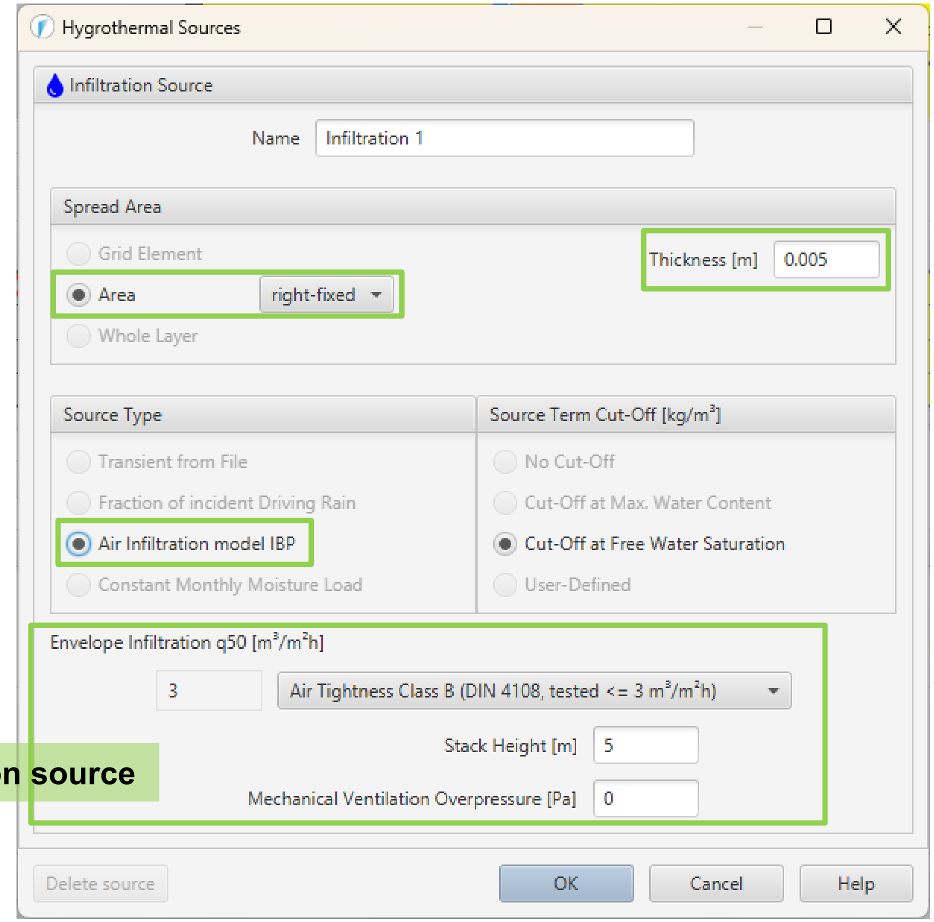
Infiltration source according to DIN 68800 in the wooden sheathing



Example B: Infiltration Source

<u>Input:</u> Component – Assembly

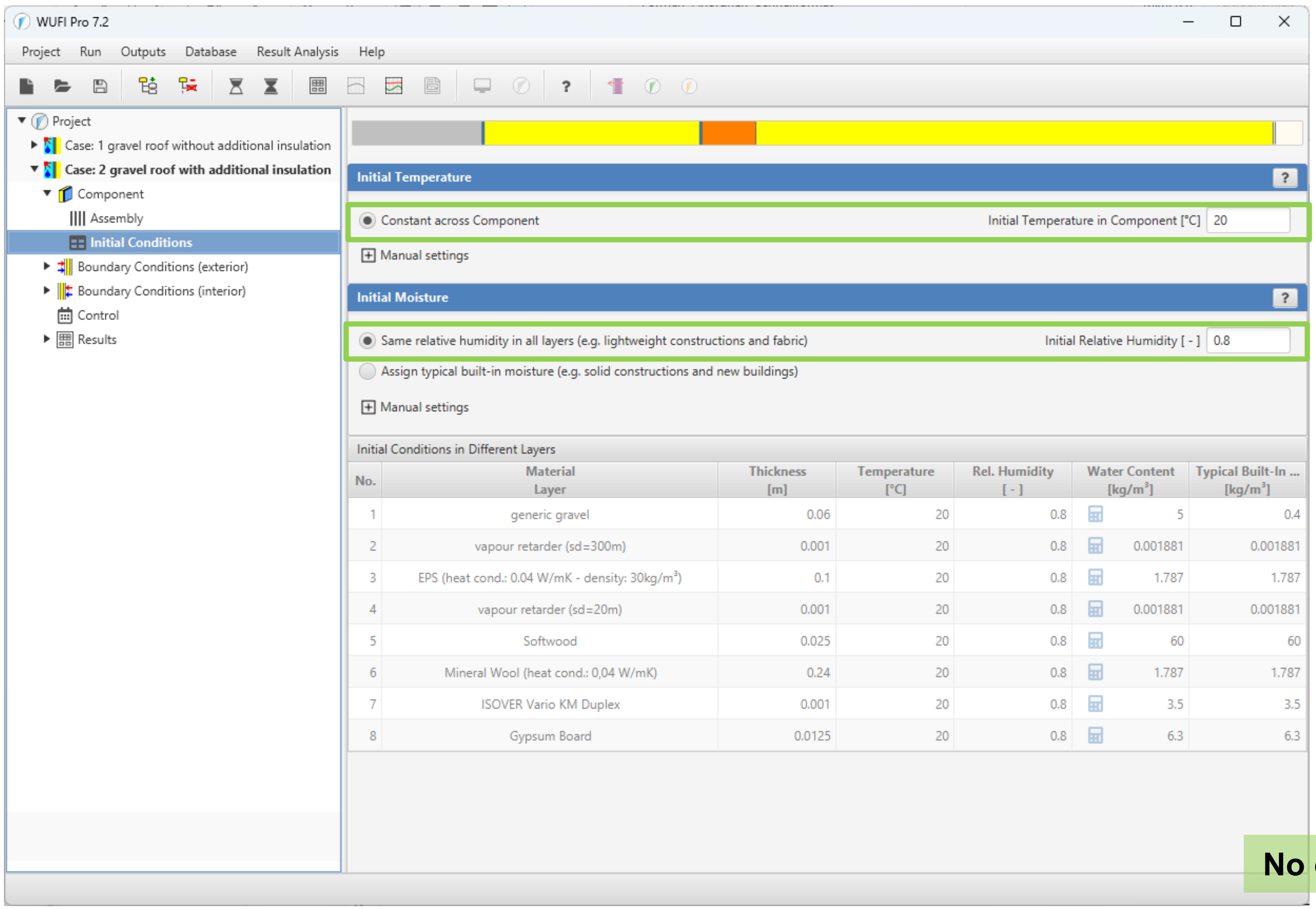
Moisture Source in the interior 5 mm of the wooden sheathing.



Adjust infiltration source

Example B: Initial Conditions

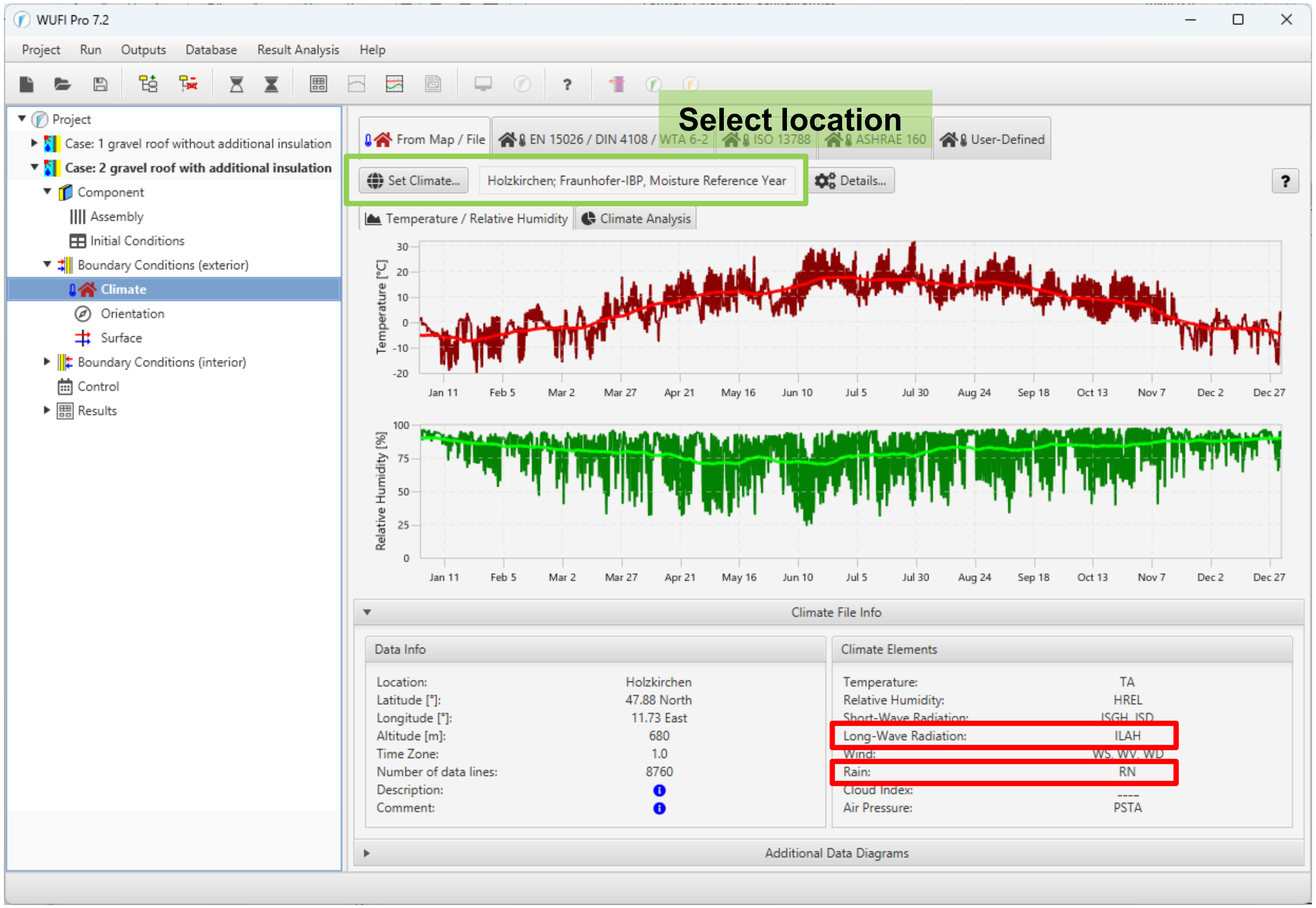
Input: Component – Initial Conditions



No changes required

Example B: Outdoor Climate

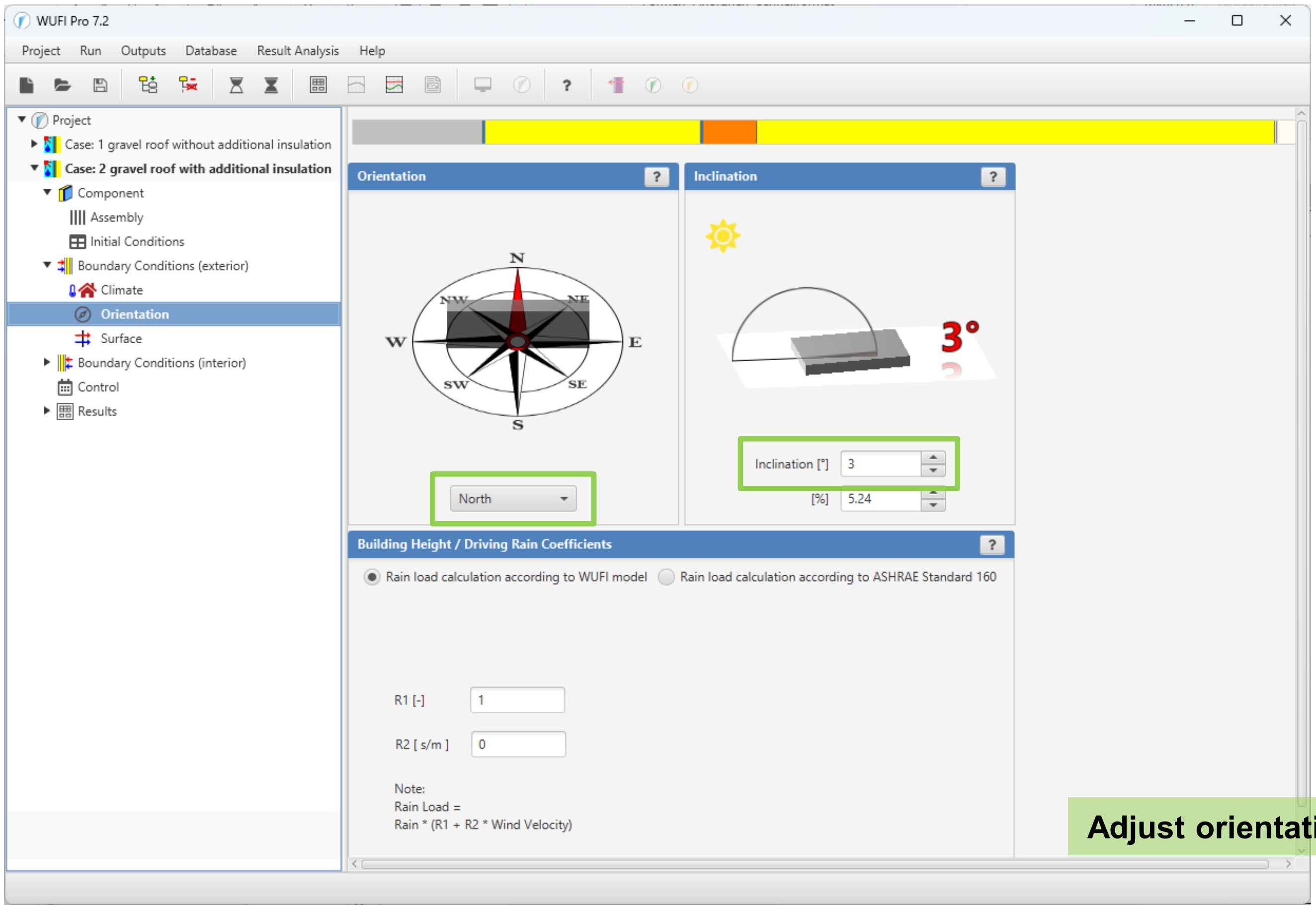
<u>Input:</u> Boundary Conditions (exterior) – Climate



Note:
For the application of the generic gravel roof model, climate data with long-wave radiation and rain data are necessary!

Example B: Orientation / Inclination

Input: Boundary Conditions (exterior) – Orientation



Adjust orientation and inclination

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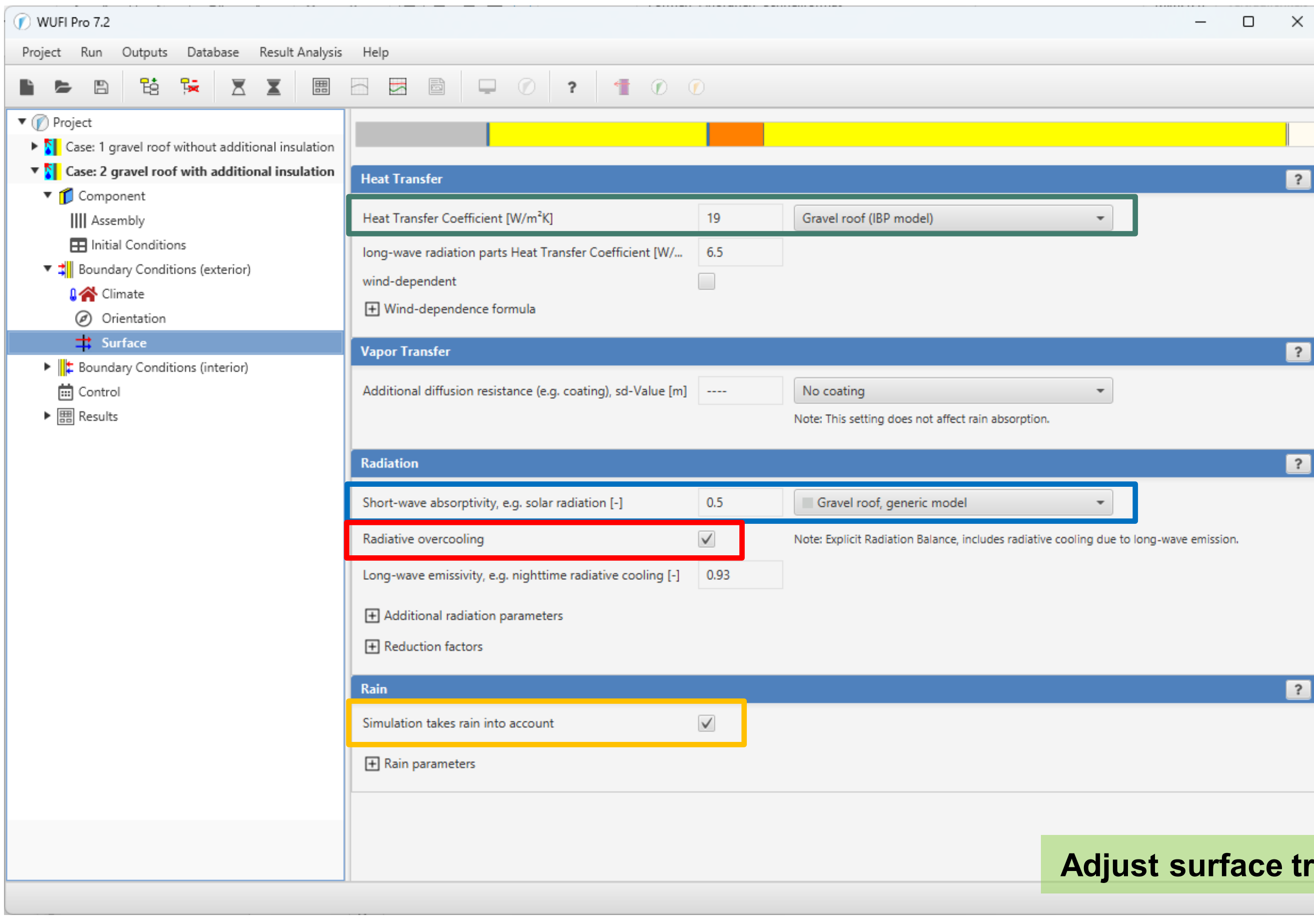
Example B: Surface Transfer Coefficients (exterior)

Input: Boundary Conditions (exterior) – Surface



Heat transfer coefficient (from list: gravel roof)

Absorption (from list: gravel roof, generic model)

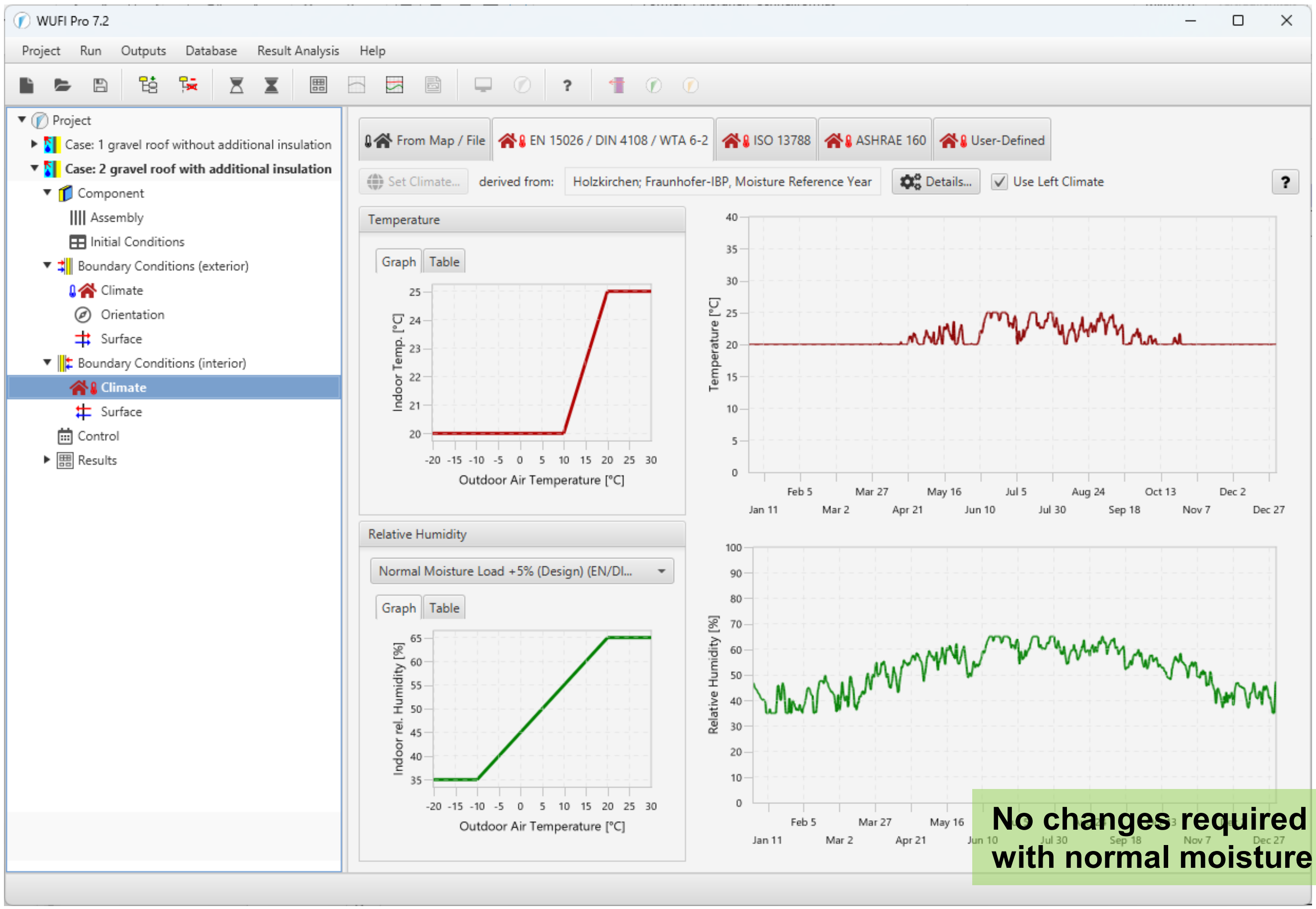
Use the radiative overcooling!

Rain is taken into account

Adjust surface transfer coefficients!

Example B: Indoor Climate

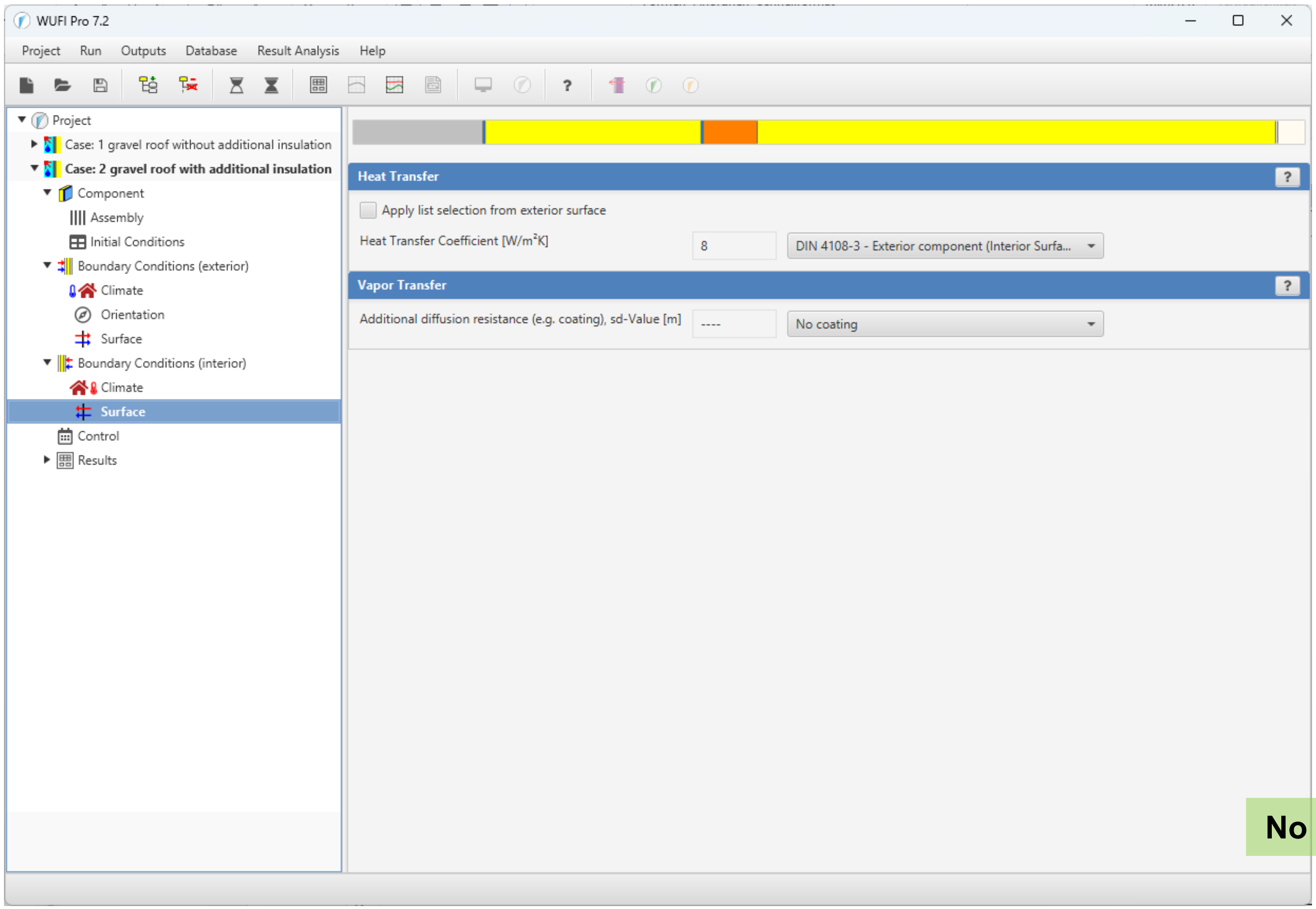
Input: Boundary Conditions (interior) – Climate



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

Example B: Surface Transfer Coefficients (interior)

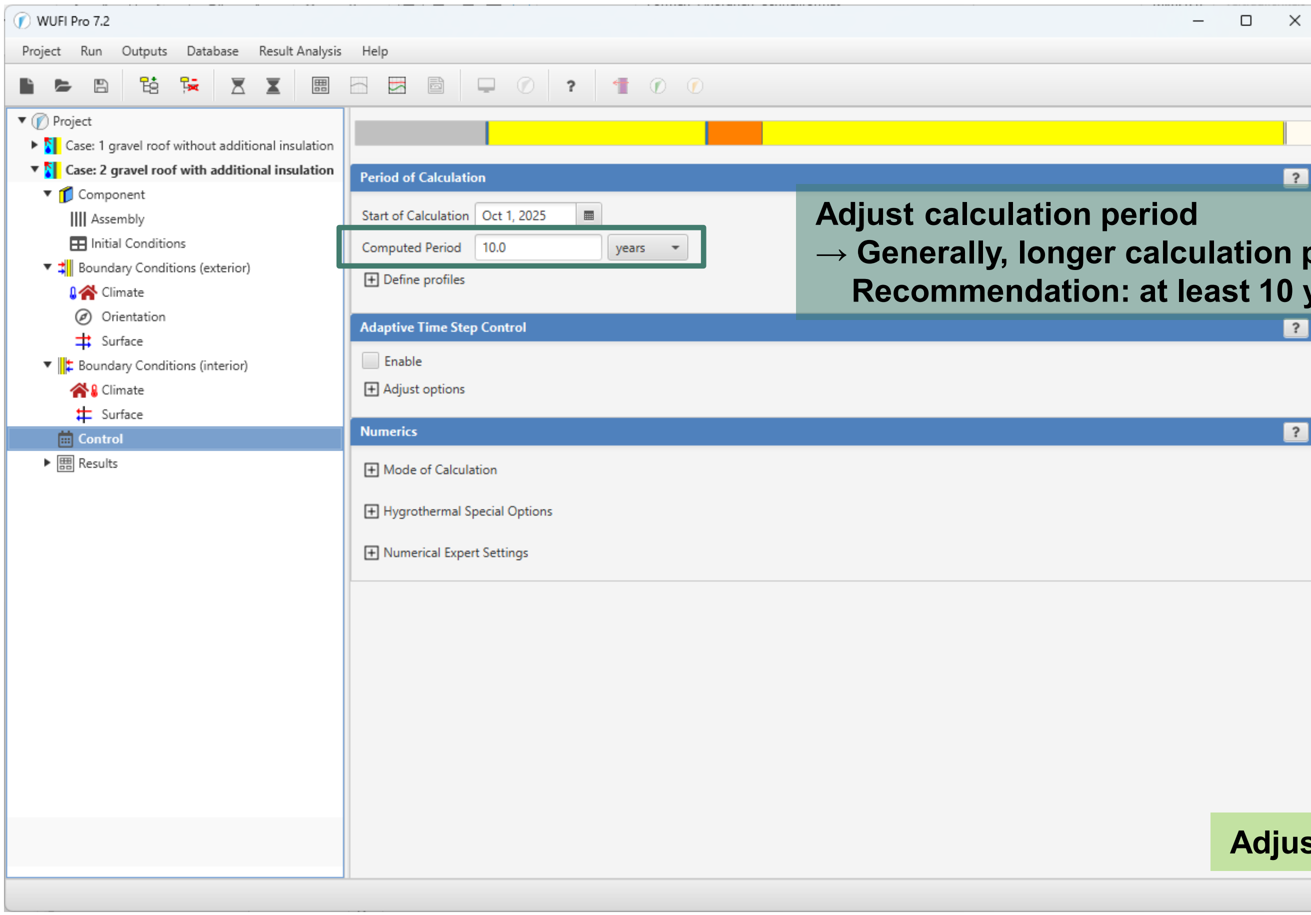
Input: Boundary conditions (interior) – Surface



No changes required

Example B: Period of Calculation and Numerics

Input: Control

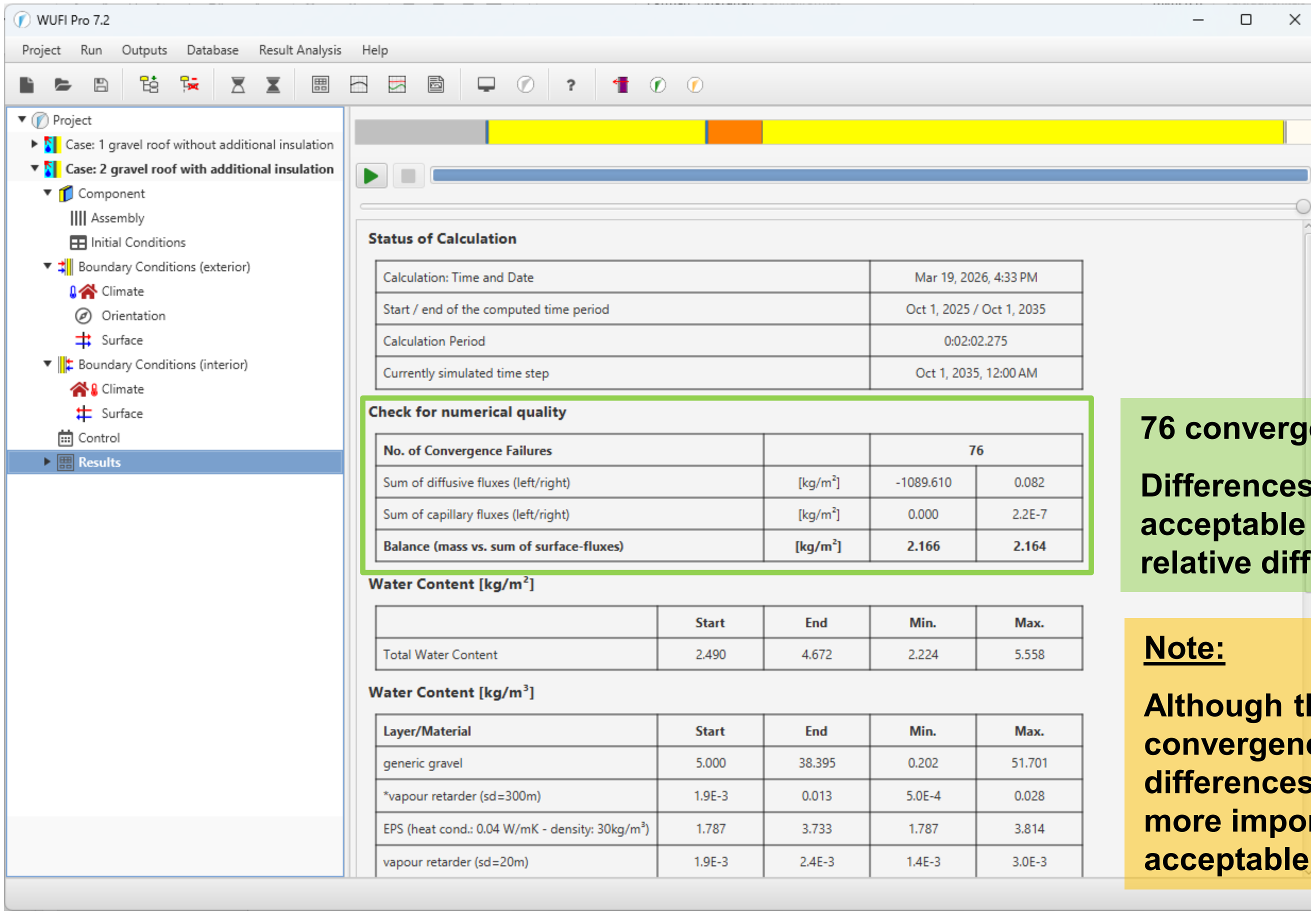


Adjust calculation period
→ Generally, longer calculation periods are required
Recommendation: at least 10 years

Adjust calculation period

Example B: Check for Numerical Quality

Results:



Status of Calculation

Calculation: Time and Date	Mar 19, 2026, 4:33 PM
Start / end of the computed time period	Oct 1, 2025 / Oct 1, 2035
Calculation Period	0:02:02.275
Currently simulated time step	Oct 1, 2035, 12:00 AM

Check for numerical quality

No. of Convergence Failures		**76**	
Sum of diffusive fluxes (left/right)	[kg/m²]	-1089.610	0.082
Sum of capillary fluxes (left/right)	[kg/m²]	0.000	2.2E-7
Balance (mass vs. sum of surface-fluxes)	**[kg/m²]**	**2.166**	**2.164**

Water Content [kg/m²]

	Start	End	Min.	Max.
Total Water Content	2.490	4.672	2.224	5.558

Water Content [kg/m³]

Layer/Material	Start	End	Min.	Max.
generic gravel	5.000	38.395	0.202	51.701
*vapour retarder (sd=300m)	1.9E-3	0.013	5.0E-4	0.028
EPS (heat cond.: 0.04 W/mK - density: 30kg/m³)	1.787	3.733	1.787	3.814
vapour retarder (sd=20m)	1.9E-3	2.4E-3	1.4E-3	3.0E-3

76 convergence failures

Differences in balance acceptable due to small relative differences!

Note:

Although there are many convergence failures, the differences in balance are more important and are acceptable in this case.

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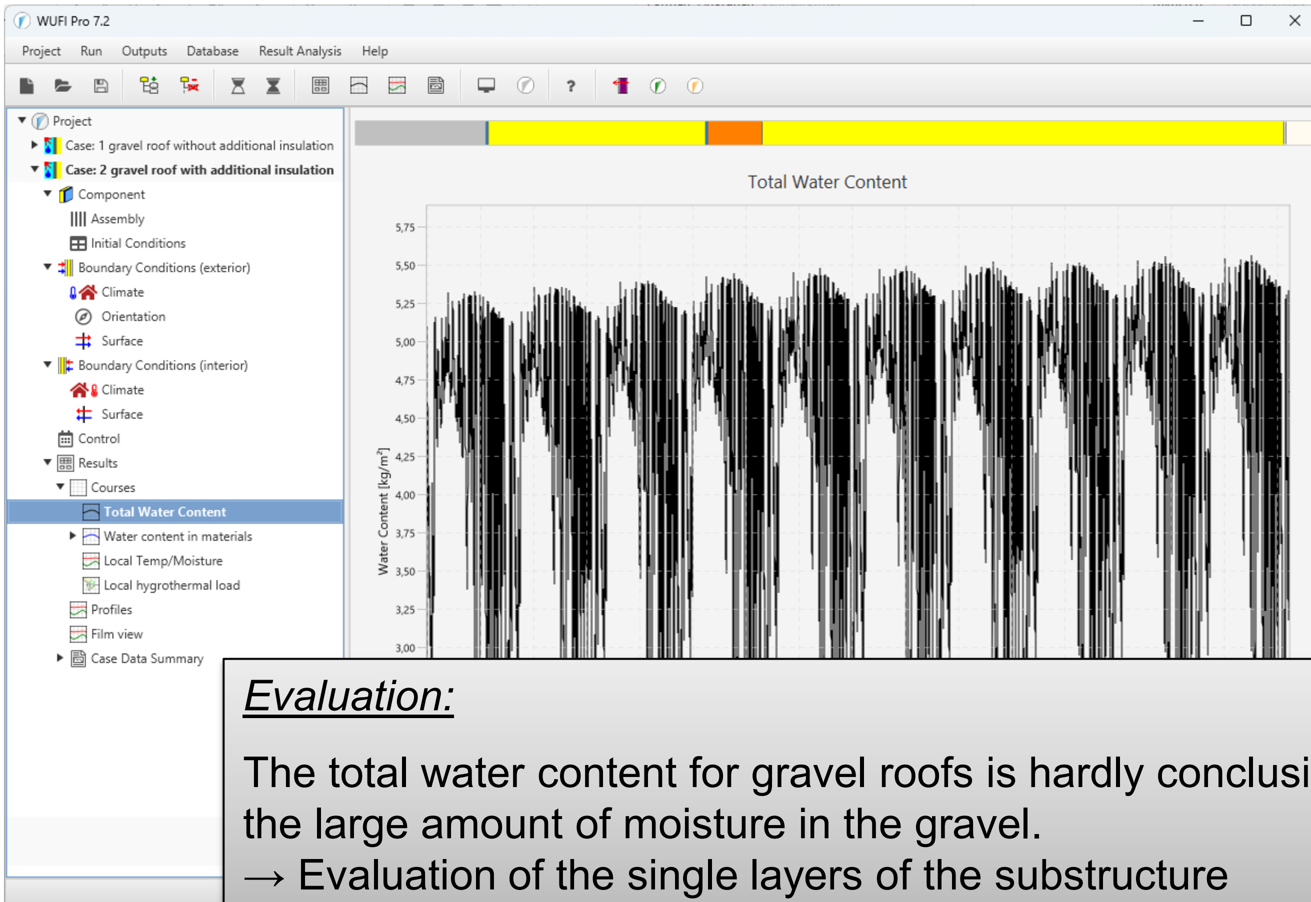
Example B: Evaluation of Total Water Content

Evaluation:
Total water content



Evaluation:

The total water content for gravel roofs is hardly conclusive because of the large amount of moisture in the gravel.
→ Evaluation of the single layers of the substructure

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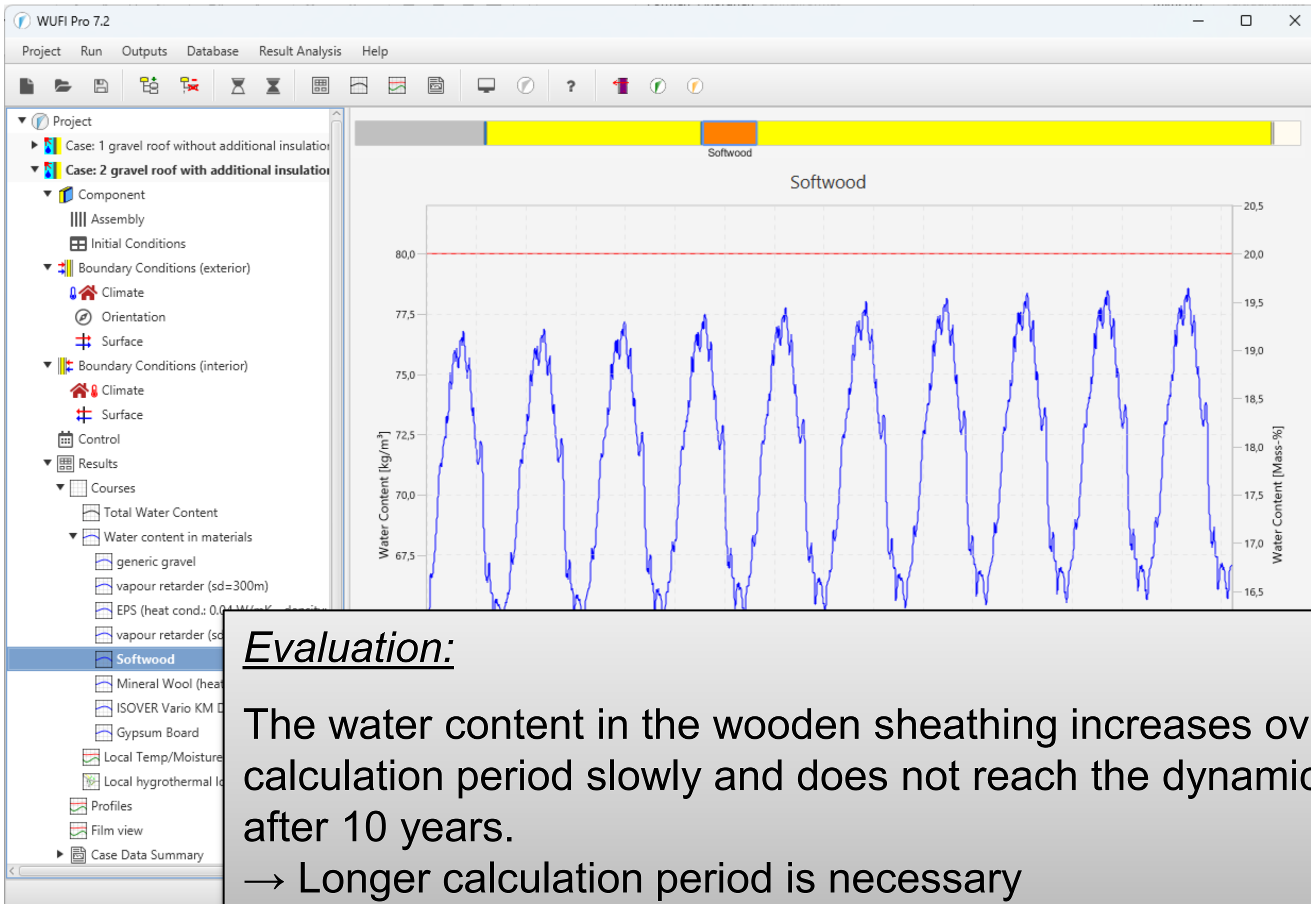
Example B: Evaluation of Wood Moisture

Evaluation:

Water Content in the wooden sheathing



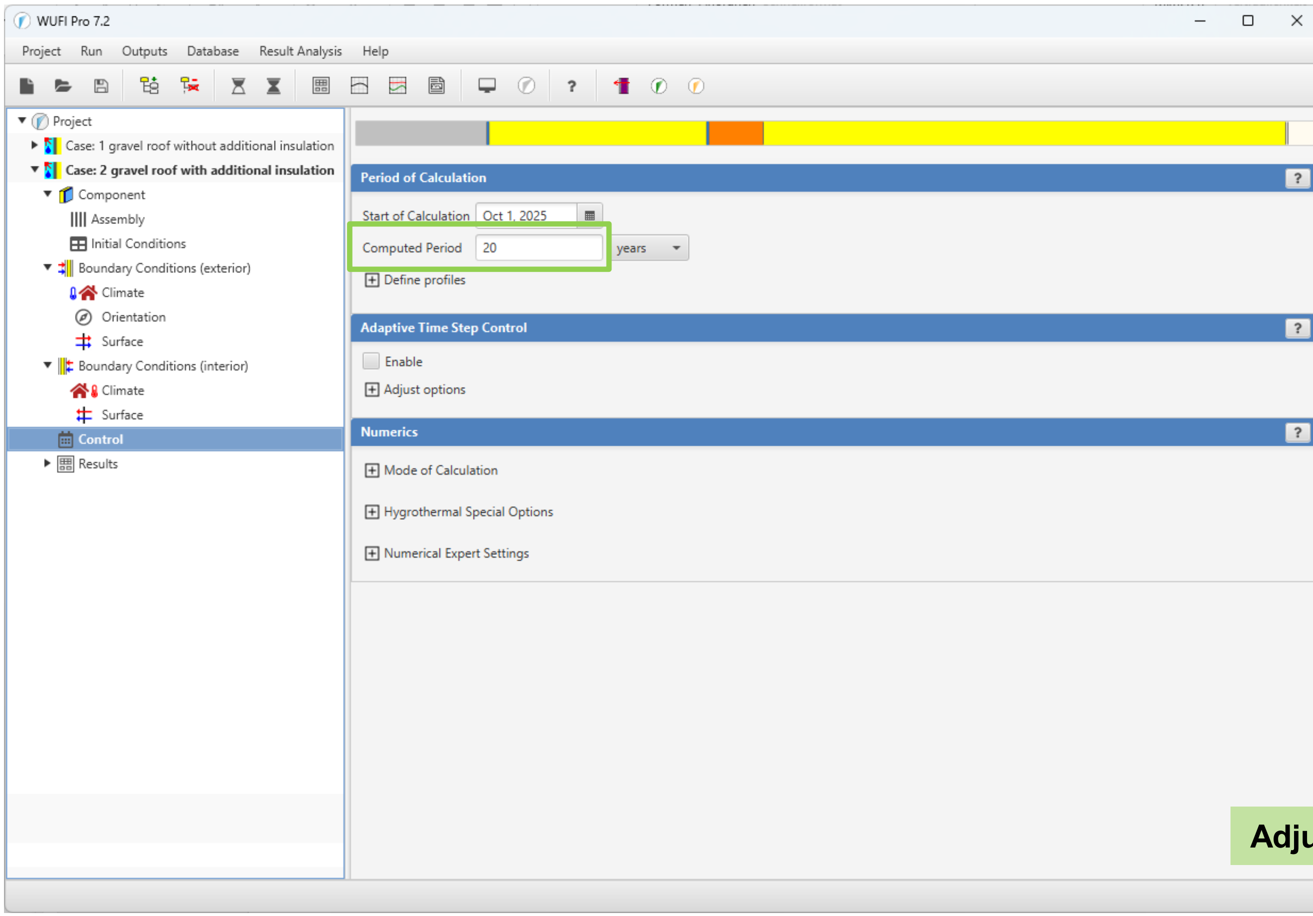
Evaluation:

The water content in the wooden sheathing increases over the calculation period slowly and does not reach the dynamic equilibrium after 10 years.

→ Longer calculation period is necessary

Example B: Evaluation of Wood Moisture

<u>Input:</u> Control

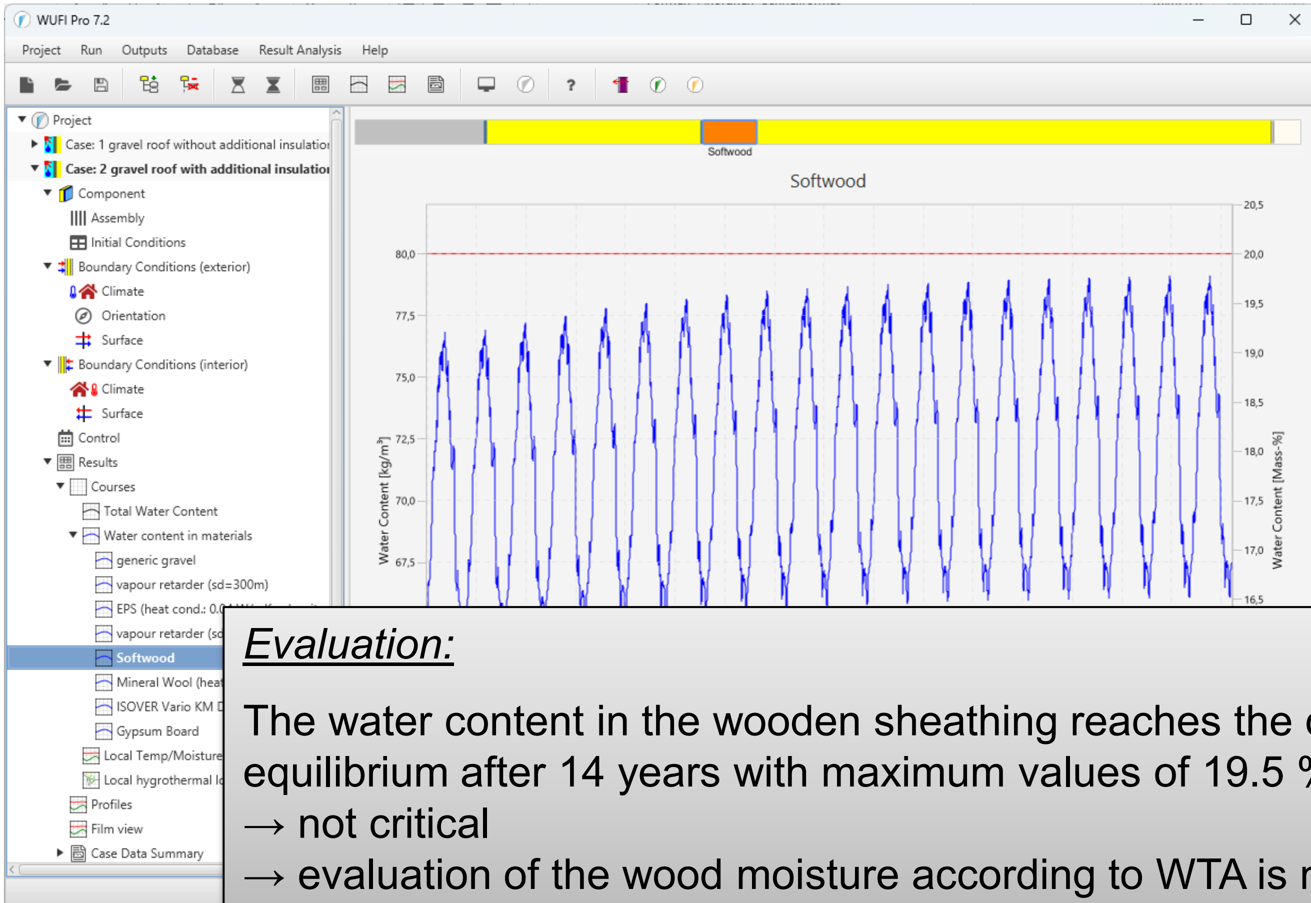


Adjust calculation time

Example B: Evaluation of Wood Moisture

Evaluation:

Water Content in the wooden sheathing



Evaluation:

The water content in the wooden sheathing reaches the dynamic equilibrium after 14 years with maximum values of 19.5 % by mass.
→ not critical
→ evaluation of the wood moisture according to WTA is not required

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