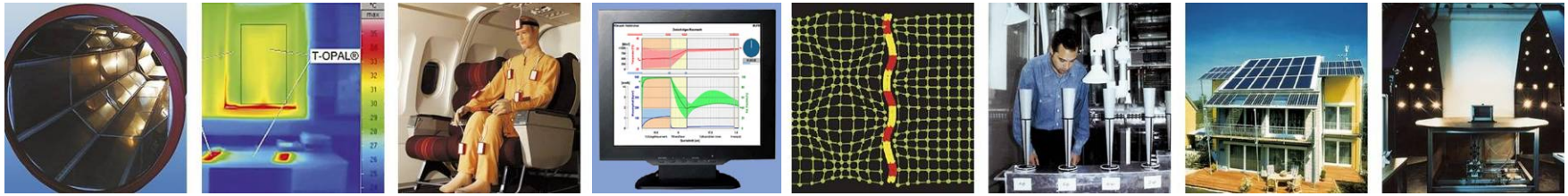


WUFI®

Example Cases WUFI® Pro: Green Roofs (generic)

Version: July 2021

Fraunhofer IBP

Content

Green Roof Data in the WUFI® - Material Database

„Generic Substrate“

This substrate should be used if no measured material properties for the green roof are available. The application is limited due to the experimental basis and the effective radiation parameters for locations in Central Europe (or comparable climates).

More information about the different models

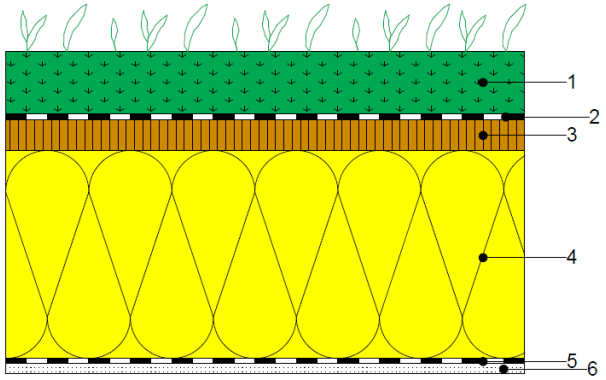
and there development can be found in the

Guideline for the Calculation of extensive Green Roofs (generic)

Extensive Green Roof on Lightweight Construction

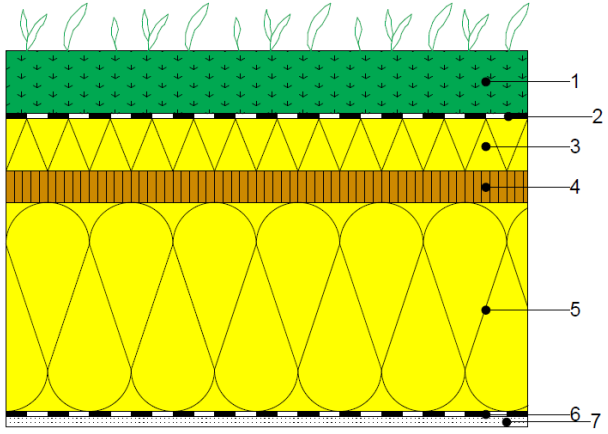
On the basis of two example cases, the procedure for the evaluation of green roofs on lightweight constructions is described below. The necessary material data, the moisture sources and the boundary conditions as well as the procedure for the evaluation of the construction are explained.

Example A:
Extensive green roof on lightweight construction without additional insulation



1 Substrate incl. Planting
2 Roofing Membrane (s_d = 300 m)
3 Wooden Sheathing
4 Mineral Wool Insulation
5 Moisture-variable Vapour Retarder
6 Gypsum Board

Example B:
Extensive green roof on lightweight construction with additional insulation



1 Substrate incl. Planting
2 Roofing Membrane (s_d = 300 m)
3 EPS-Insulation
4 Wooden Sheathing
5 Mineral Wool Insulation
6 Moisture-variable Vapour Retarder
7 Gypsum Board

Example A: Assembly

Assembly (from outside to inside):

• Generic Substrate	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

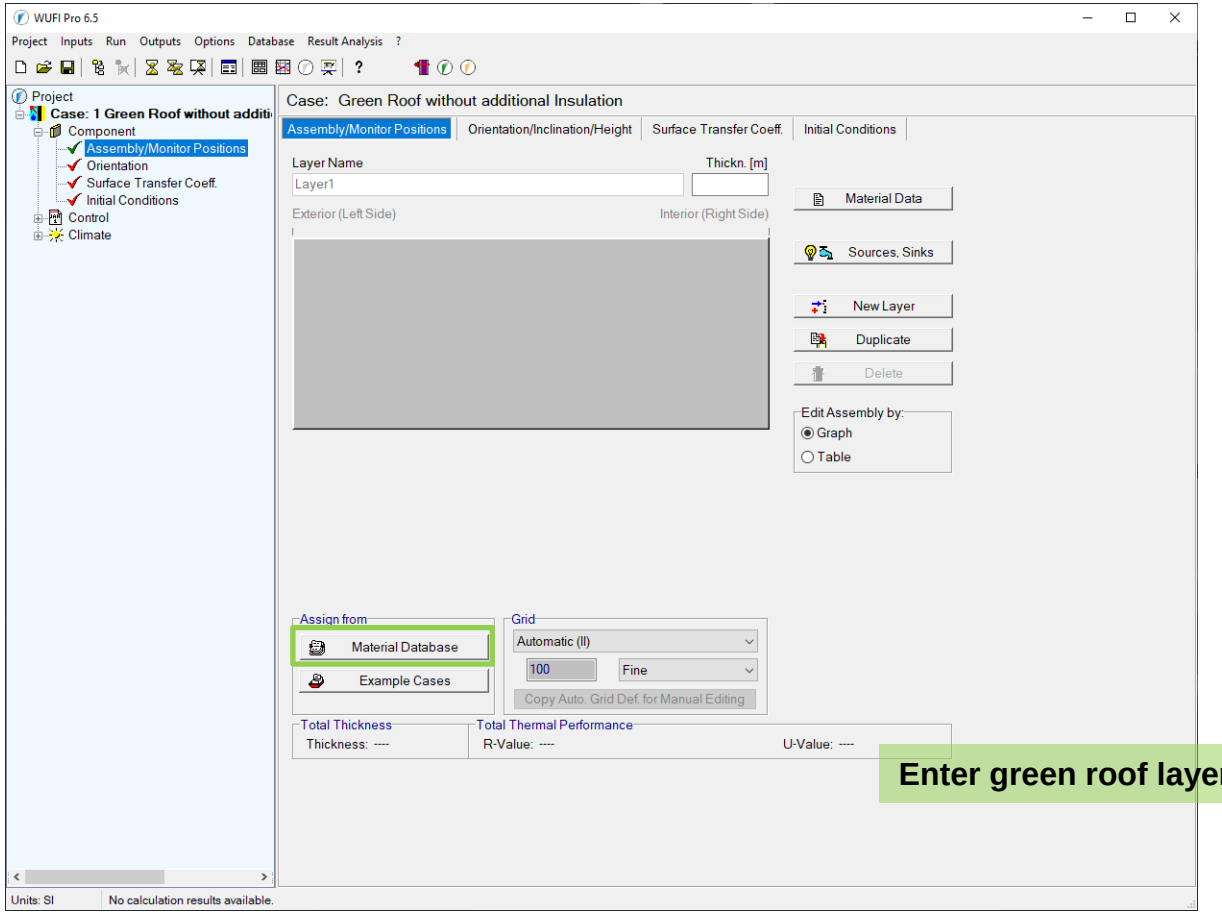
Example A: Boundary Conditions

Boundary Conditions:

- Flat roof (3° to the North)
- Short-Wave Radiation Absorptivity / Long-Wave Radiation Emissivity: according to the Generic Green 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

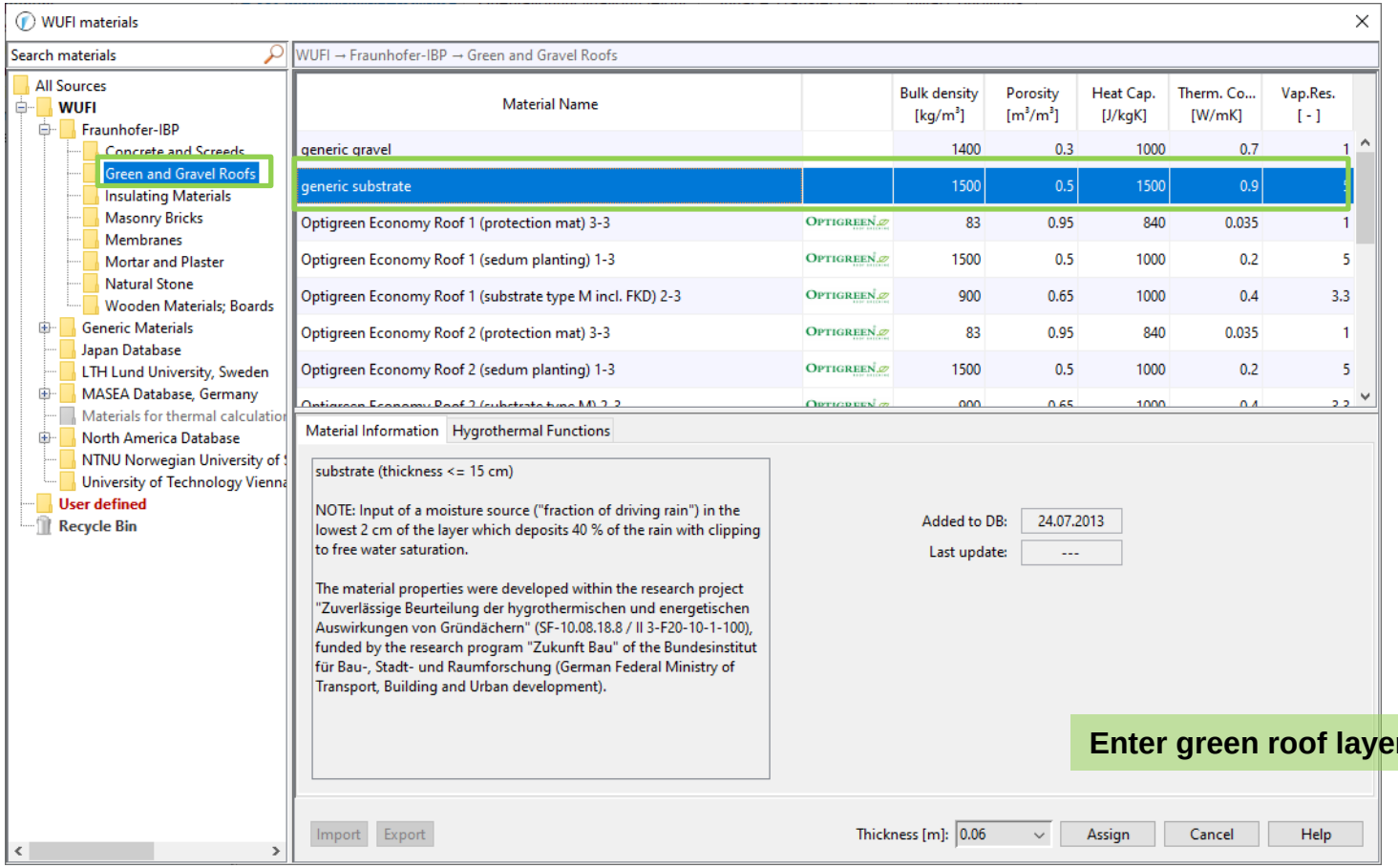
Example A: Component Assembly

Input: Component – Assembly / Monitor Positions



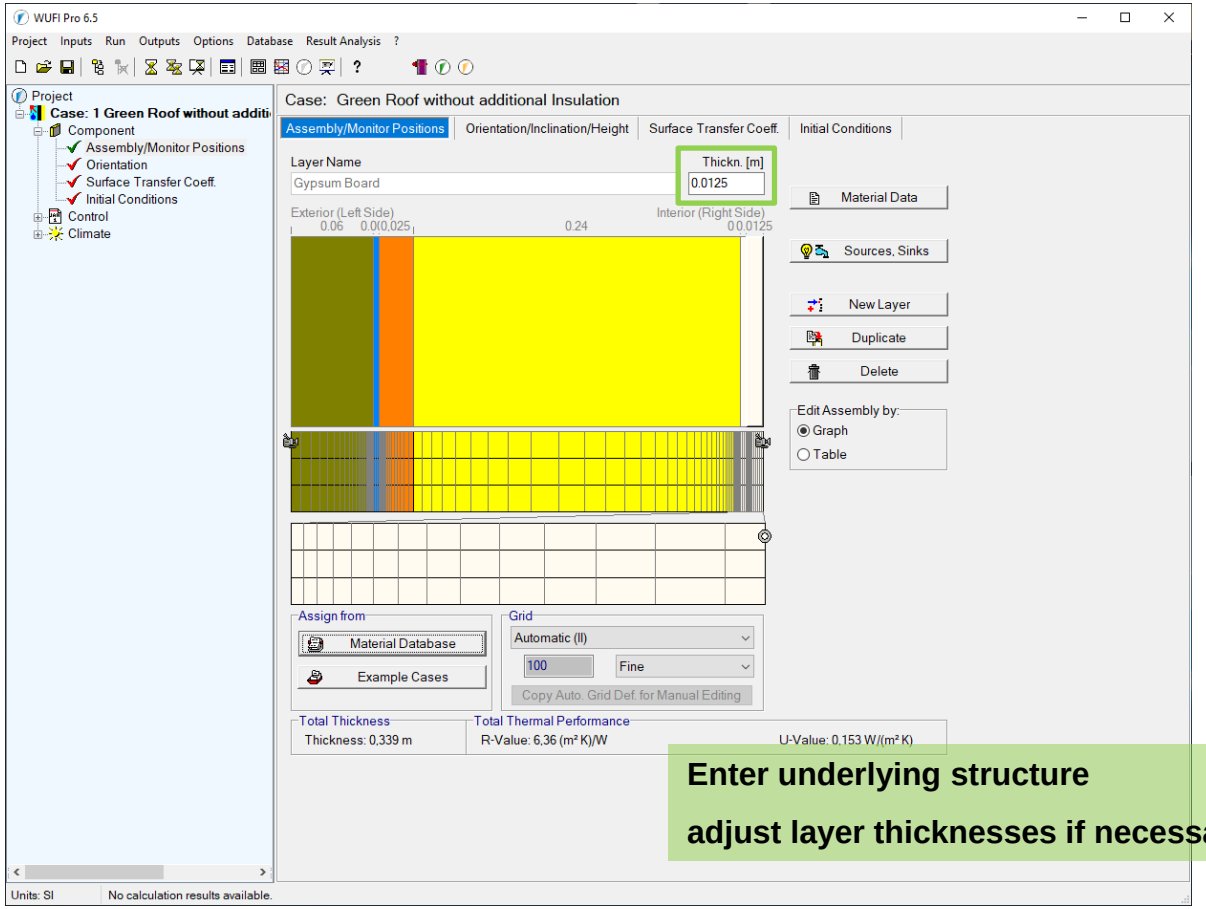
Example A: Component Assembly

Input: Component – Assembly / Monitor Positions



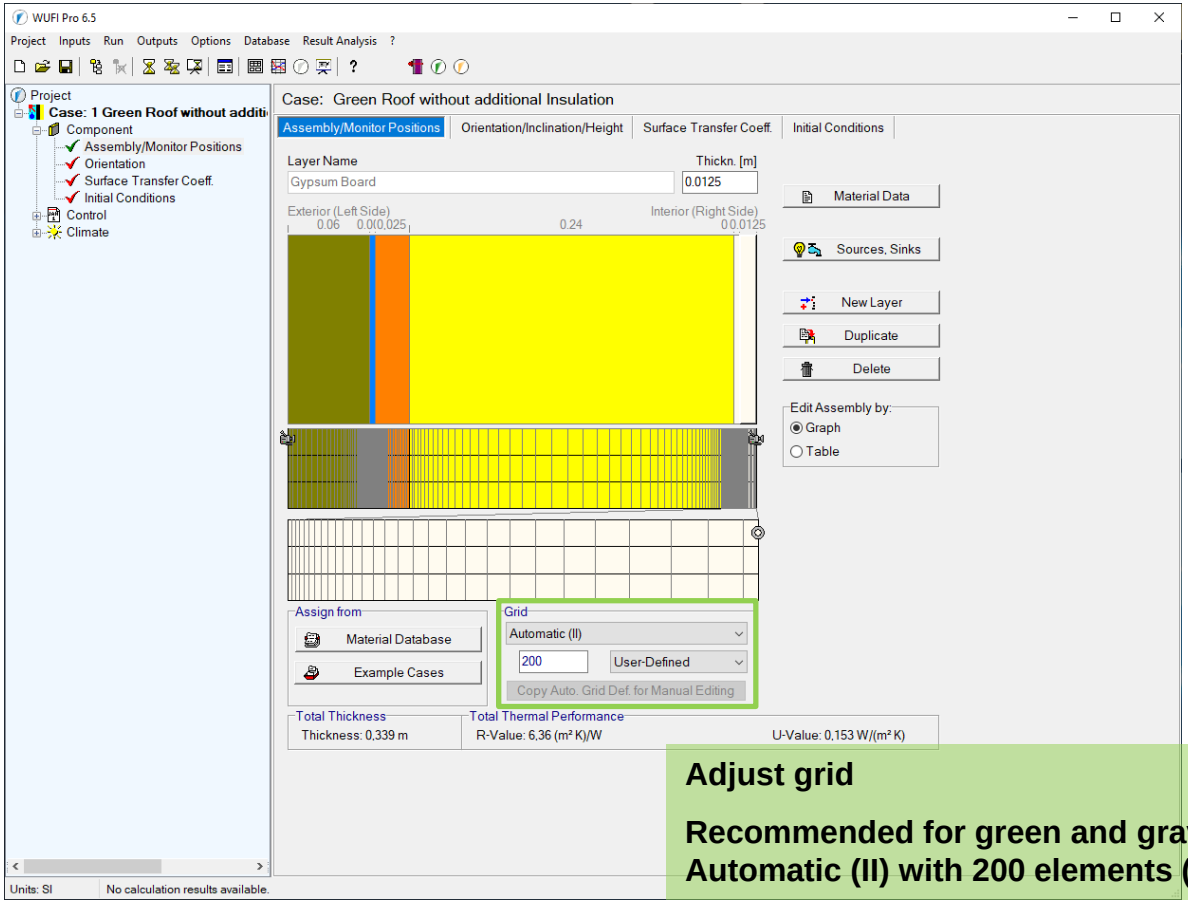
Example A: Component Assembly

Input: Component – Assembly / Monitor Positions



Example A: Grid

Input: Component – Assembly / Monitor Positions



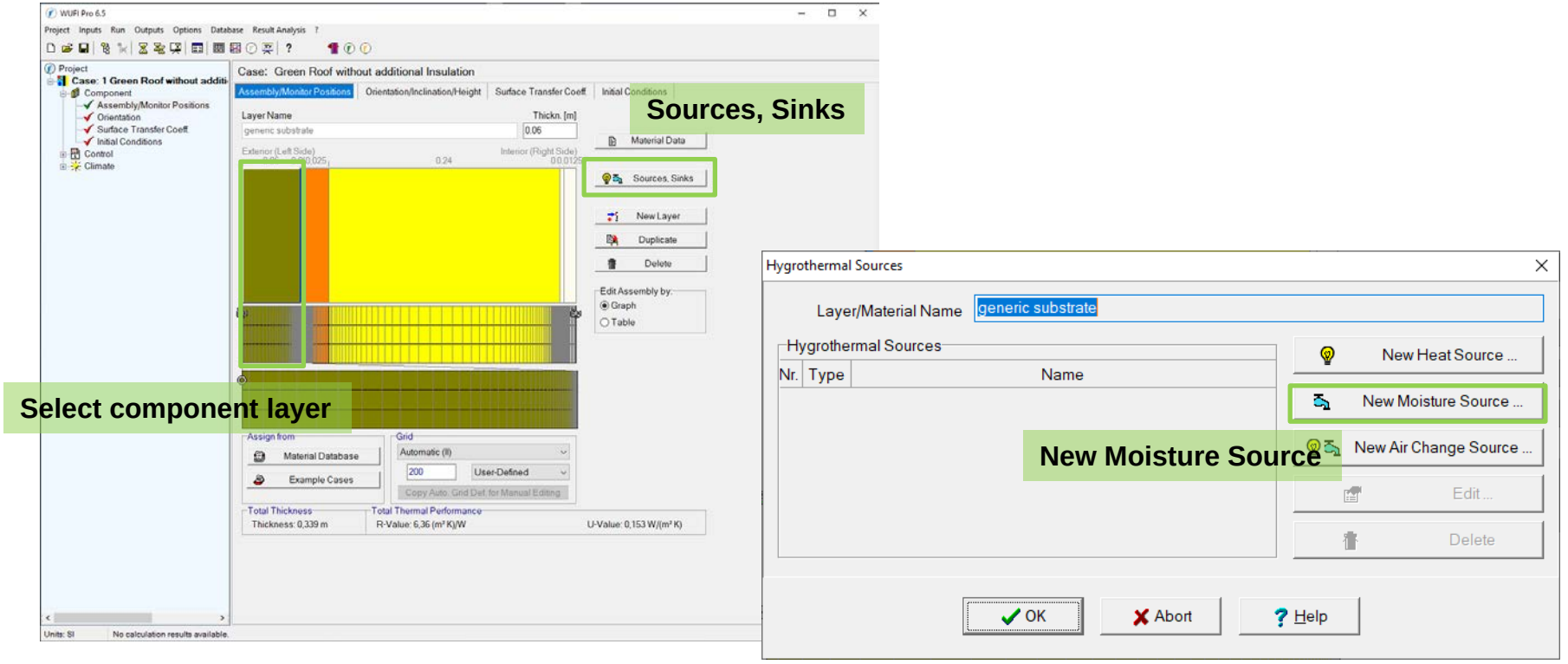
Adjust grid

Recommended for green and gravel roofs: Automatic (II) with 200 elements (user-defined)

Example A: Moisture Source in the Substrate Layer

Input: Component – Assembly / Monitor Positions

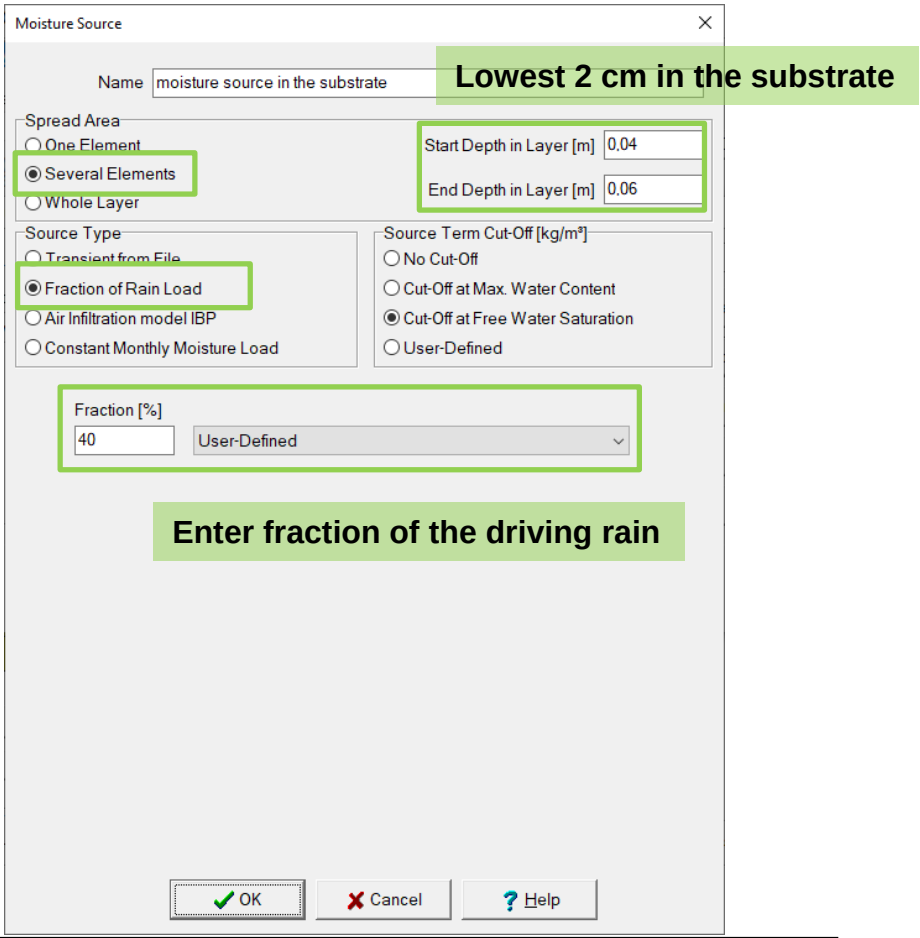
Enter moisture source in the layer „Generic Substrate“.



Example A: Moisture Source in the Substrate Layer

Input: Component – Assembly / Monitor Positions

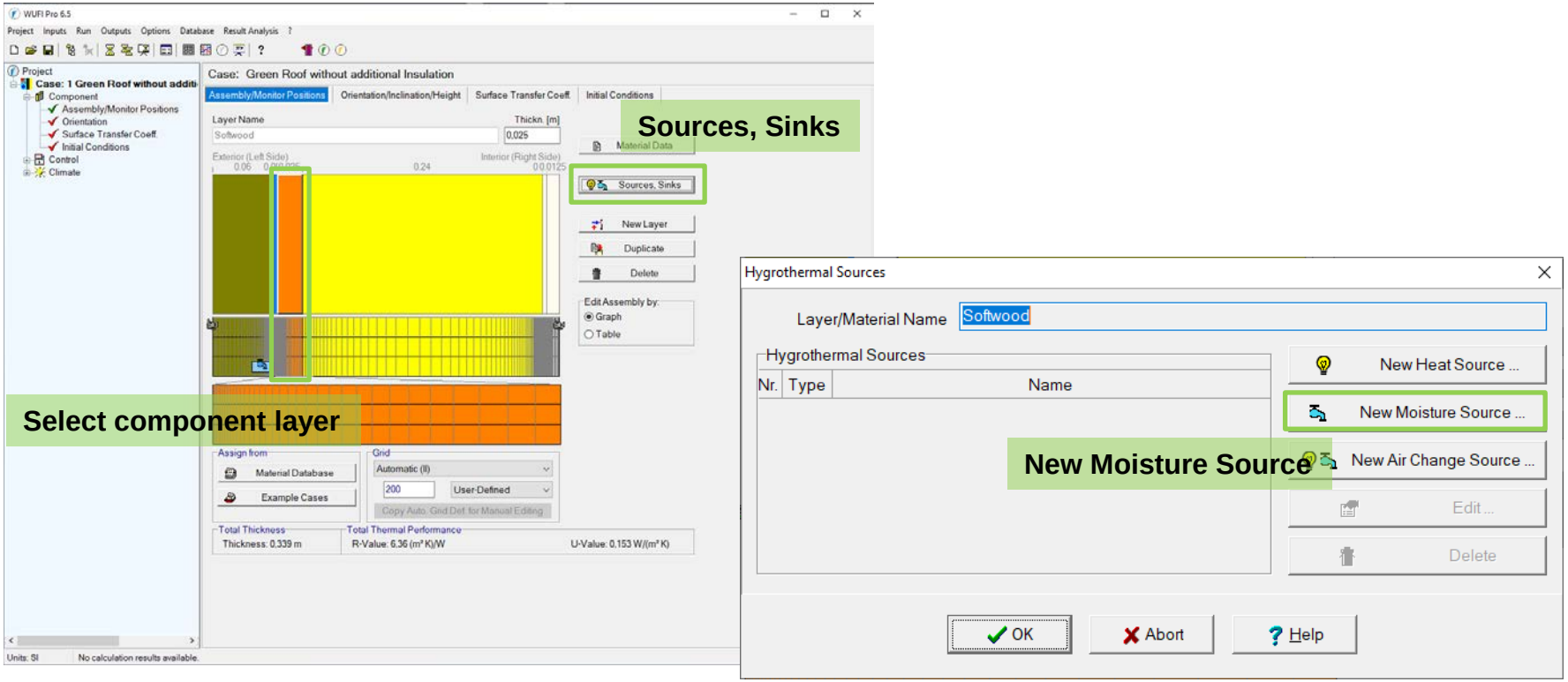
Moisture source in the lowest 2 cm of the layer „Generic Substrate“.



Example A: Infiltration Source

Input: Component – Assembly / Monitor Positions

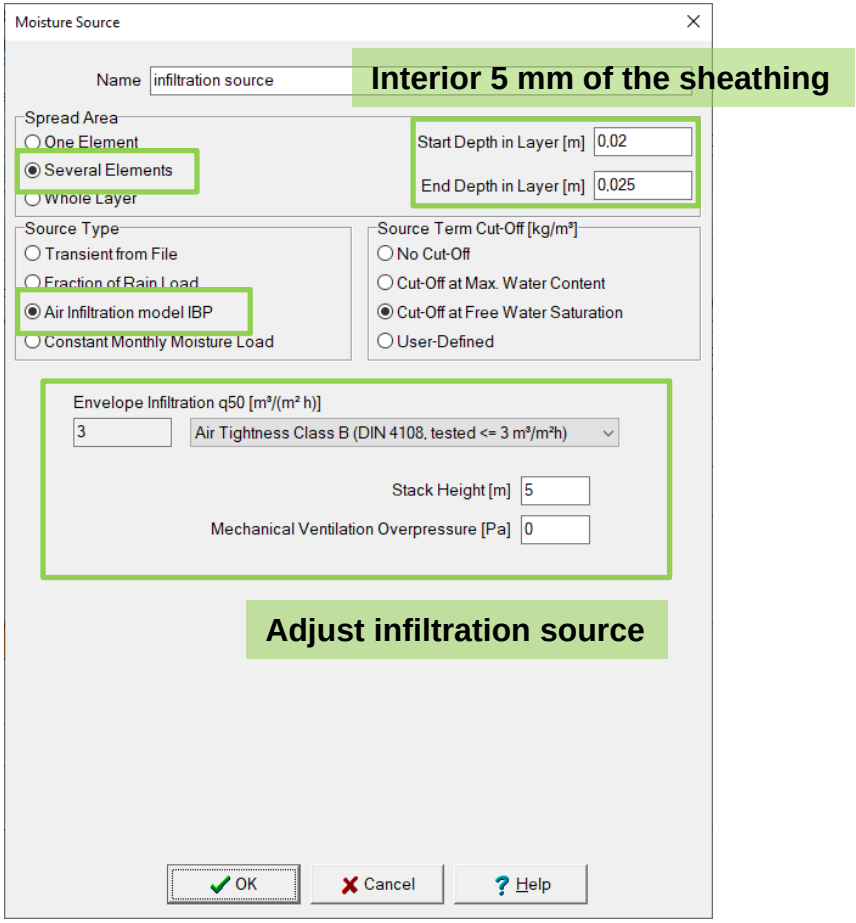
Infiltration source according to DIN 68800 in the wooden sheathing.



Example A: Infiltration Source

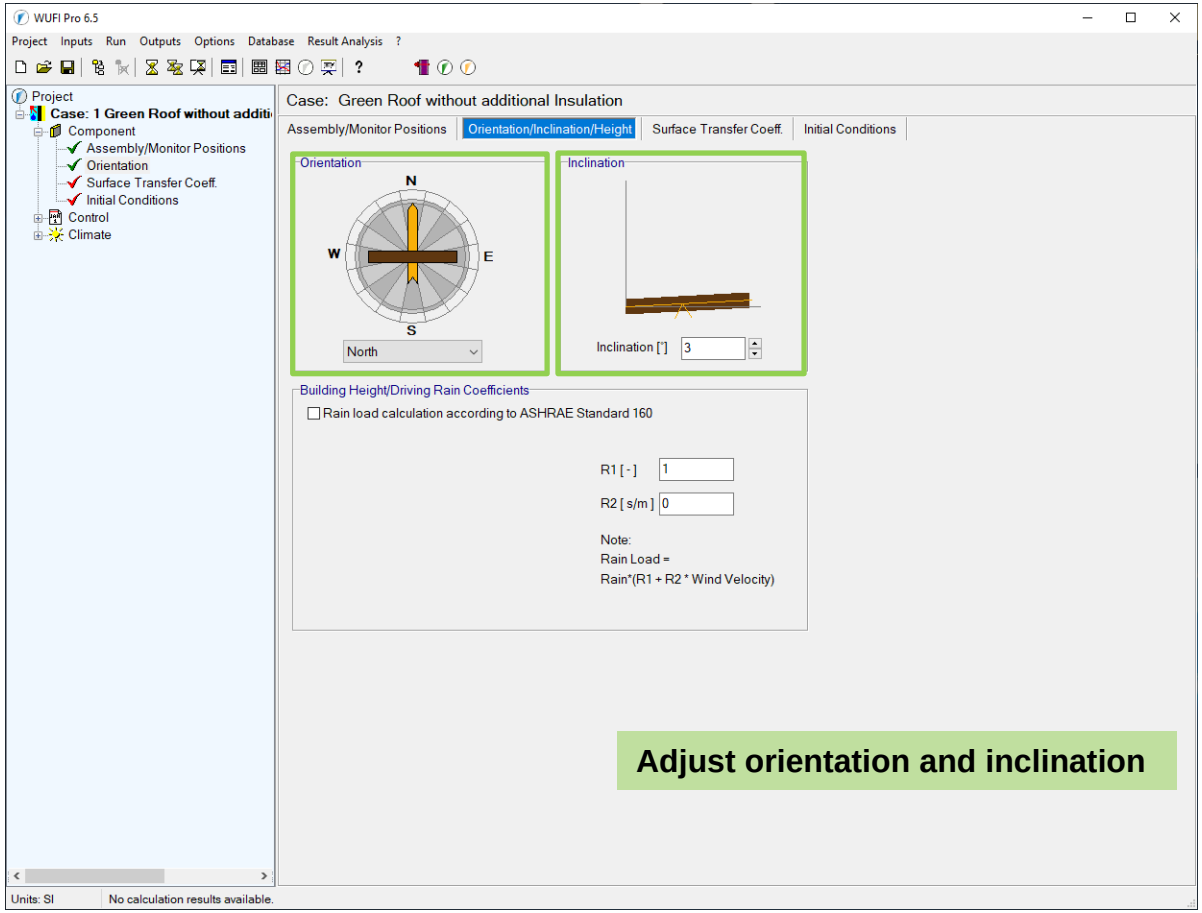
Input: Component – Assembly / Monitor Positions

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



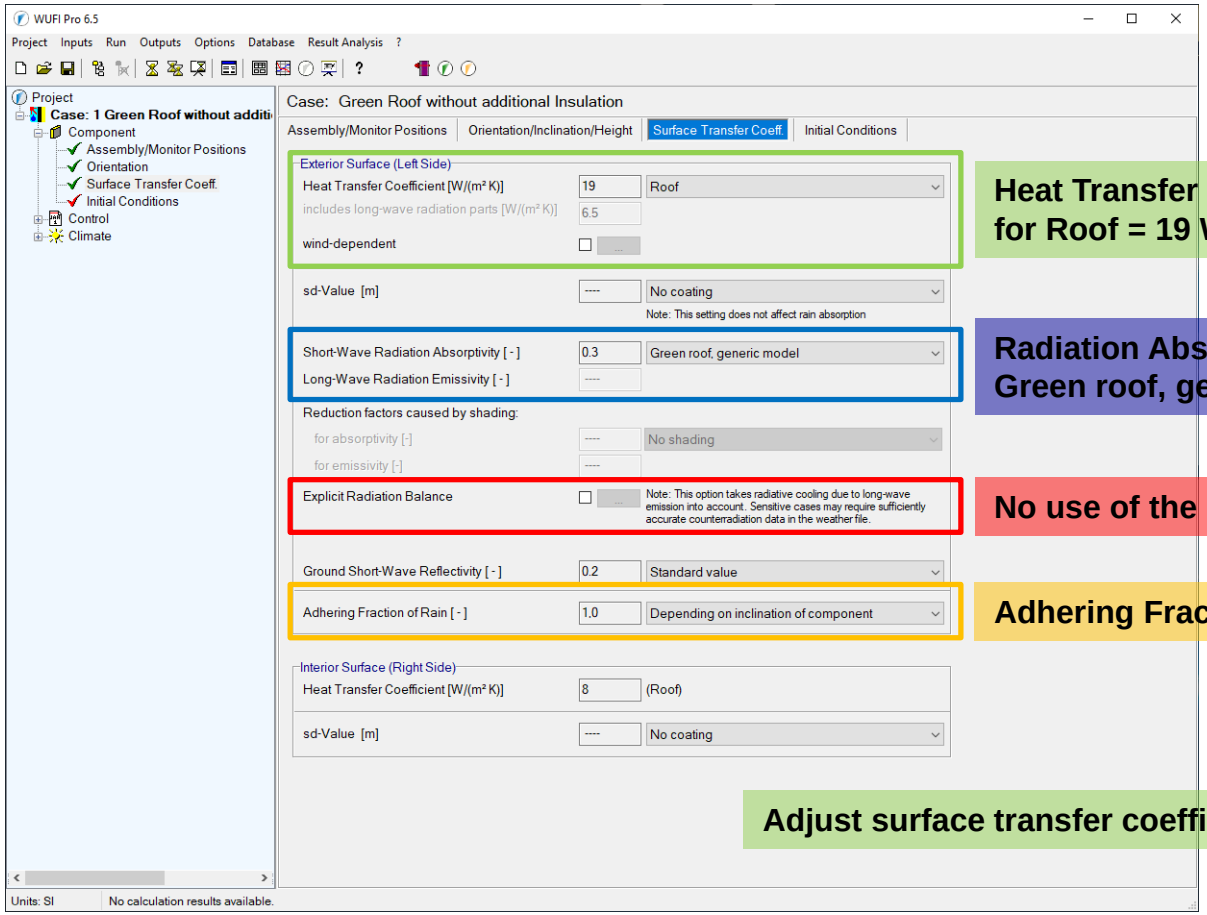
Example A: Orientation / Inclination

Input: Component – Orientation



Example A: Surface Transfer Coefficients

Input: Component – Surface Transfer Coeff.



Heat Transfer Coefficient for Roof = 19 W/m²K

Radiation Absorptivity and Emissivity: Green roof, generic model

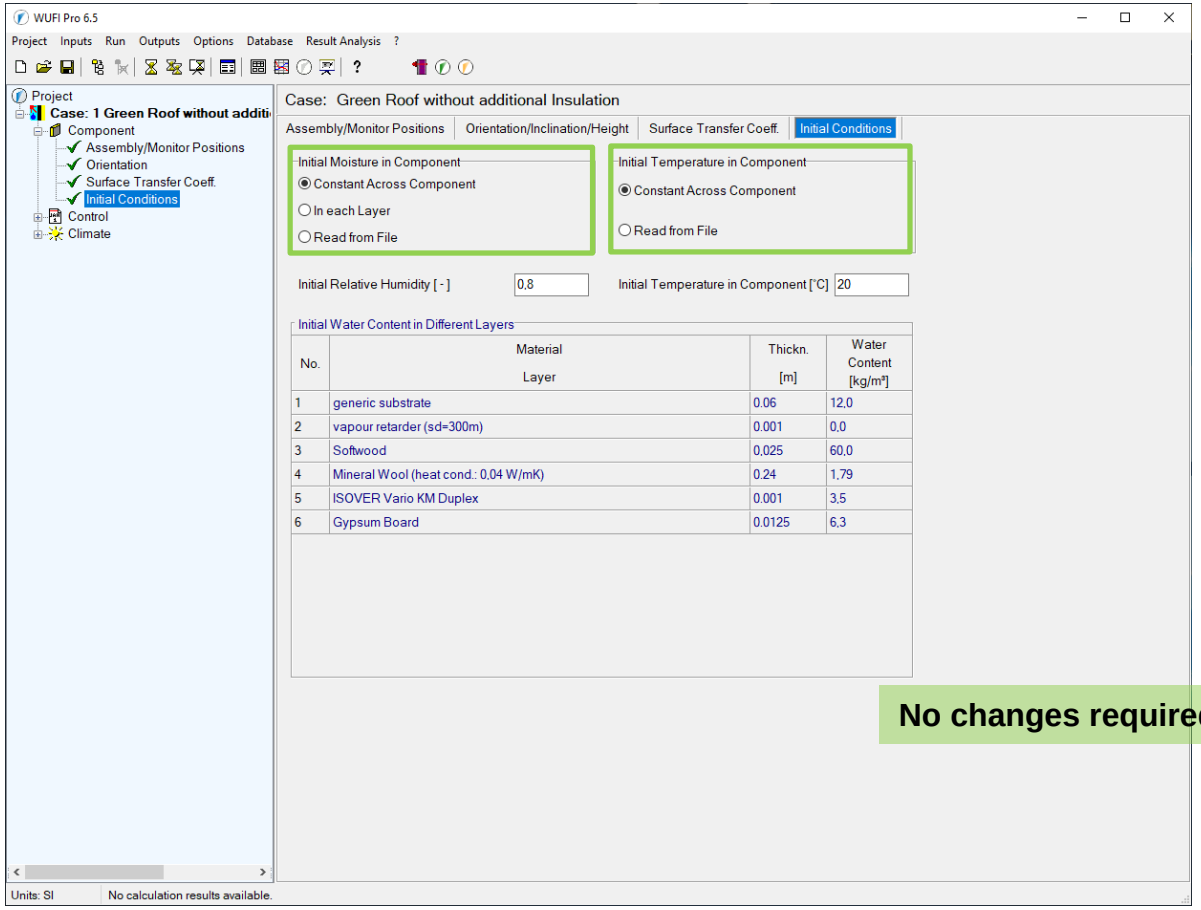
No use of the Explicit Radiation Balance

Adhering Fraction of Rain = 1

Adjust surface transfer coefficients!

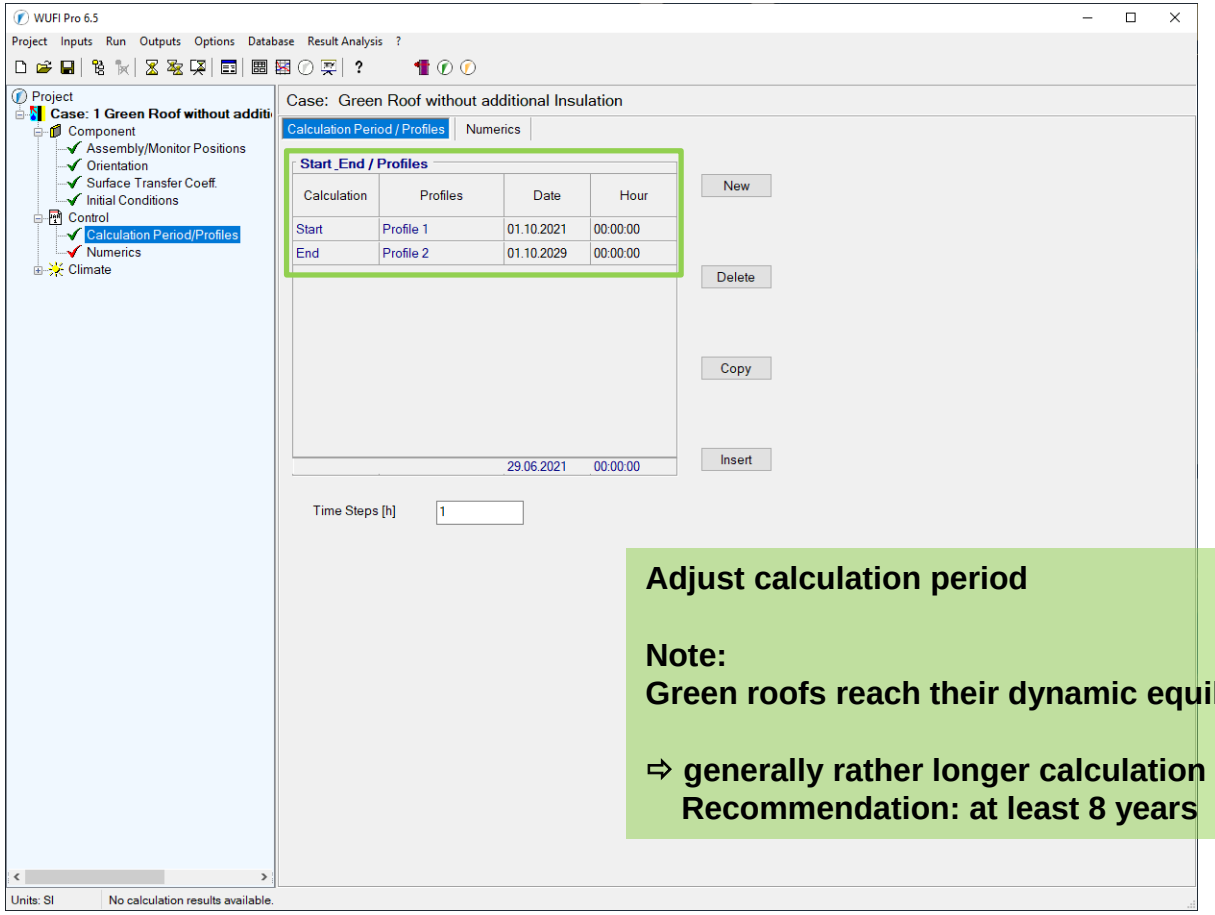
Example A: Initial Conditions

Input: Component – Initial Conditions



Example A: Calculation Period

Input: Control – Calculation Period/ Profiles



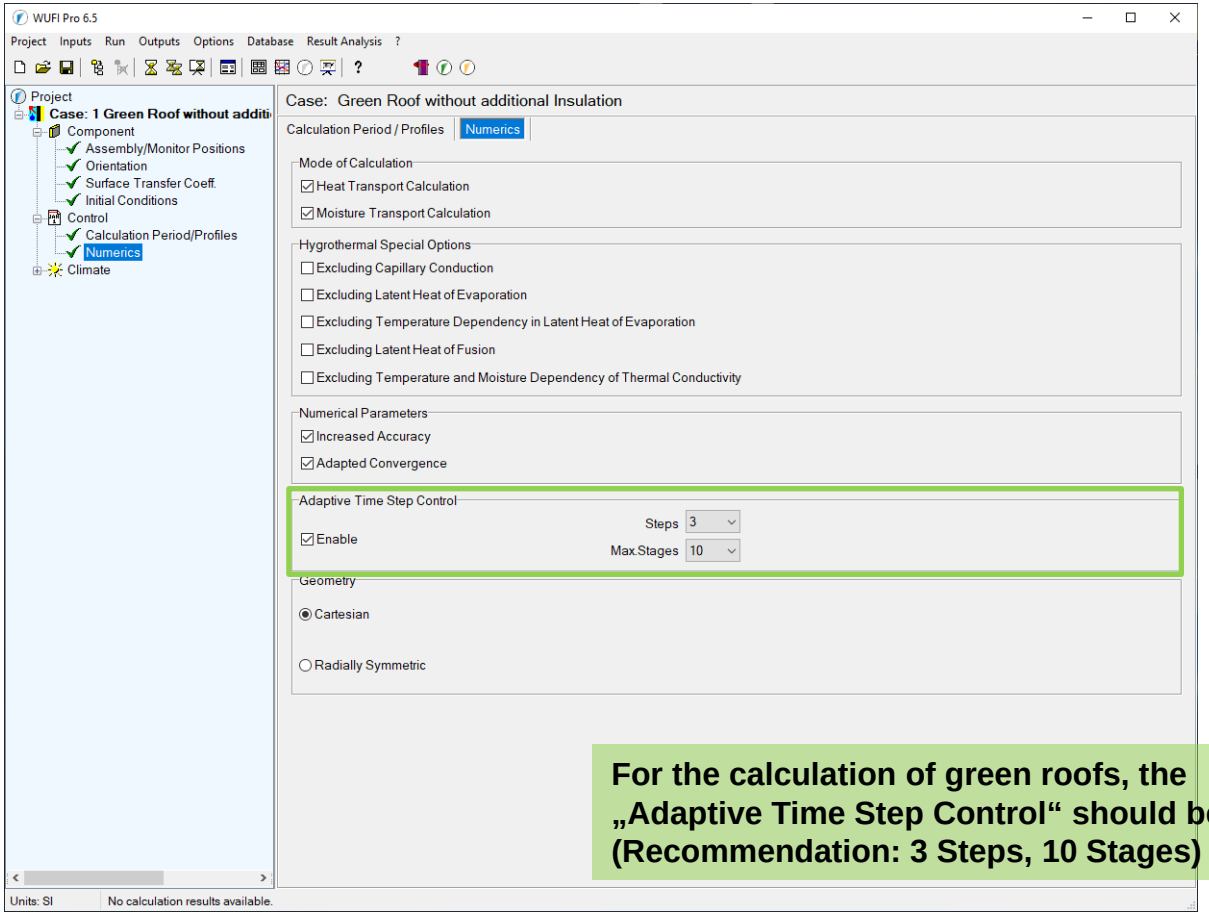
Adjust calculation period

Note:
Green roofs reach their dynamic equilibrium very slowly

⇨ generally rather longer calculation periods are required
Recommendation: at least 8 years

Example A: Numerical Settings

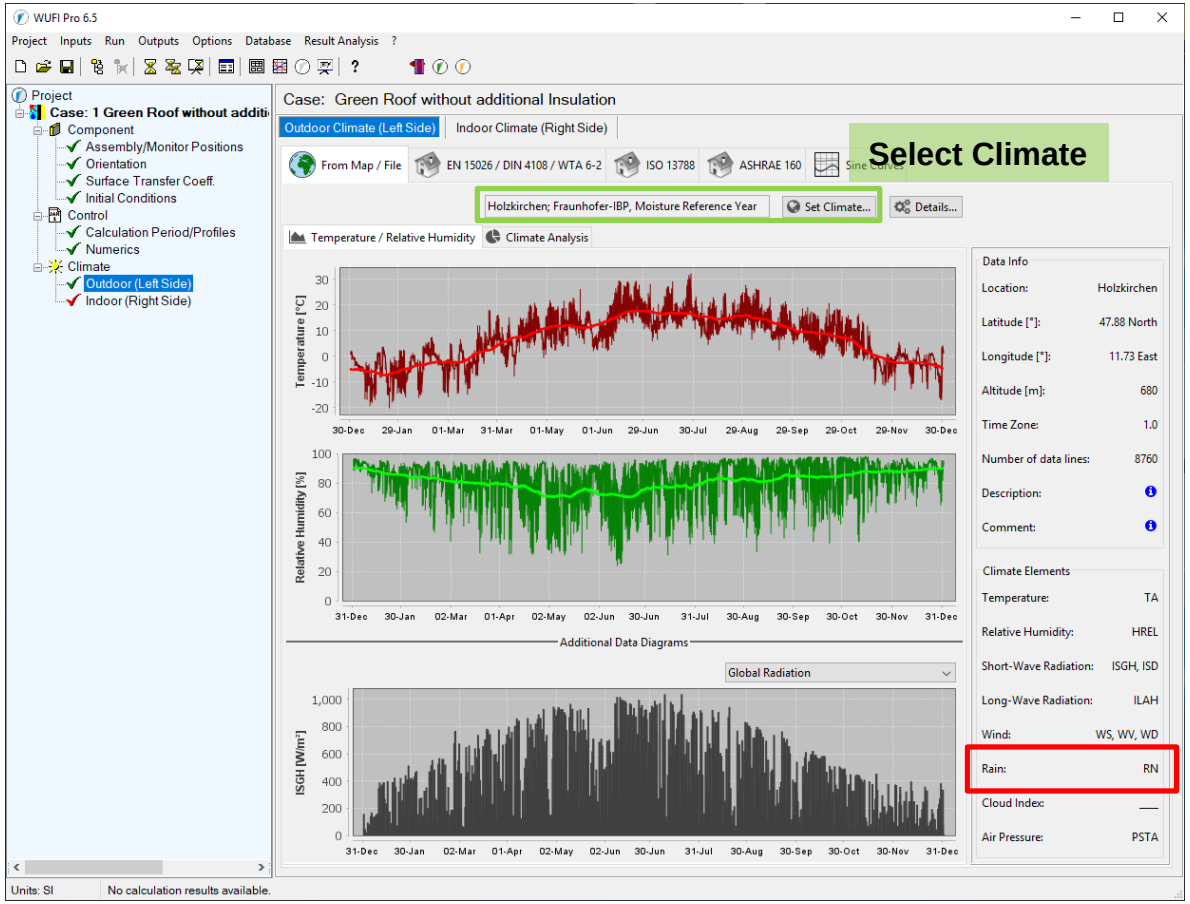
Input: Control – Numerics



For the calculation of green roofs, the „Adaptive Time Step Control“ should be enabled! (Recommendation: 3 Steps, 10 Stages)

Example A: Outdoor Climate

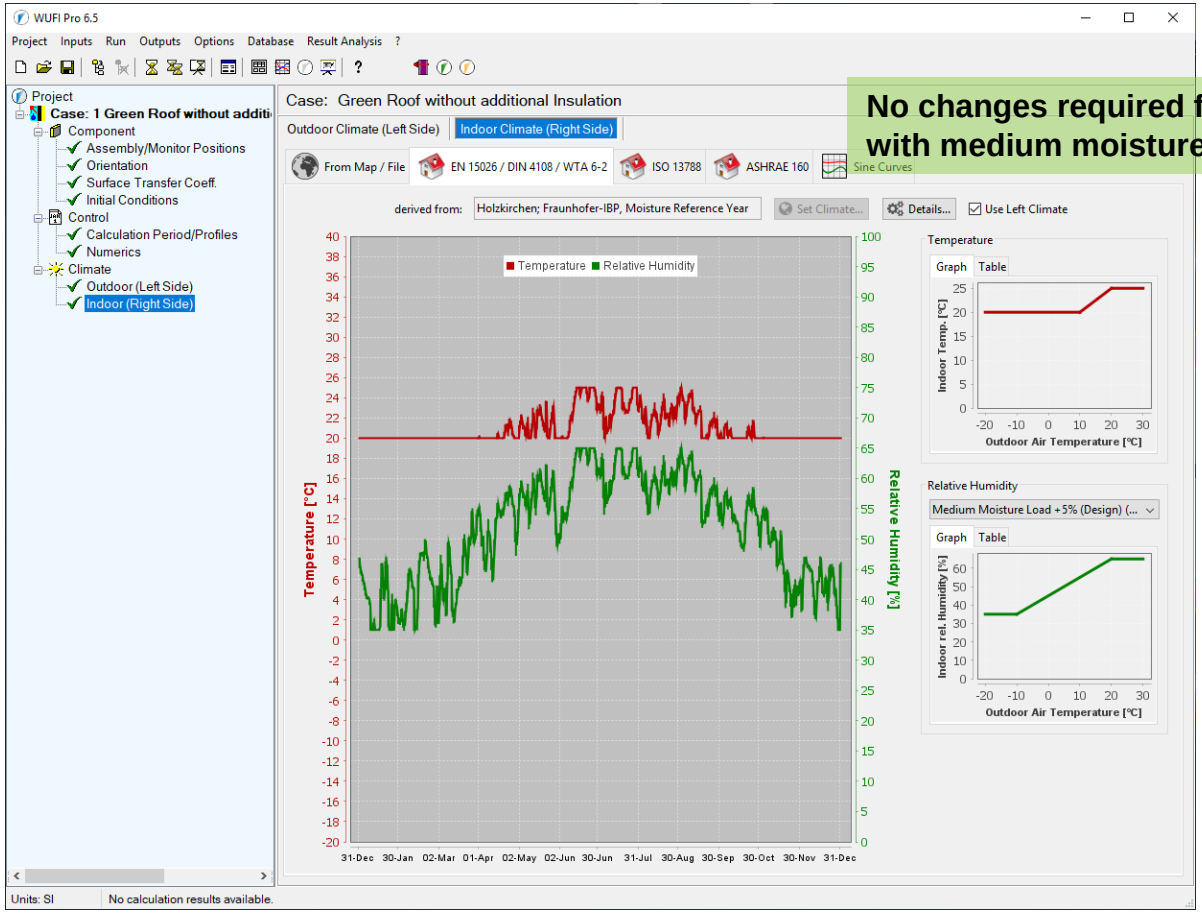
Input: Climate – Outdoor (Left Side)



Note:
The generic green roof model is also suitable for climate data without long-wave radiation. Rain data is necessary!

Example A: Indoor Climate

Input: Climate – Indoor (Right Side)



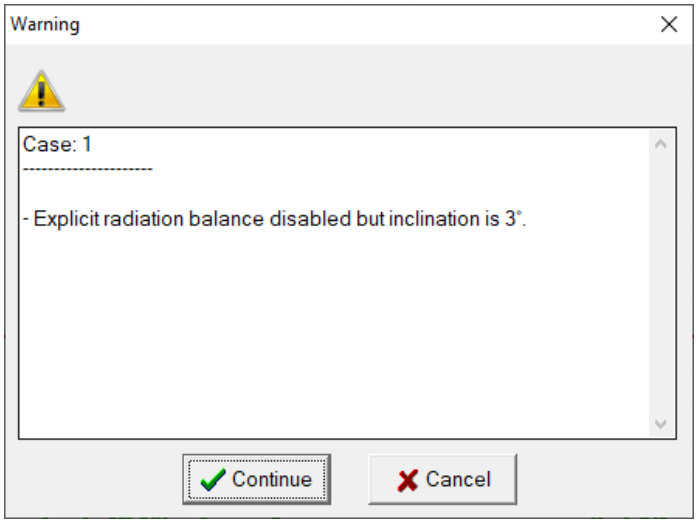
No changes required for indoor climate with medium moisture load + 5%

Example A: Note when Calculation Start

Calculation Start:

Note:

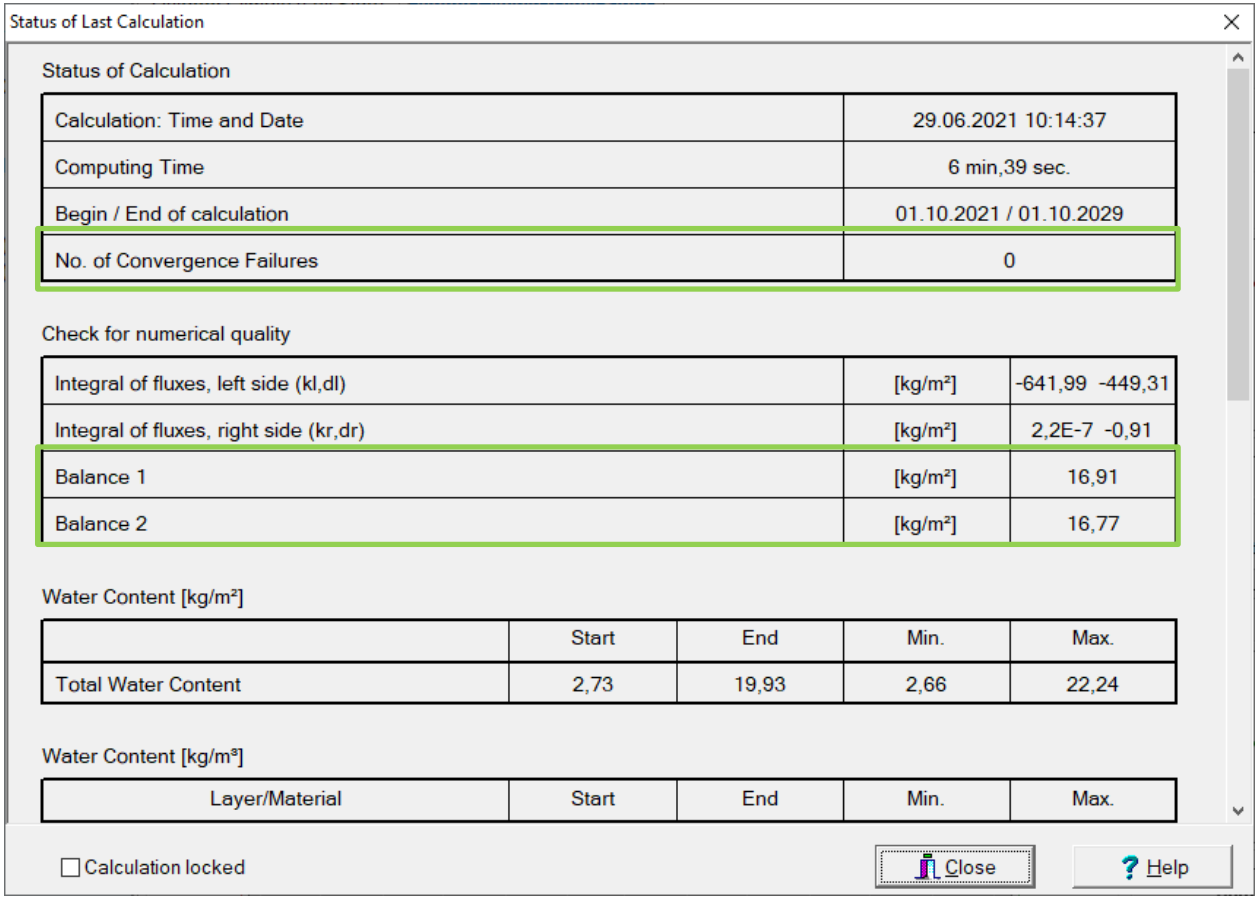
After calculation start this warning appears:



→ this warning can be ignored for the calculation of a green roof with the generic model!

Example A: Evaluation Calculation Quality

Status of Last Calculation:


Status of Last Calculation

Status of Calculation

Calculation: Time and Date	29.06.2021 10:14:37
Computing Time	6 min,39 sec.
Begin / End of calculation	01.10.2021 / 01.10.2029
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[kg/m²]	-641,99 -449,31
Integral of fluxes, right side (kr,dr)	[kg/m²]	2,2E-7 -0,91
Balance 1	[kg/m²]	16,91
Balance 2	[kg/m²]	16,77

Water Content [kg/m²]

	Start	End	Min.	Max.
Total Water Content	2,73	19,93	2,66	22,24

Water Content [kg/m³]

Layer/Material	Start	End	Min.	Max.

Calculation locked

Close

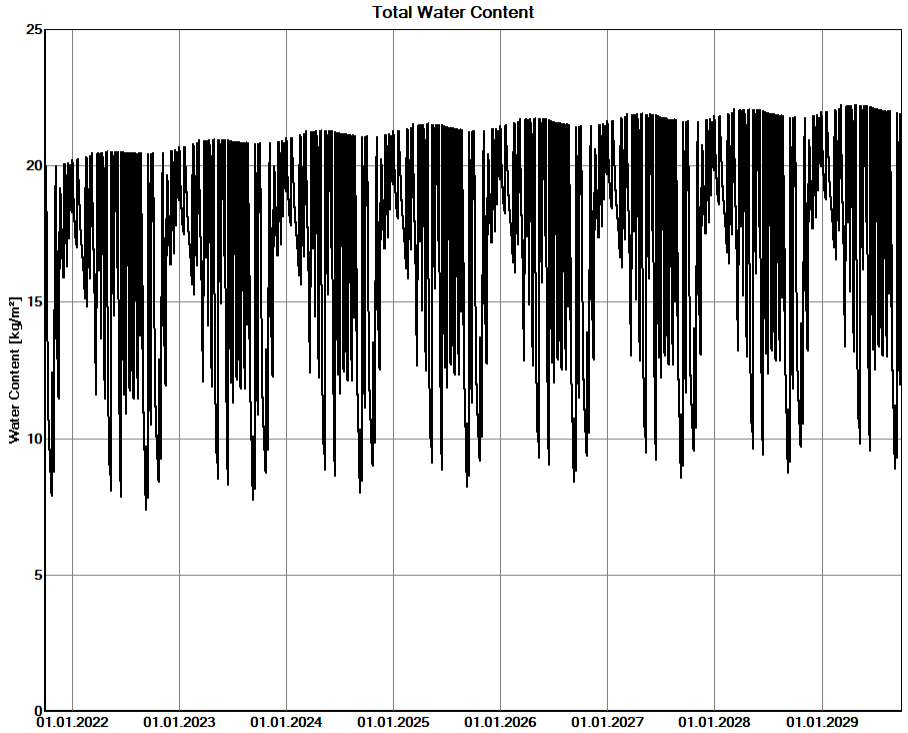
Help

No convergence failures!

Balance differences acceptable!

Example A: Evaluation Total water content

Evaluation with the help of the Quick Graphs:
Total Water Content



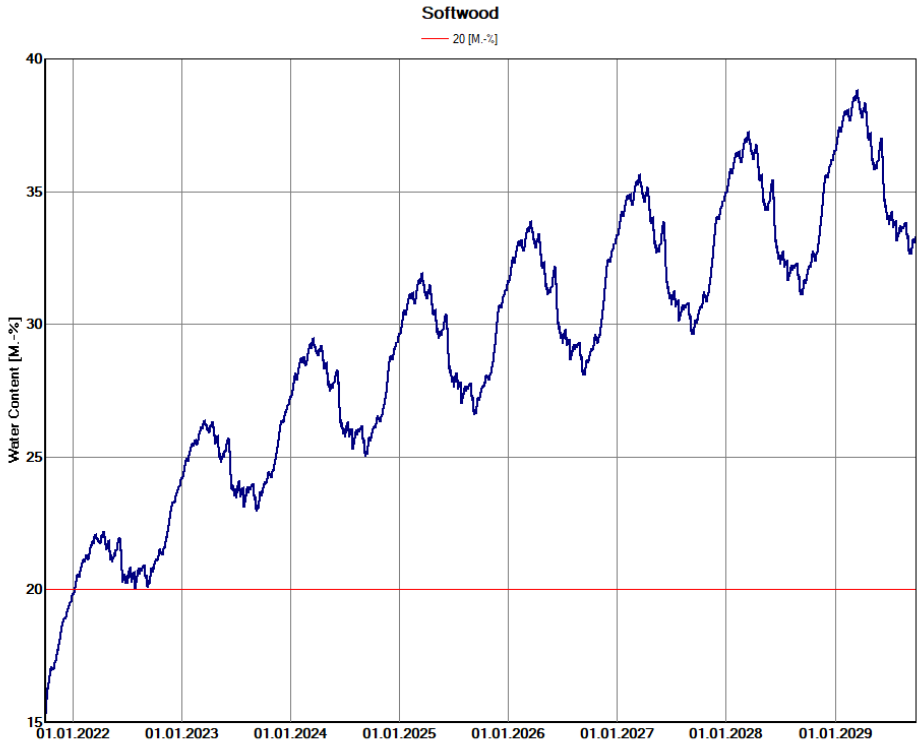
Evaluation:

The total water content for green roofs is hardly conclusive because of the large amount of moisture in the substrate.

→ Evaluation of the single layers of the substructure

Example A: Evaluation Wooden Sheathing

Evaluation with the help of the Quick Graphs:
Water Content in the wooden sheathing



Evaluation:

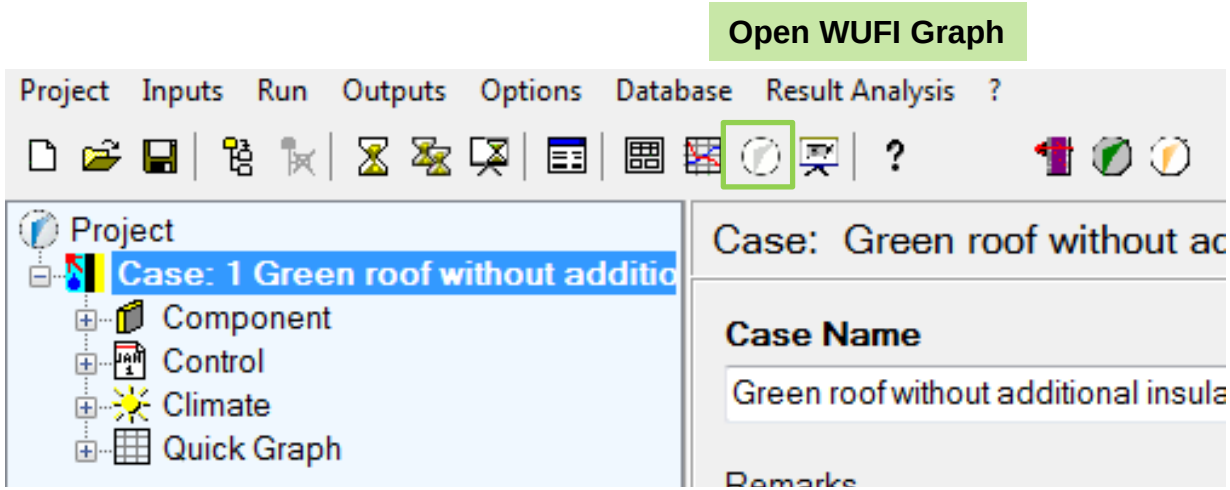
The water content in the wooden sheathing increases over the calculation period and exceeds the limit value of 20 % by mass clearly.

→ Evaluation of the wood moisture according to WTA

Example A: Evaluation Wood Moisture Content with WUFI® Graph

Evaluation with the help of WUFI® Graph:

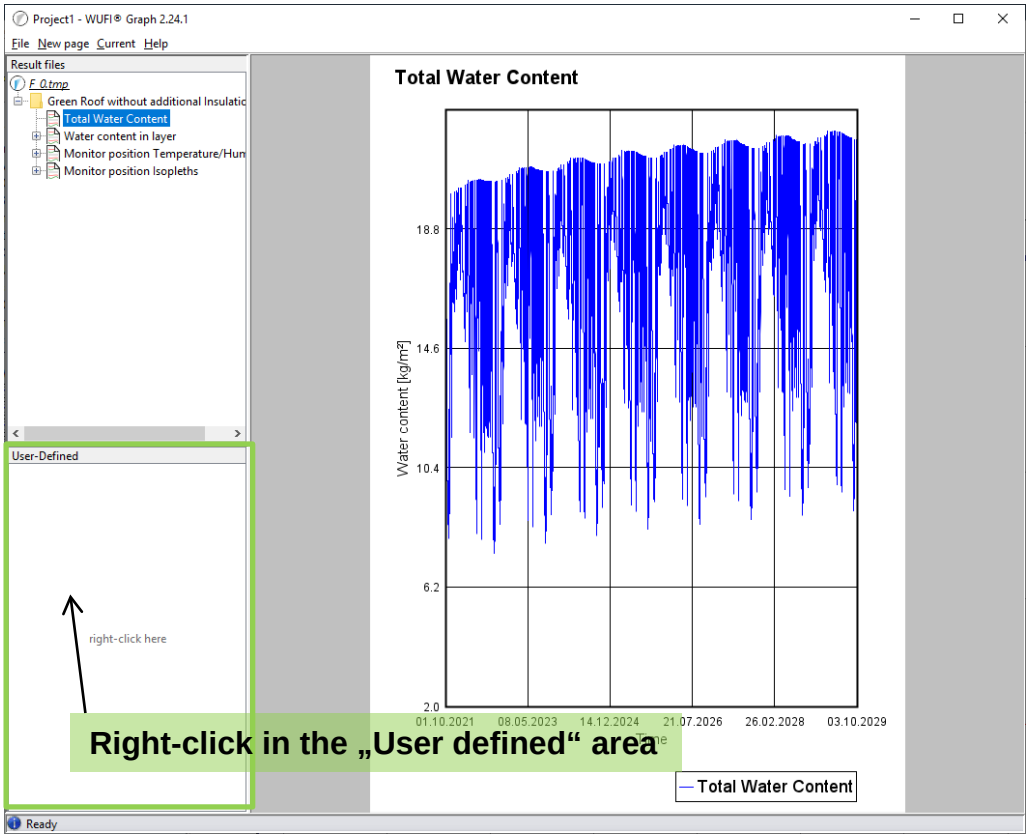
Wood moisture in the wooden sheathing according to WTA 6-8



Example A: Evaluation Wood Moisture Content with WUFI® Graph

Evaluation with the help of WUFI® Graph:

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

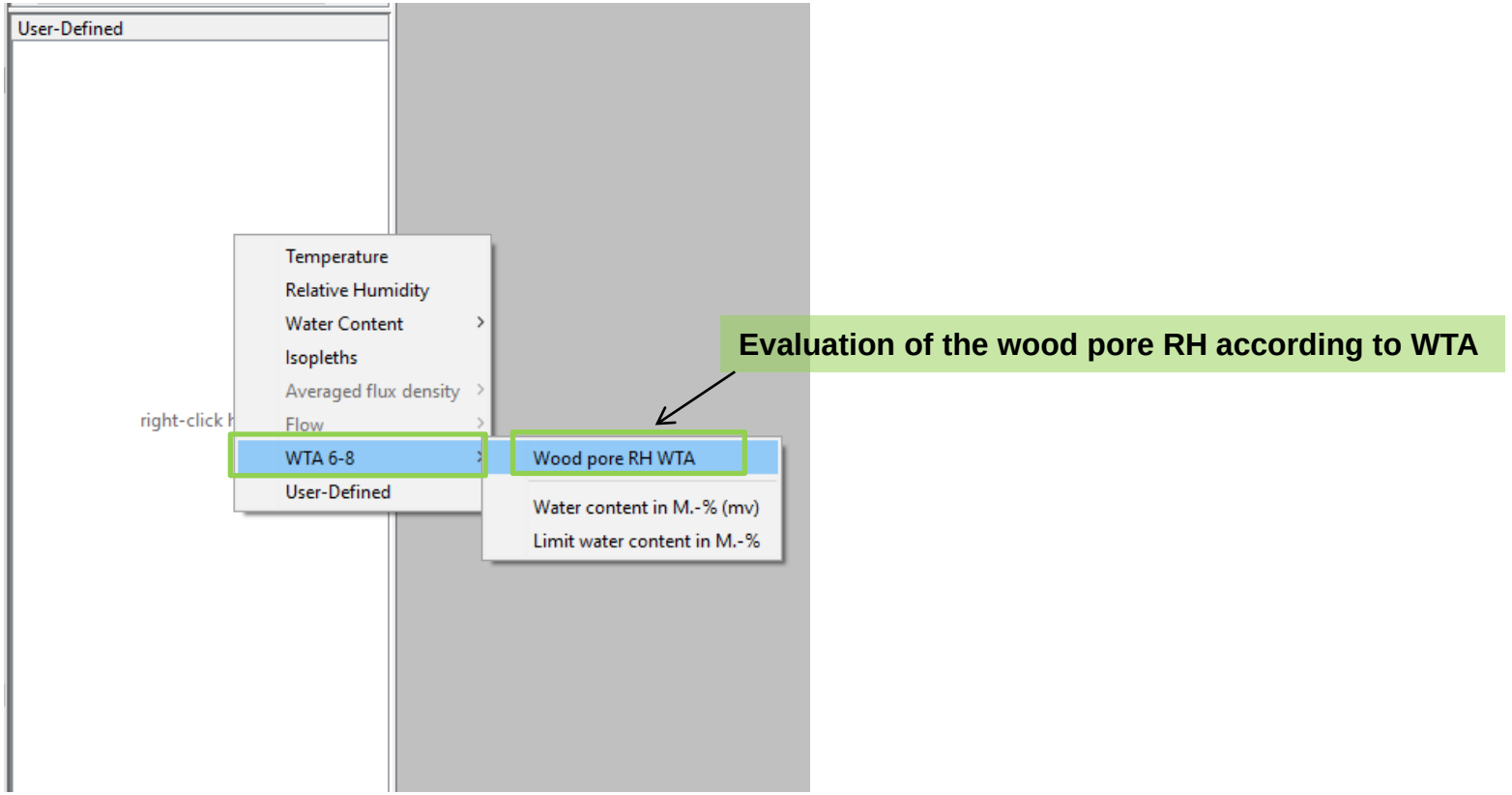


Right-click in the „User defined“ area

Example A: Evaluation Wood Moisture Content with WUFI® Graph

Evaluation with the help of WUFI® Graph:

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

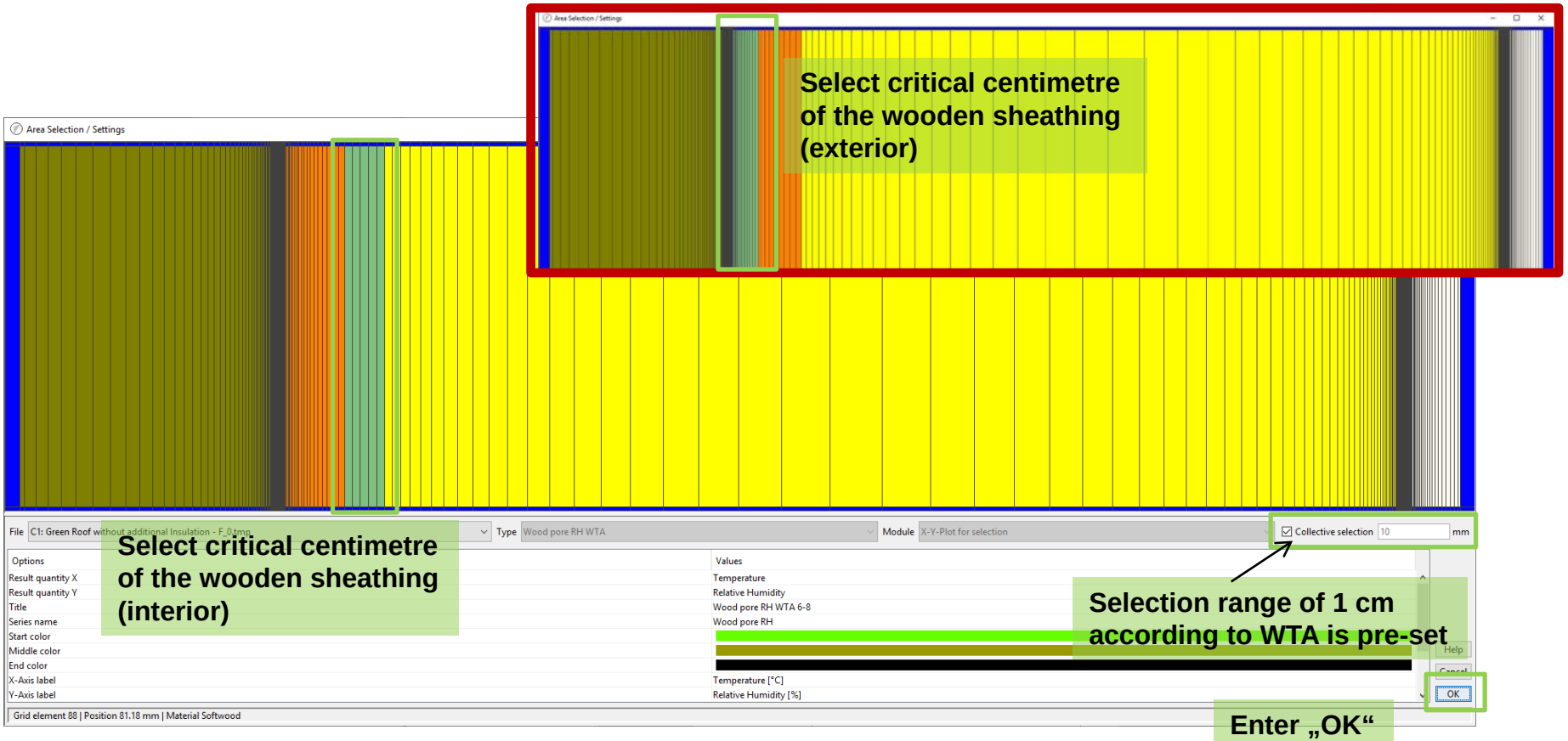


Example A: Evaluation Wood Moisture Content with WUFI® Graph

<u>Evaluation with the help of WUFI® Graph:</u>

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

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

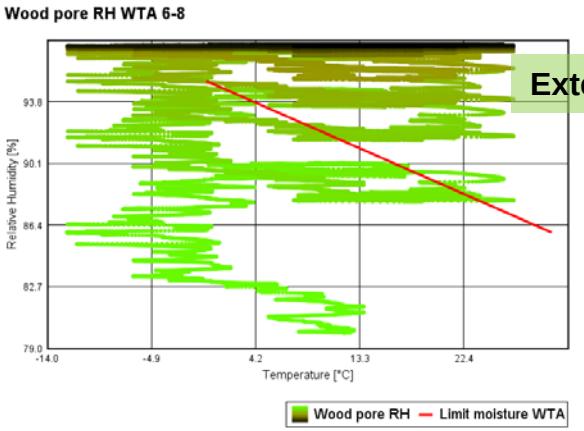


Example A: Evaluation Wood Moisture Content with WUFI® Graph

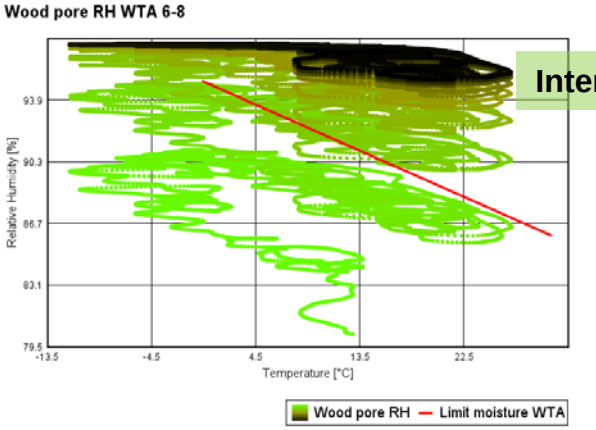
Evaluation with the help of WUFI® Graph:

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

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



Exterior centimetre



Interior centimetre

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 Substrate	0.06	m
• Roofing Membrane (s_d = 300m)	0.001	m
• EPS (heat cond.: 0.04 W/mK - density: 30kg/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

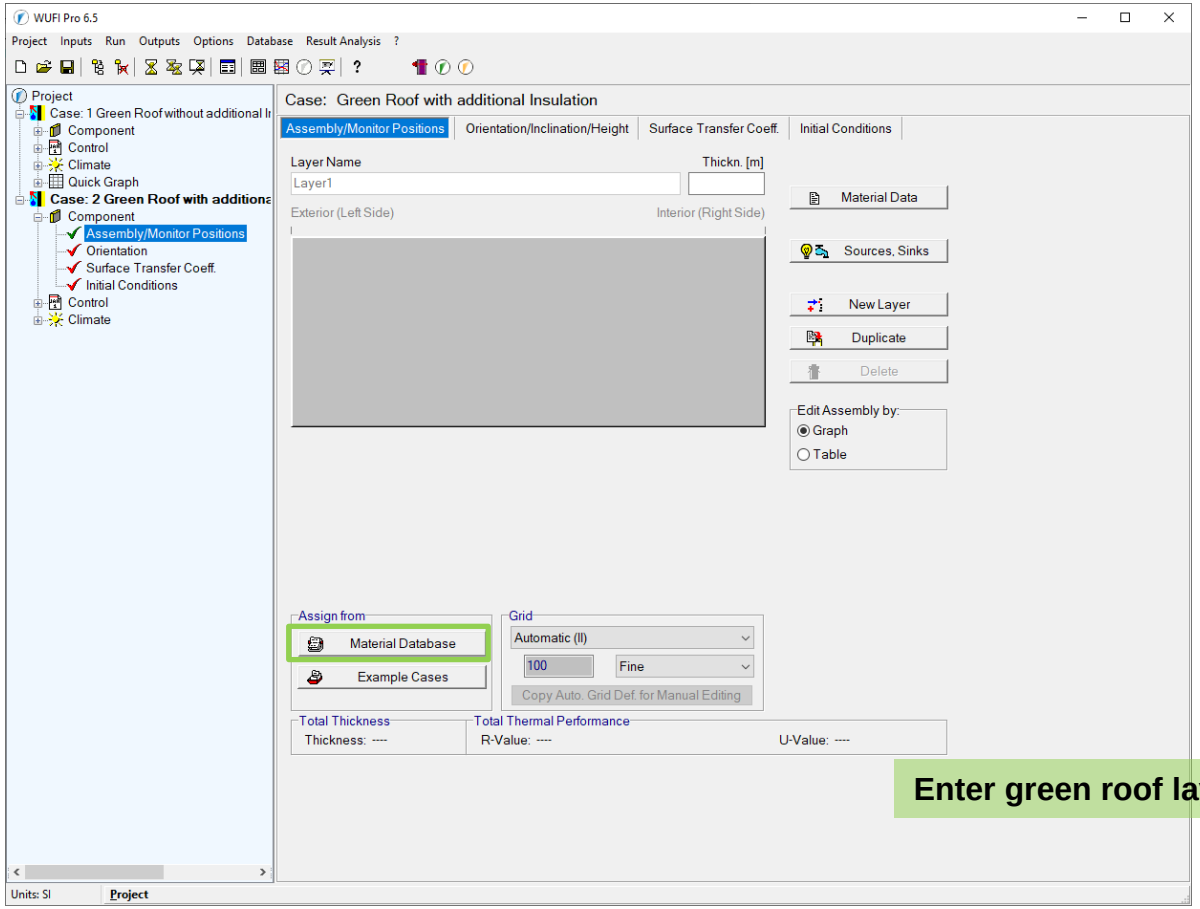
Example B: Boundary Conditions

Boundary Conditions:

- Flat roof (3° to the North)
- Short-Wave Radiation Absorptivity / Long-Wave Radiation Emissivity: according to the Generic Green 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

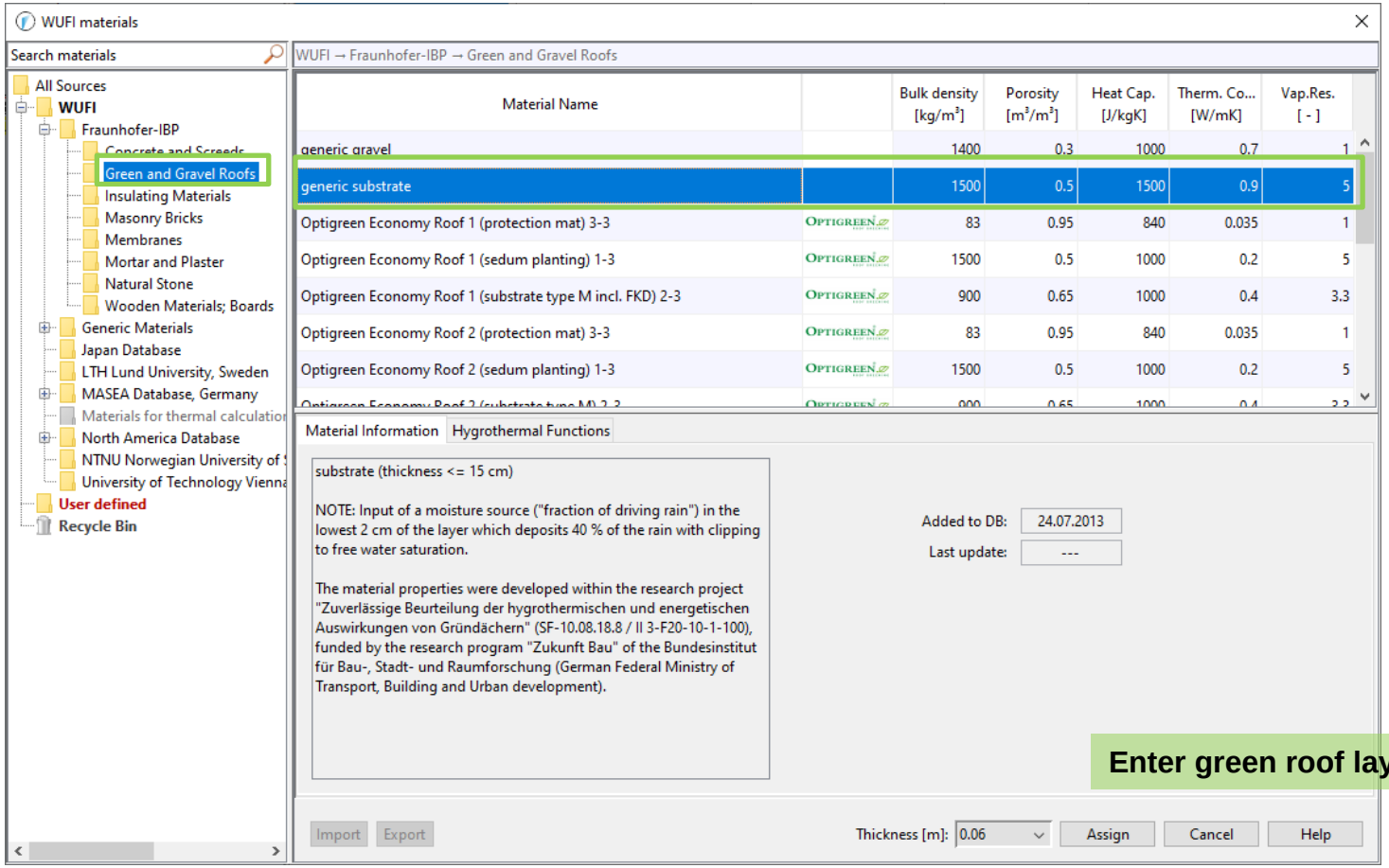
Example B: Component Assembly

Input: Component – Assembly / Monitor Positions



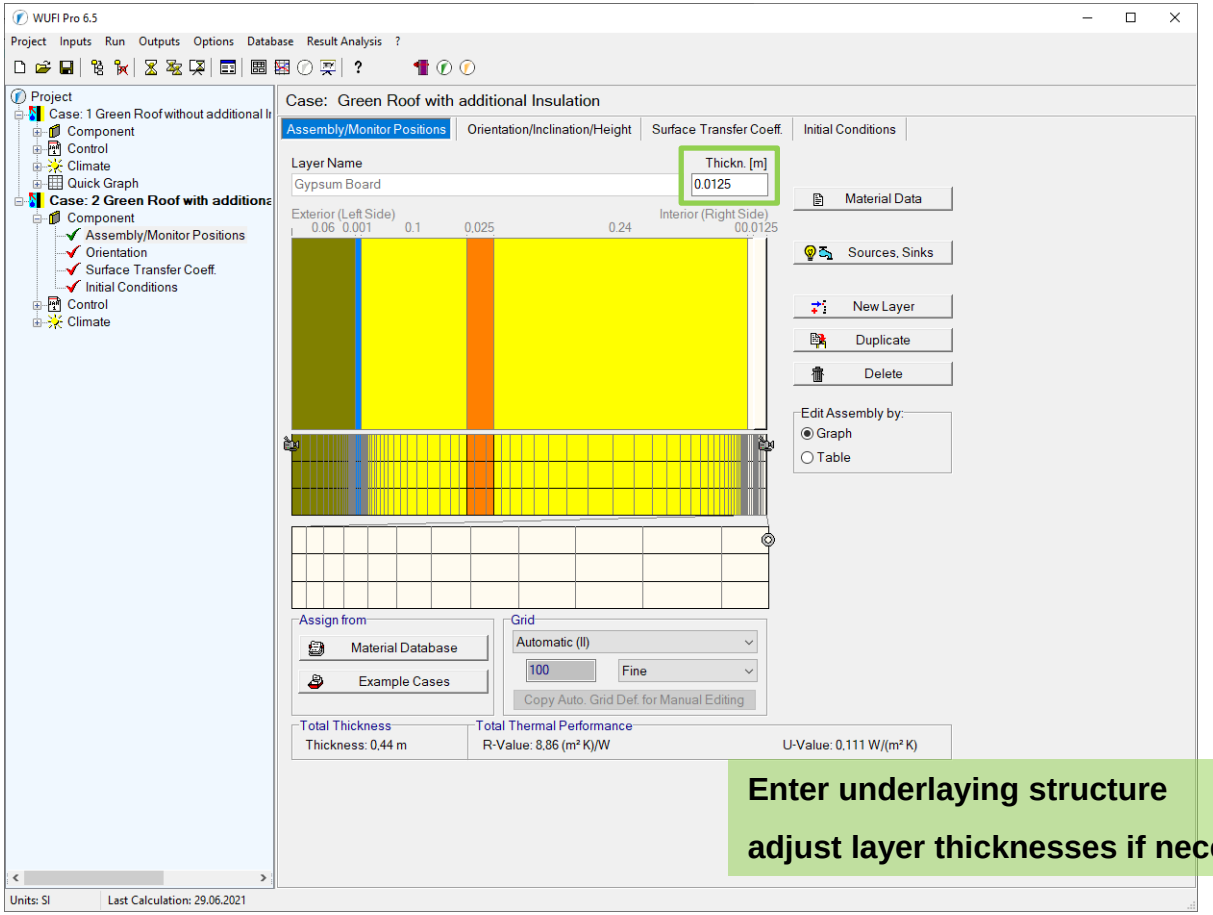
Example B: Component Assembly

Input: Component – Assembly / Monitor Positions



Example B: Component Assembly

Input: Component – Assembly / Monitor Positions

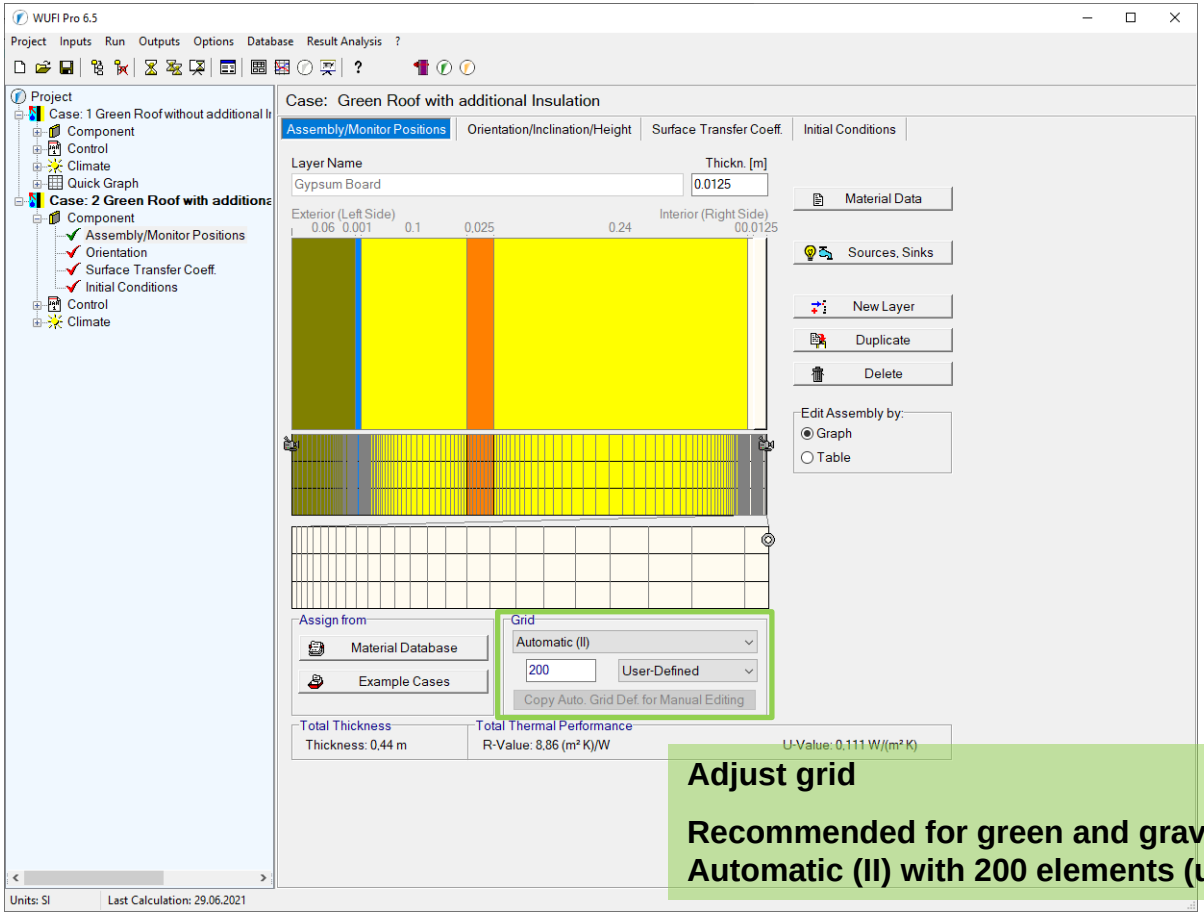


Enter underlaying structure

adjust layer thicknesses if necessary

Example B: Grid

Input: Component – Assembly / Monitor Positions



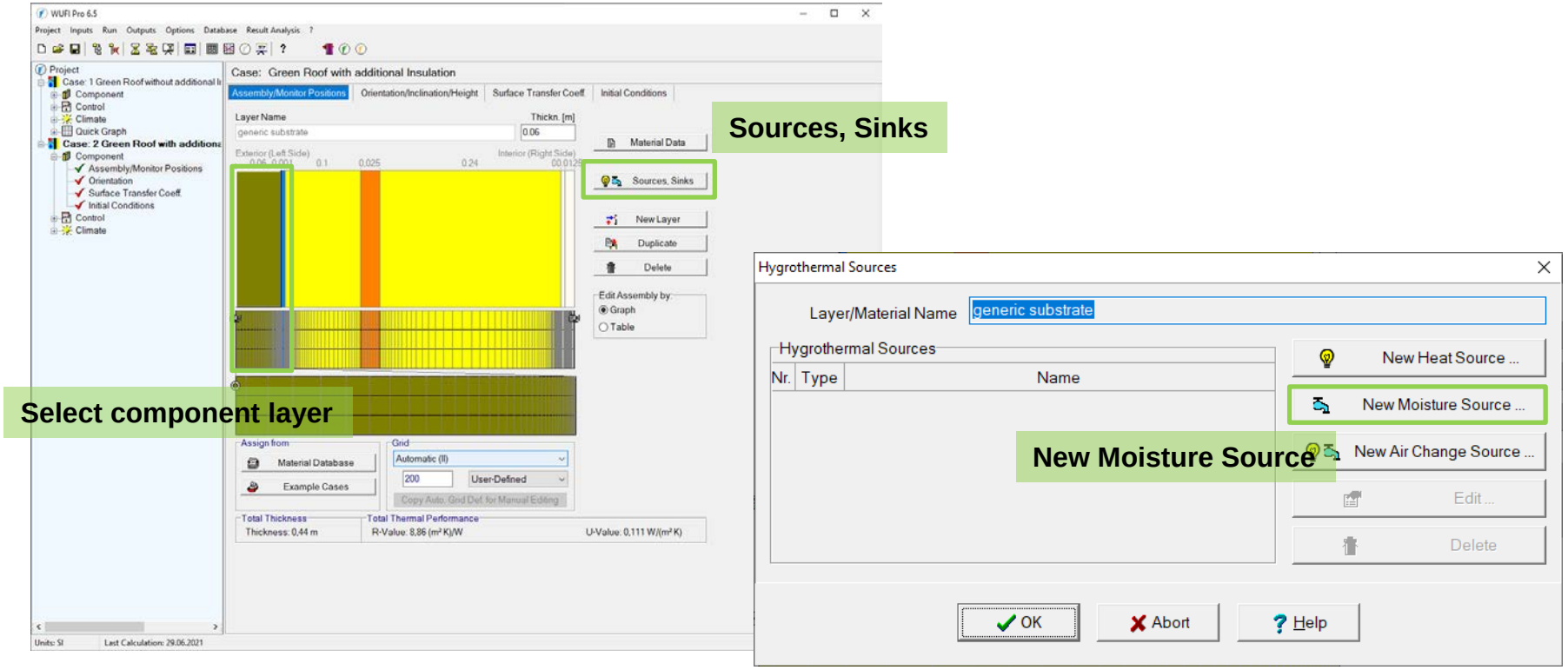
Adjust grid

Recommended for green and gravel roofs: Automatic (II) with 200 elements (user-defined)

Example B: Moisture Source in the Substrate Layer

Input: Component – Assembly / Monitor Positions

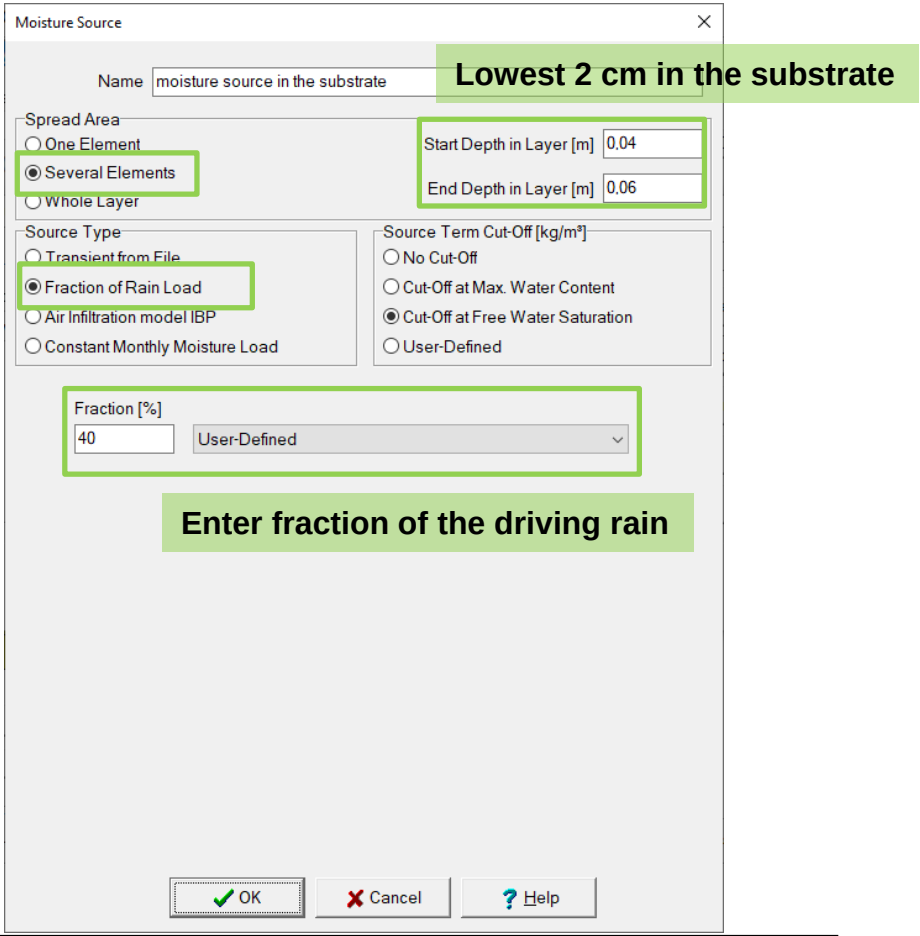
Enter moisture source in the layer „Generic Substrate“.



Example B: Moisture Source in the Substrate Layer

Input: Component – Assembly / Monitor Positions

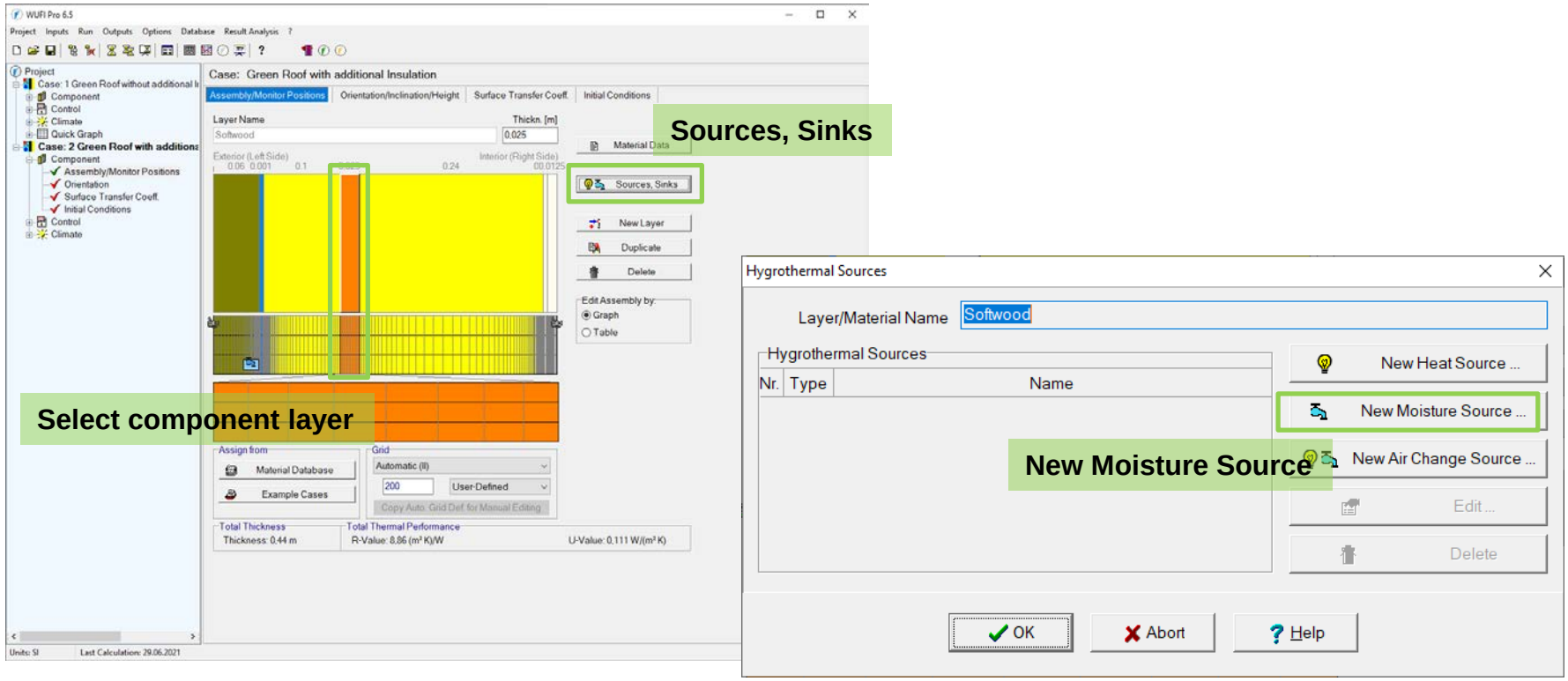
Moisture source in the lowest 2 cm of the layer „Generic Substrate“.



Example B: Infiltration Source

Input: Component – Assembly / Monitor Positions

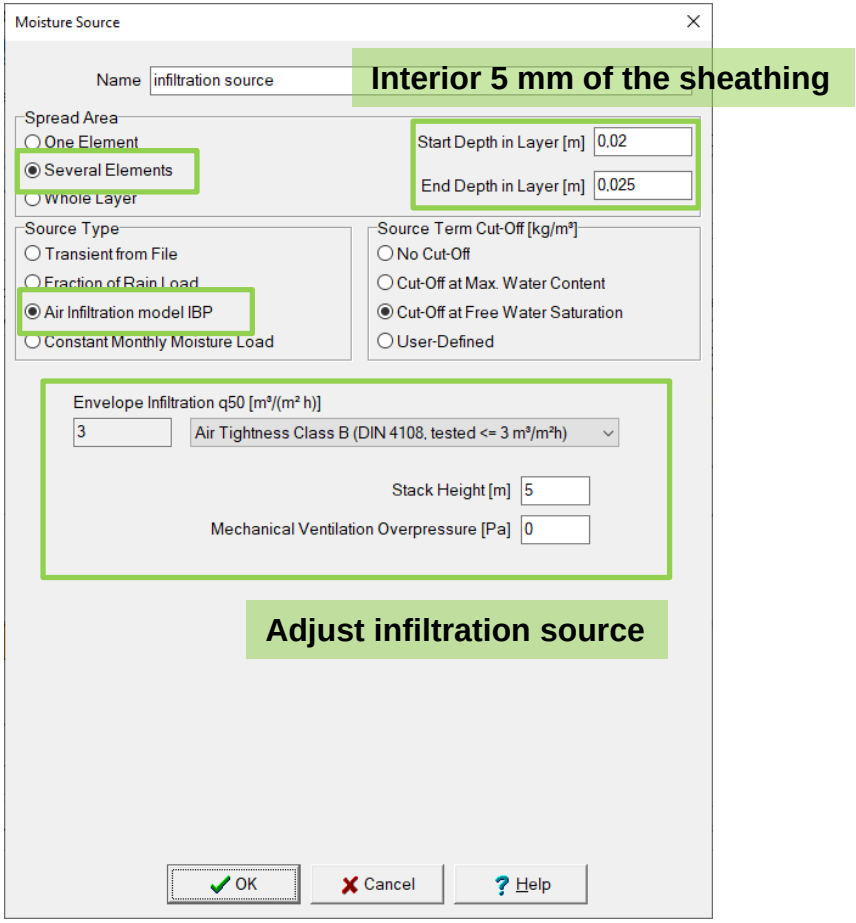
Infiltration source according to DIN 68800 in the wooden sheathing.



Example B: Infiltration Source

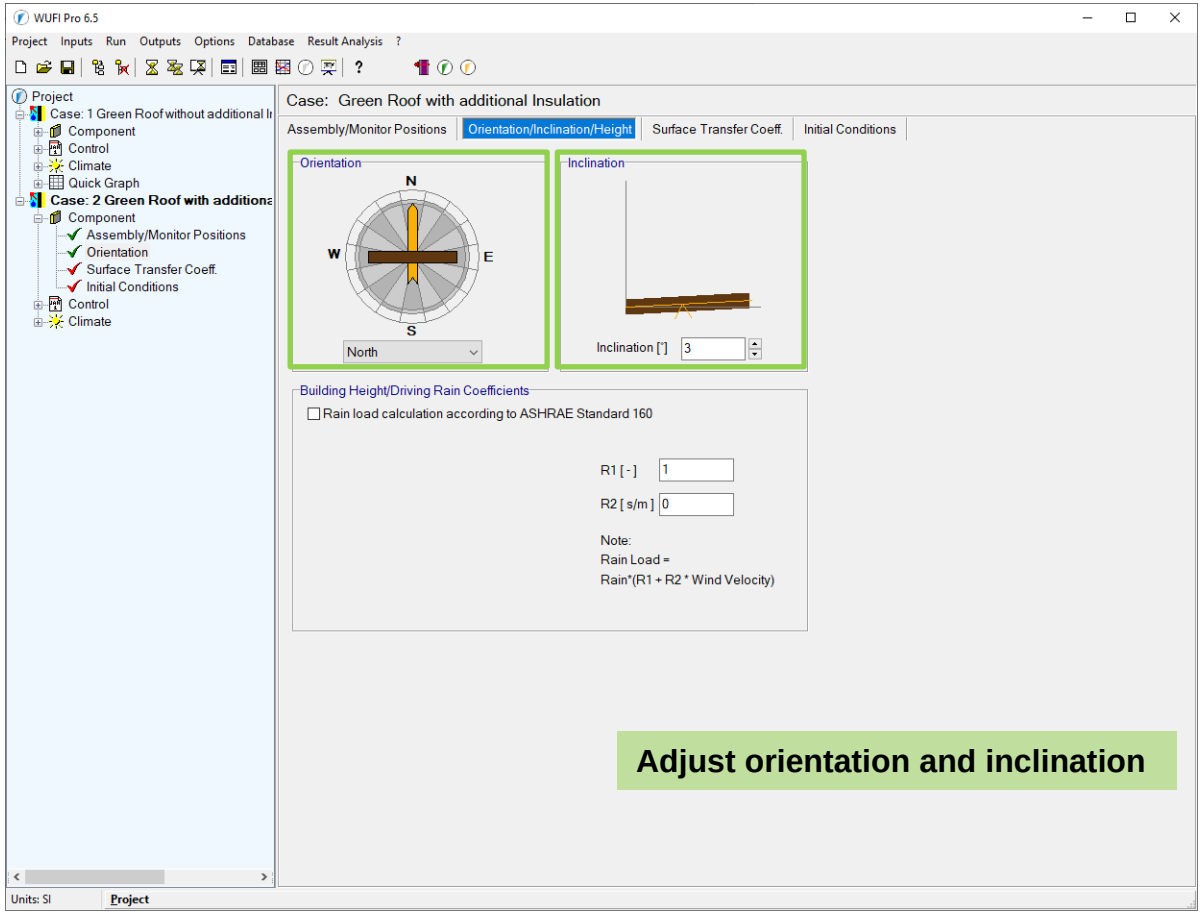
Input: Component – Assembly / Monitor Positions

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



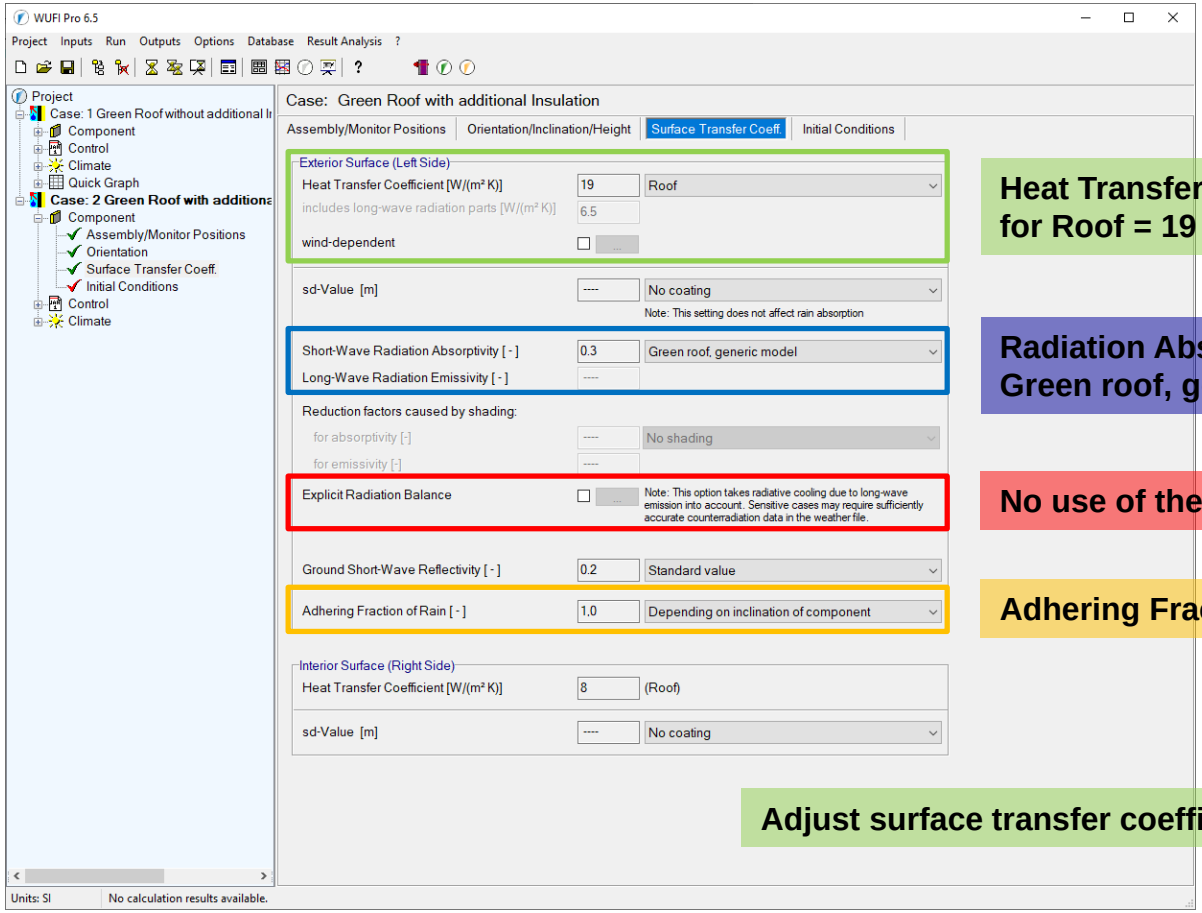
Example B: Orientation / Inclination

Input: Component – Orientation



Example B: Surface Transfer Coefficients

Input: Component – Surface Transfer Coeff.



Heat Transfer Coefficient for Roof = 19 W/m²K

Radiation Absorptivity and Emissivity: Green roof, generic model

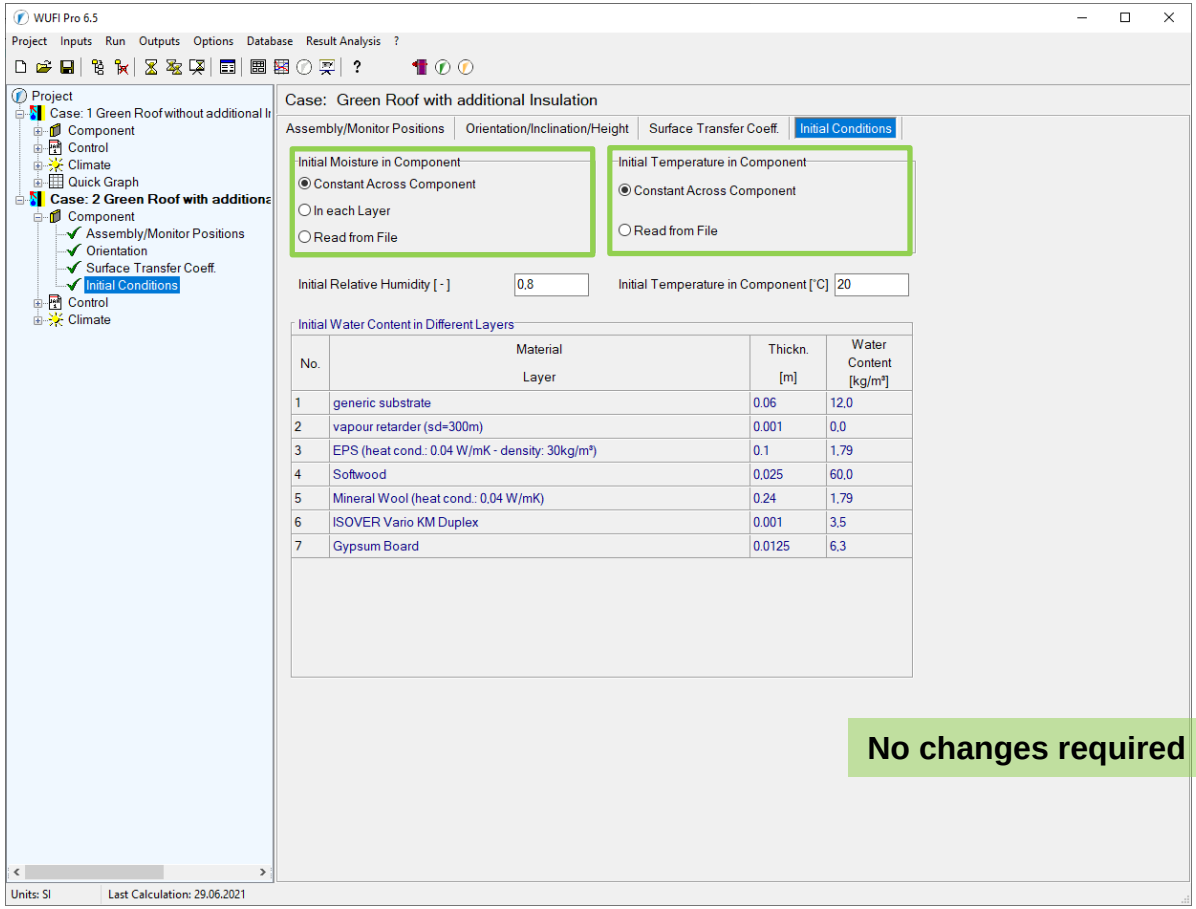
No use of the Explicit Radiation Balance

Adhering Fraction of Rain = 1

Adjust surface transfer coefficients!

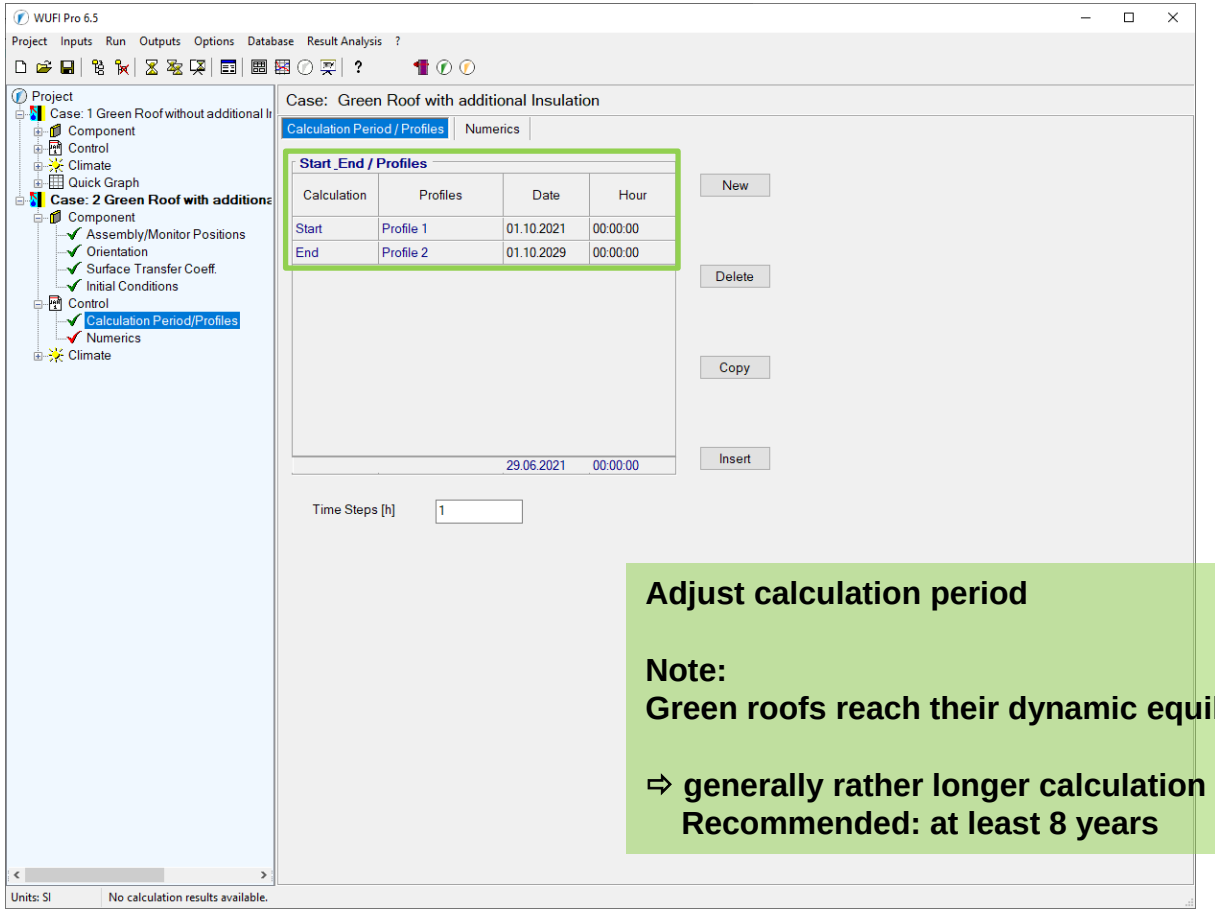
Example B: Initial Conditions

Input: Component – Initial Conditions



Example B: Calculation Period

Input: Control – Calculation Period/ Profiles



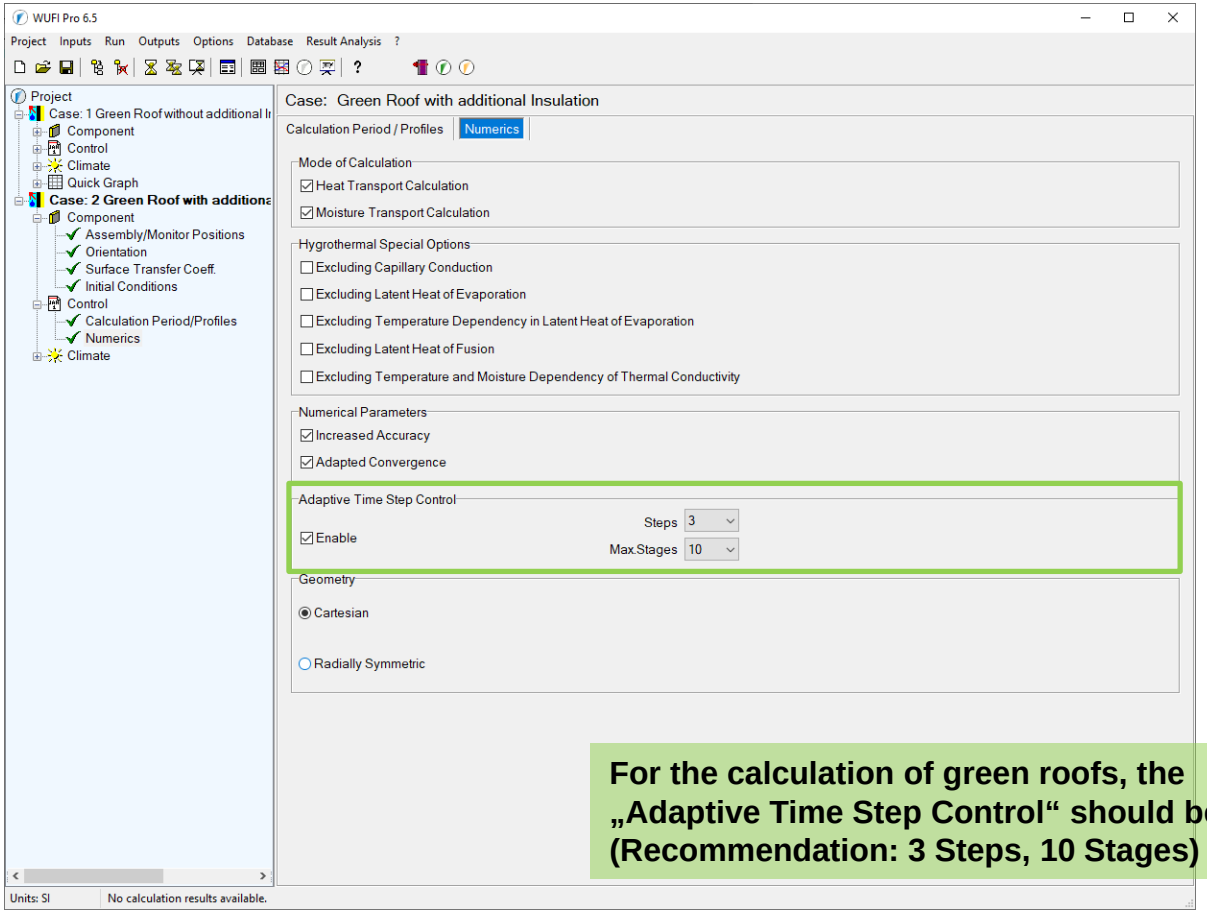
Adjust calculation period

Note:
Green roofs reach their dynamic equilibrium very slowly

⇨ generally rather longer calculation periods are required
Recommended: at least 8 years

Example B: Numerical Settings

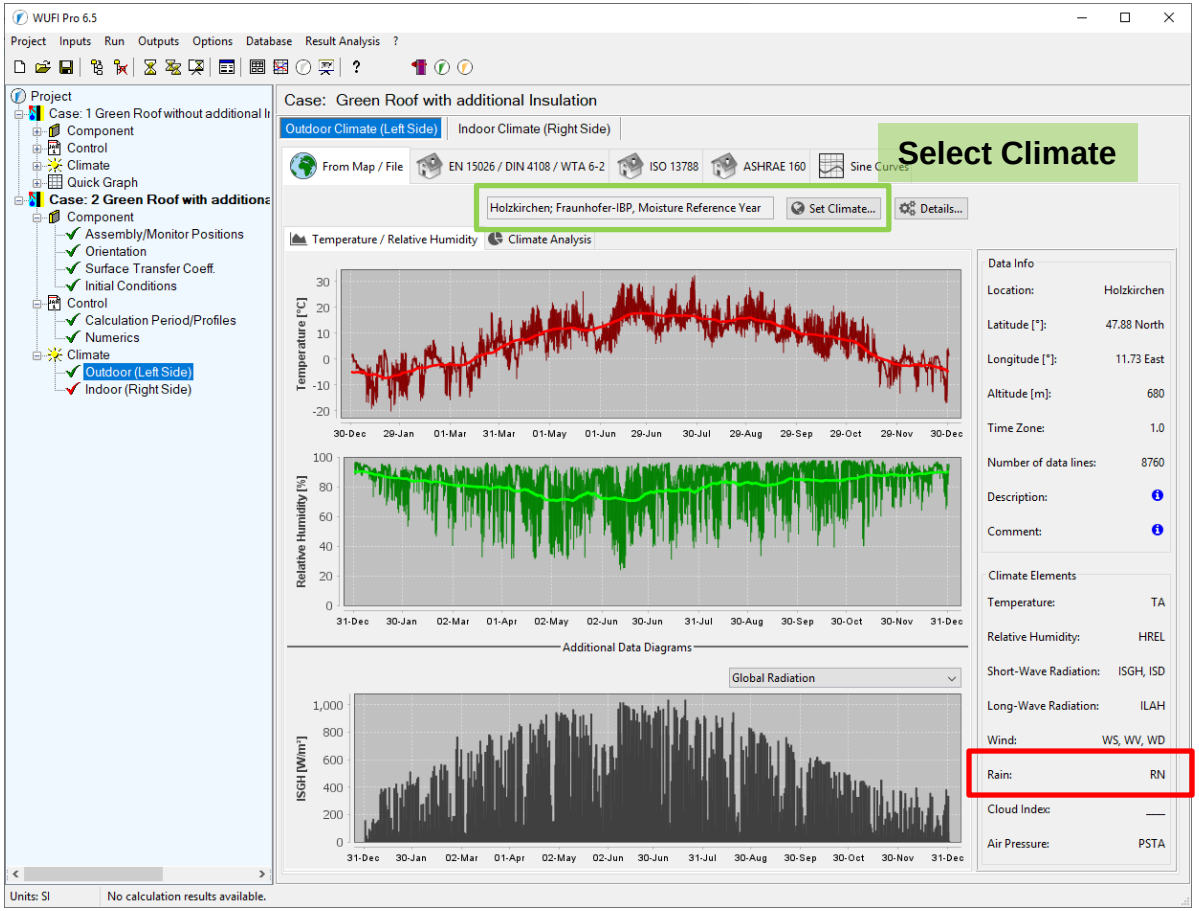
Input: Control – Numerics



For the calculation of green roofs, the „Adaptive Time Step Control“ should be enabled! (Recommendation: 3 Steps, 10 Stages)

Example B: Outdoor Climate

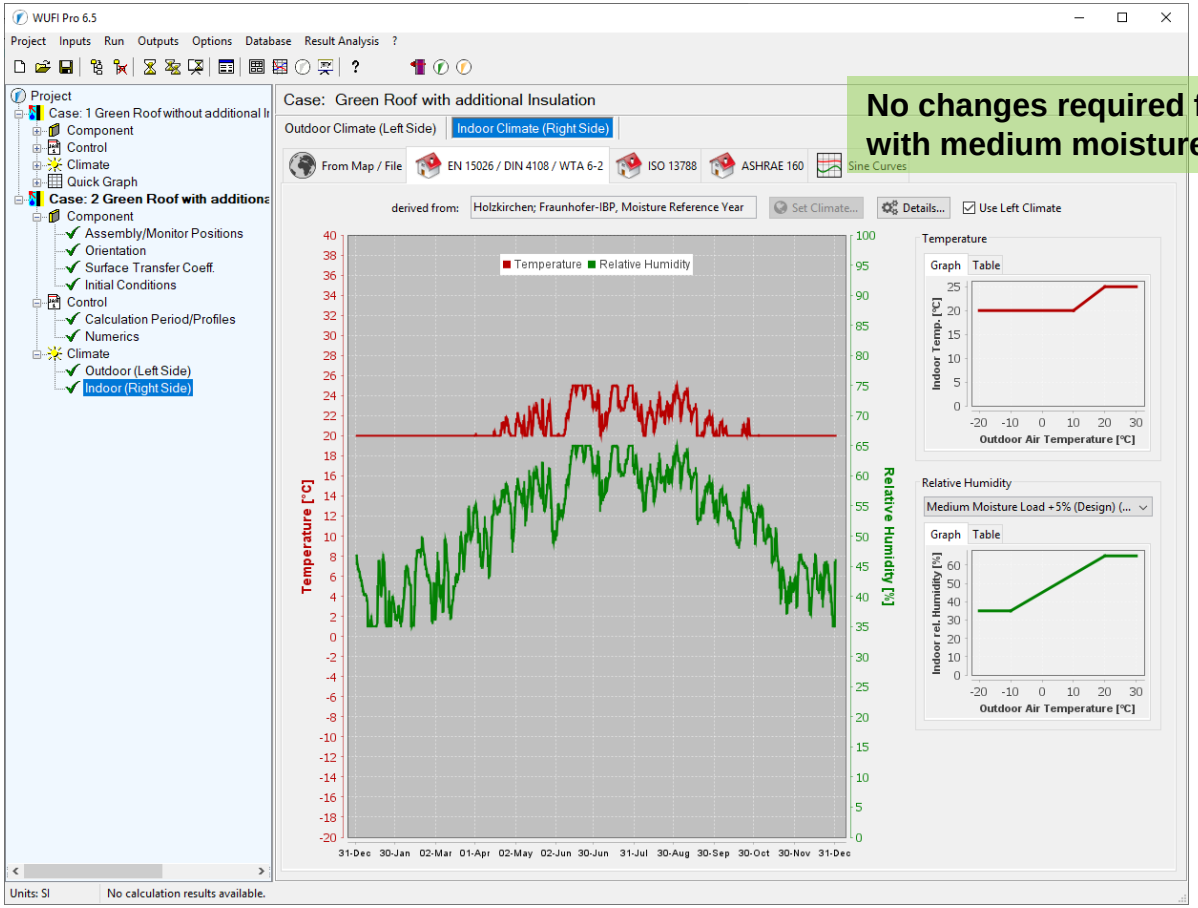
Input: Climate – Outdoor (Left Side)



Note:
The generic green roof model is also suitable for climate data without long-wave radiation. Rain data is necessary!

Example B: Indoor Climate

Input: Climate – Indoor (Right Side)



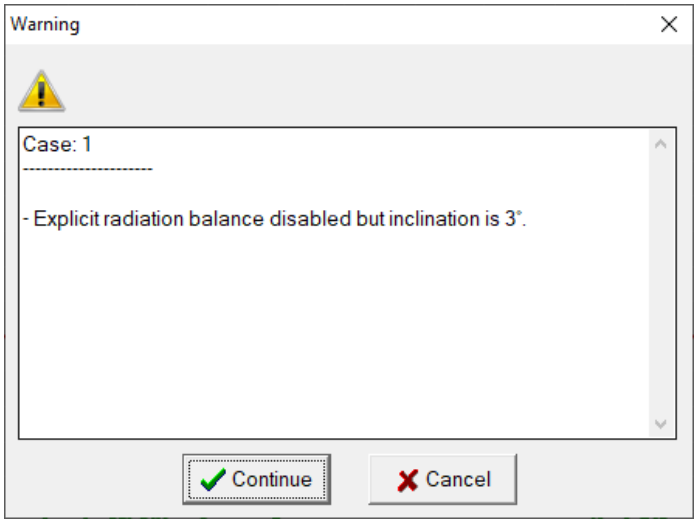
No changes required for indoor climate with medium moisture load + 5 %

Example B: Note when Calculation Start

Calculation Start:

Note:

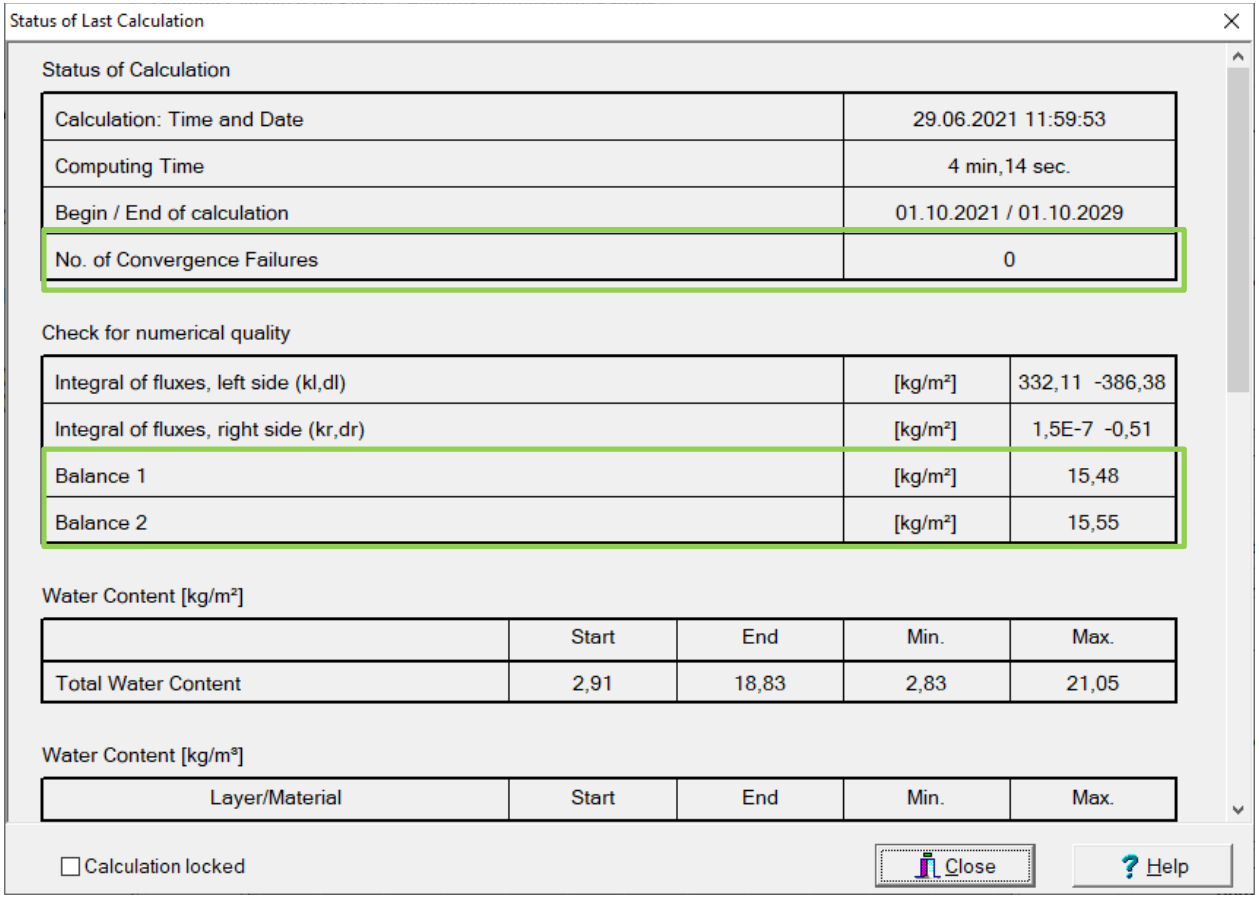
After calculation start this warning appears:



→ this warning can be ignored for the calculation of a green roof with the generic model!

Example B: Evaluation Calculation Quality

Status of Last Calculation:



Status of Last Calculation

Status of Calculation

Calculation: Time and Date	29.06.2021 11:59:53
Computing Time	4 min,14 sec.
Begin / End of calculation	01.10.2021 / 01.10.2029
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[kg/m²]	332,11 -386,38
Integral of fluxes, right side (kr,dr)	[kg/m²]	1,5E-7 -0,51
Balance 1	[kg/m²]	15,48
Balance 2	[kg/m²]	15,55

Water Content [kg/m²]

	Start	End	Min.	Max.
Total Water Content	2,91	18,83	2,83	21,05

Water Content [kg/m³]

Layer/Material	Start	End	Min.	Max.

Calculation locked

Close

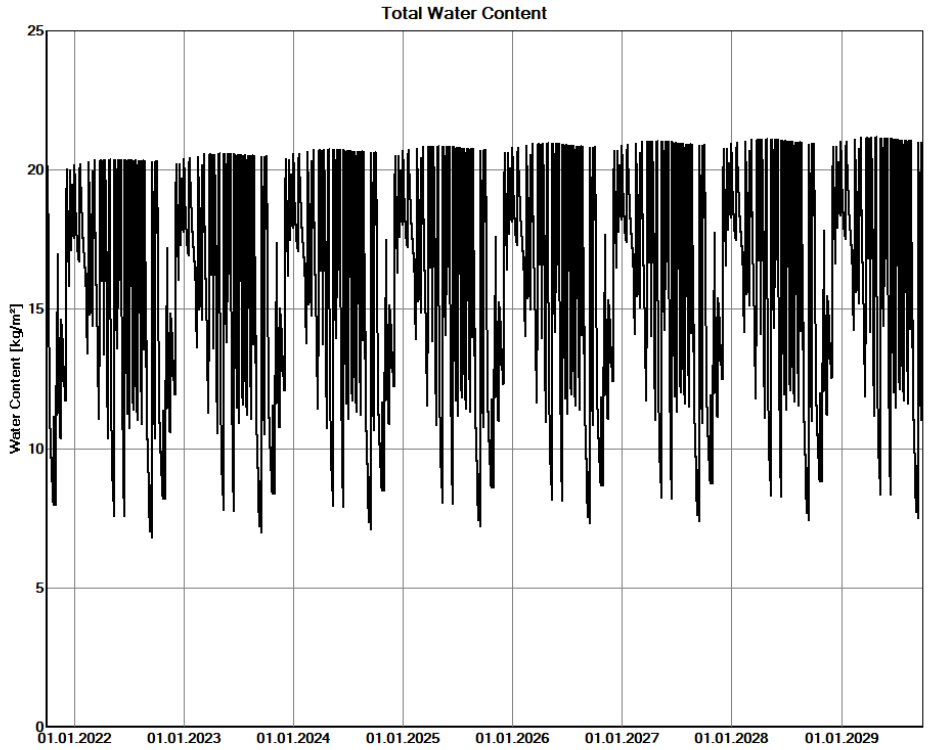
Help

No convergence failures!

Balance differences acceptable!

Example B: Evaluation Total Water Content

Evaluation with the help of the Quick Graphs:
Total Water Content



Evaluation:

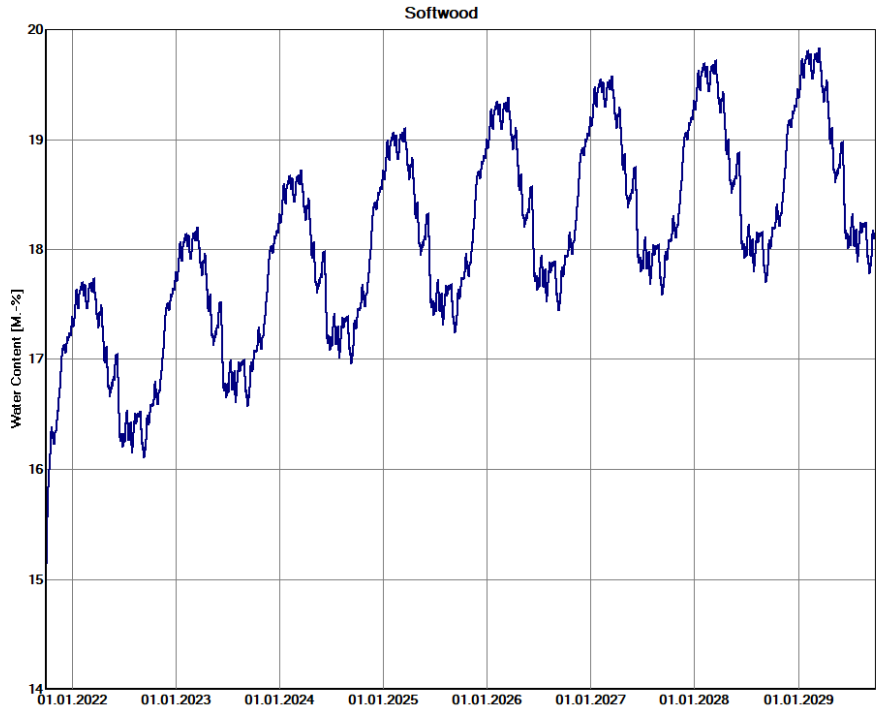
The total water content for green roofs is hardly conclusive because of the large amount of moisture in the substrate.

→ Evaluation of the single layers of the substructure

Example B: Evaluation Wooden Sheathing

Evaluation with the help of the Quick Graphs:

Water Content in the wooden sheathing



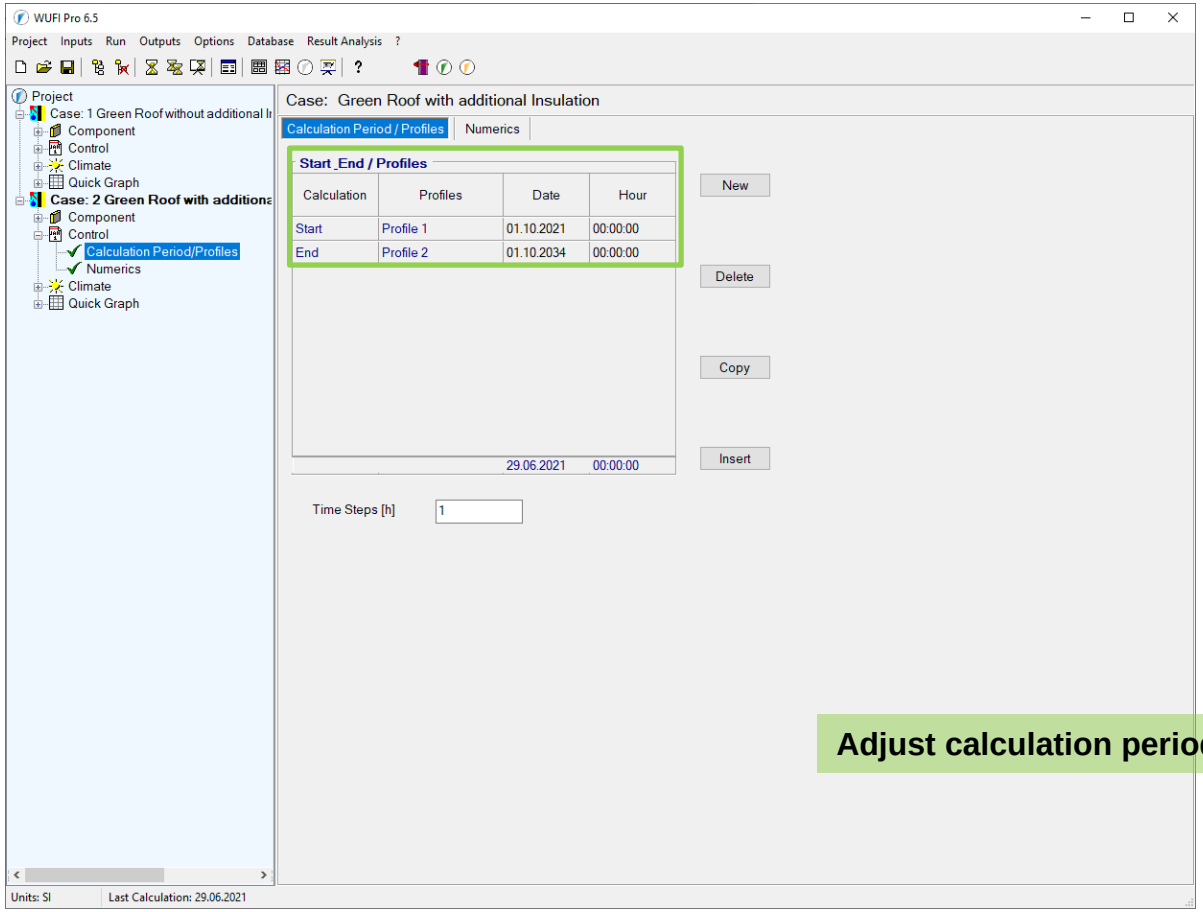
Evaluation:

The water content in the wooden sheathing increases over the calculation period slowly und doesn‘t reach the dynamic equilibrium after 8 years.

→ Longer calculation period is necessary

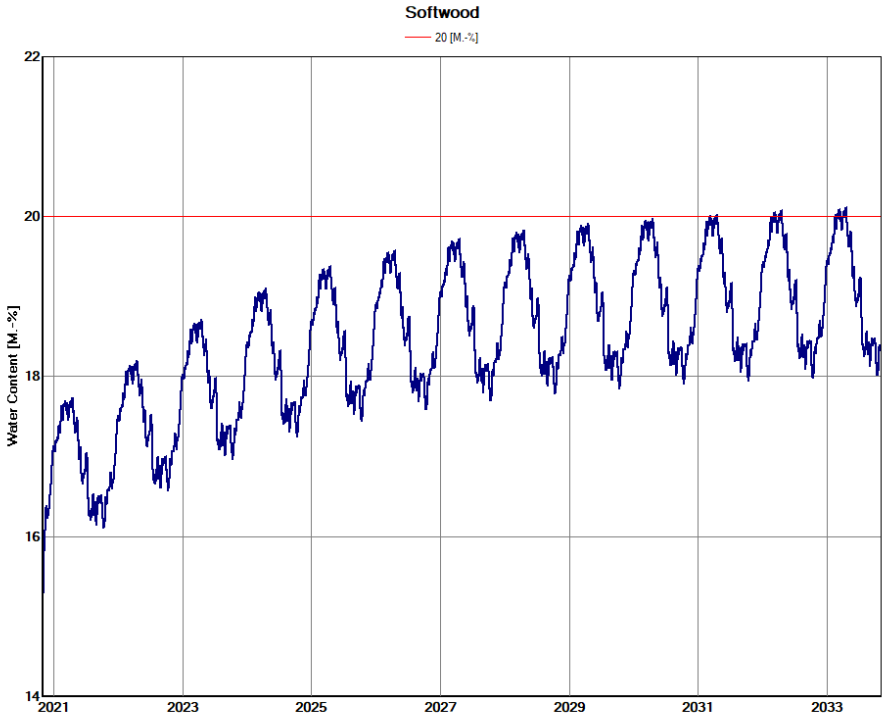
Example B: Calculation Period

Input: Control – Calculation Period/ Profiles



Example B: Evaluation Wooden Sheathing

Evaluation with the help of the Quick Graphs:
Water Content in the wooden sheathing



Evaluation:

The water content in the wooden sheathing reaches the dynamic equilibrium after 12 years with maximum values of just over 20 % by mass.

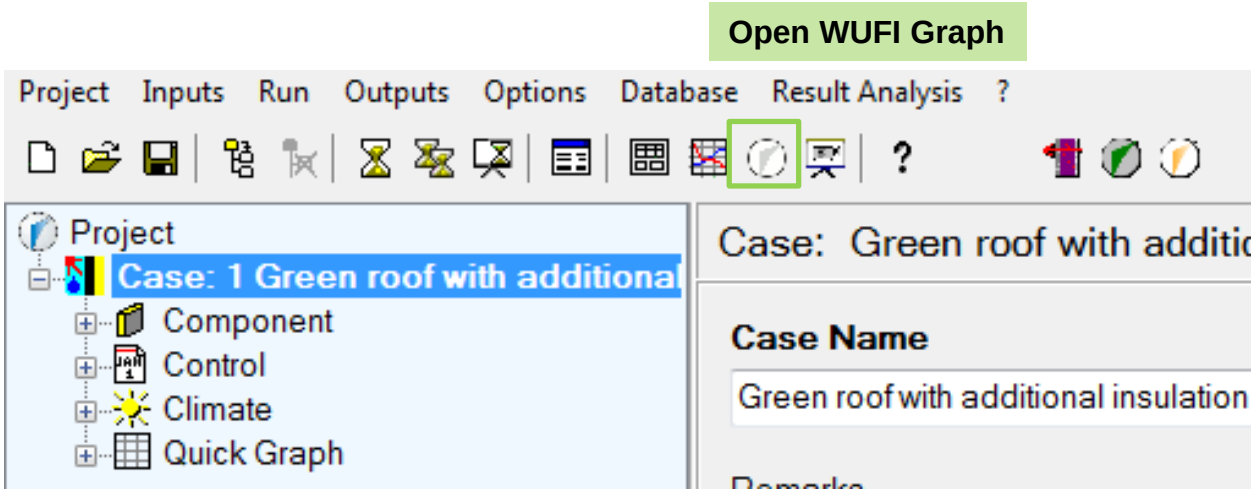
The limit value according to DIN 68800 of 20 % by mass is minimally exceeded.

→ Evaluation of the wood moisture according to WTA

Example B: Evaluation Wood Moisture Content with WUFI® Graph

Evaluation with the help of WUFI® Graph:

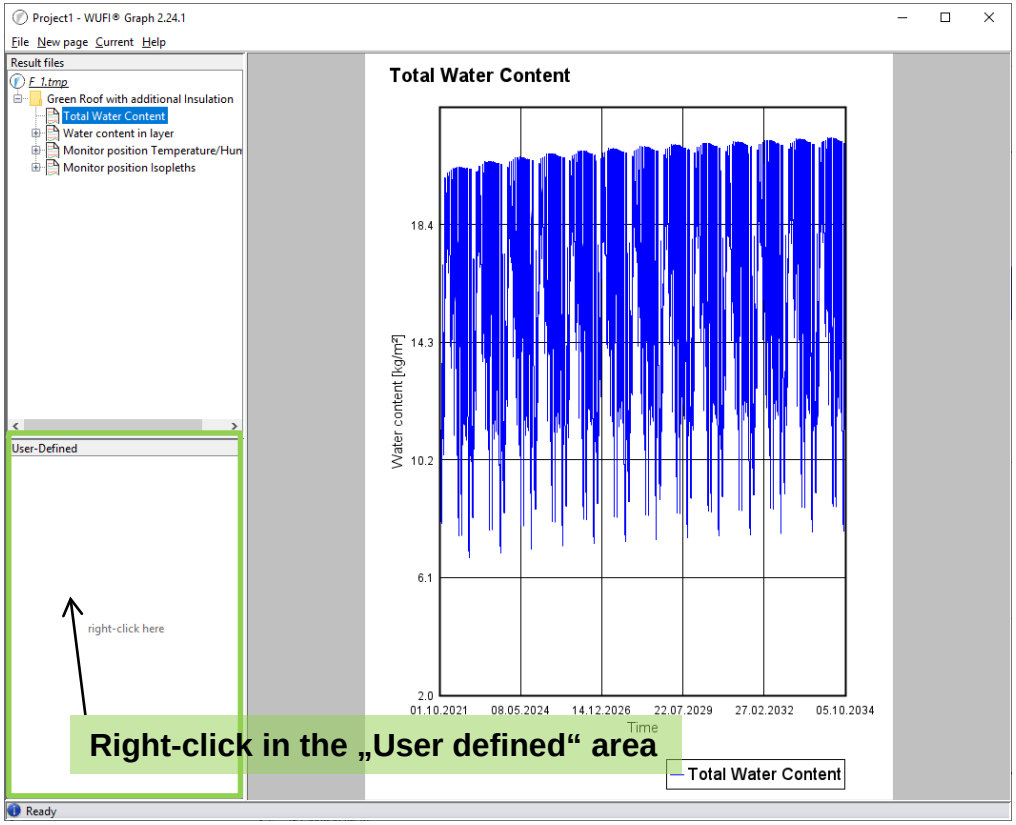
Wood moisture in the wooden sheathing according to WTA 6-8



Example B: Evaluation Wood Moisture Content with WUFI® Graph

Evaluation with the help of WUFI® Graph:

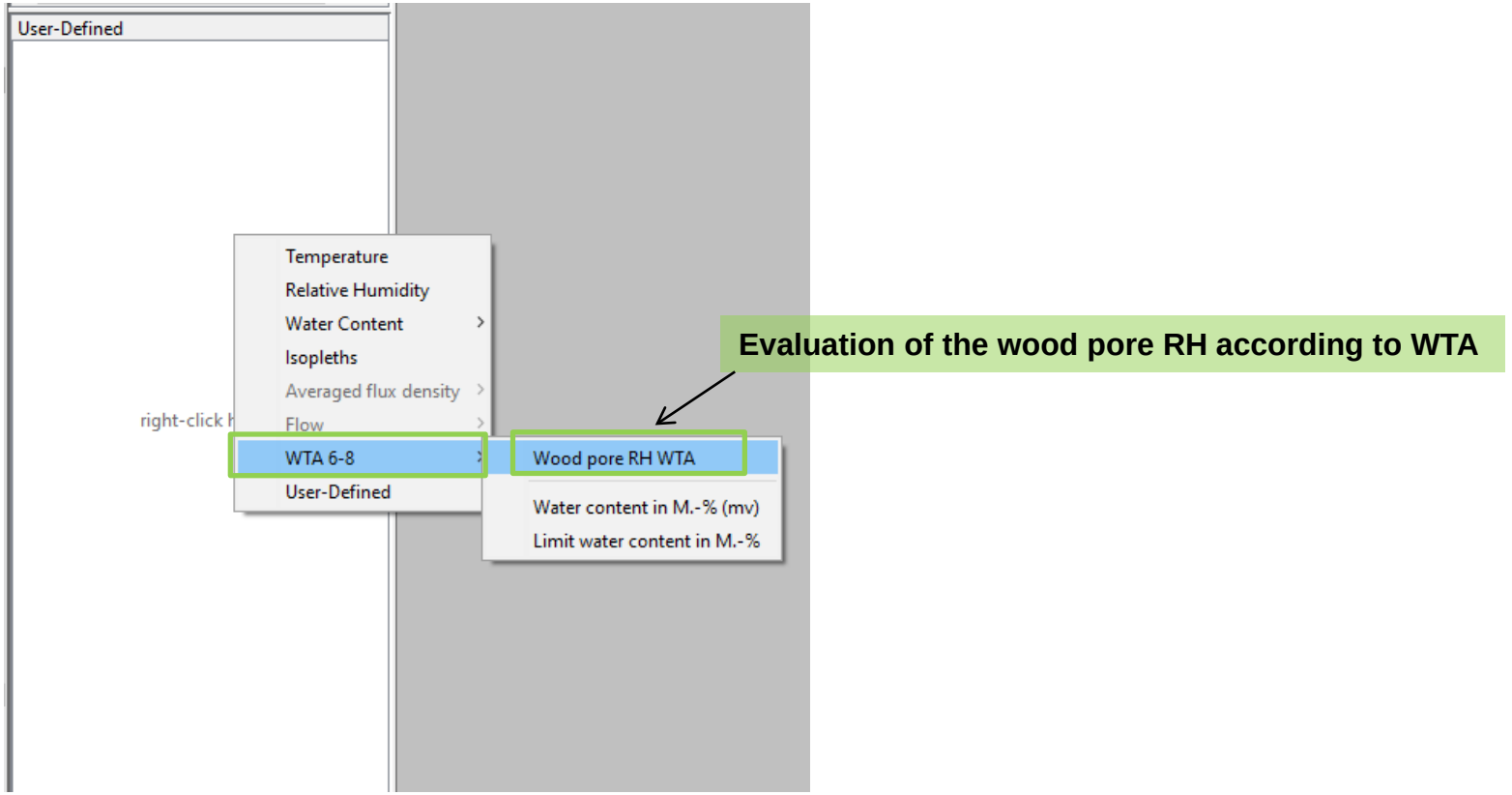
Wood moisture in the wooden sheathing according to WTA 6-8



Example B: Evaluation Wood Moisture Content with WUFI® Graph

Evaluation with the help of WUFI® Graph:

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



Example B: Evaluation Wood Moisture Content with WUFI® Graph

<u>Evaluation with the help of WUFI® Graph:</u>

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

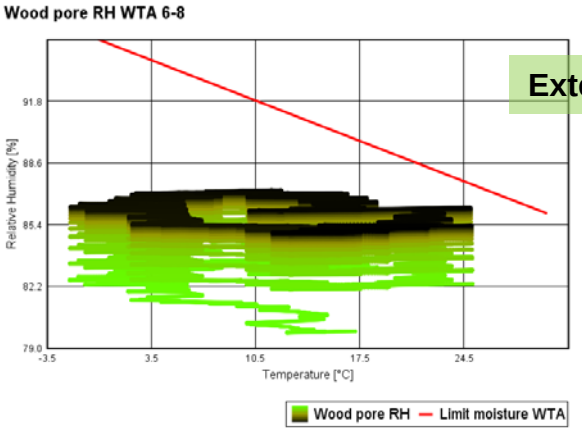
Evaluation in the most critical centimetre (in case of doubt consider both sides)

Example B: Evaluation Wood Moisture Content with WUFI® Graph

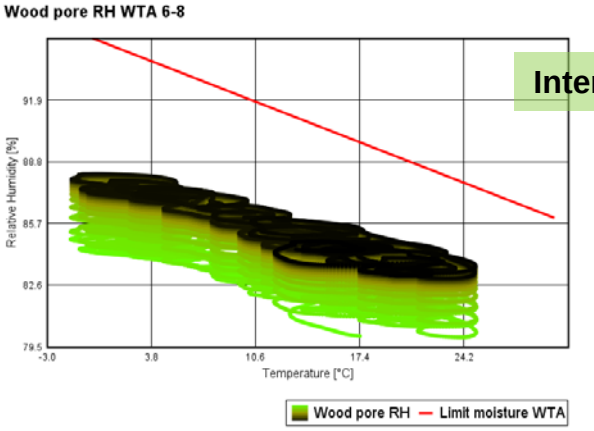
Evaluation with the help of WUFI® Graph:

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

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



Exterior centimeter



Interior centimeter

Evaluation:

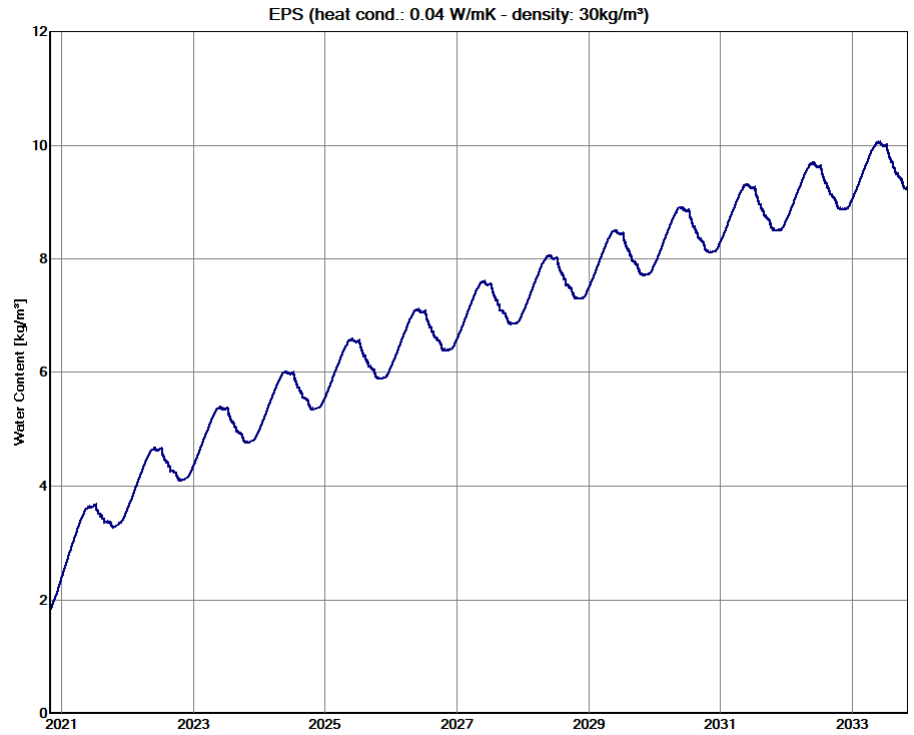
The relative pore air moisture in the interior and the exterior centimetre of the sheathing doesn't exceed the limit moisture according to WTA.

→ No damage by wood-decay fungi

Example B: Evaluation Water Content Additional Insulation

Evaluation with the help of the Quick Graphs:

Water Content in the additional insulation



Evaluation:

The water content in the additional insulation also increases over 13 years.

A relevant increase of the thermal conductivity occurs only from a water content of about 20 kg/m³ and should be consider if the insulation is taken in account for the R-value.

Otherwise a slight moisture accumulation has no negative effect on this material.