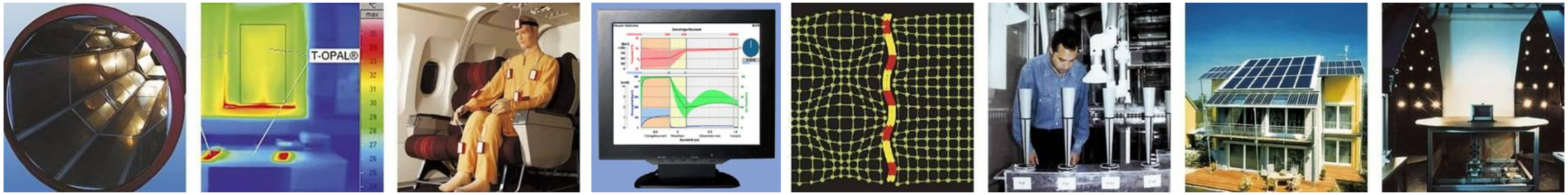


WUFI®

Guideline for the Calculation of extensive Green Roofs (Optigreen)

Date: July 2026

Fraunhofer
IBP

Content

Development of Green Roof Models

Within the research project

„Ermittlung von Materialeigenschaften und effektiven Übergangsparametern von Dachbegrünungen zur zuverlässigen Simulation der hygrothermischen Verhältnisse in und unter Gründächern bei beliebigen Nutzungen und unterschiedlichen Standorten“ [1]

(Funded by the research programme "Zukunft Bau" of the Bundesinstitut für Bau-, Stadt- und Raumforschung (German Federal Ministry of Transport, Building and Urban Development); file number: SF-10.08.18.7-11.18 / II 3-F20-10-1-100)

one generic and several product-specific models were developed in order to simulate and design green roofs – especially on wooden constructions – reliably with the help of hygrothermal simulations.

Development of Green Roof Models

Generic Approach:

The generic green roof model was developed based on field studies in Holzkirchen, Leipzig [2], Vienna [3] and Kassel [4]. The climate data available for the test period didn't contain any data for the atmospheric counter radiation, so it was necessary to consider their influence in a simplified way by the available climate elements and appropriate surface transfer coefficients. Therefore this model is suitable especially for locations in Central Europe respectively locations with a comparable climate. They can be used if no measured data for the atmospheric counter radiation or no detailed information about the applied substrate type are available.

See also "Guideline for the Calculation of extensive Green Roofs (generic)"

Product-Specific Approach:

On the basis of the generic model, product-specific approaches for five green roof systems of the company Optigreen (partly with solid drainage) were developed by means of additional laboratory and field tests in Holzkirchen. Hereby the influence of the measured atmospheric counter radiation was considered explicitly, so these approaches are in principle also suitable for other climate regions. Validations have been performed for Holzkirchen and Milan [5].

Application of the Specific Green Roof Models

Due to the fact that the **product-specific approaches also consider the long-wave counter radiation** and thus all relevant climate elements, these approaches are in principle also suitable for other climate regions.

Prerequisite is the availability of data for the atmospheric counter radiation. Validations have been performed for the European locations Holzkirchen and Milan.

Within the research project all necessary input data for the hygrothermal simulation of five Optigreen-Systems with WUFI® were developed in collaboration with the company.

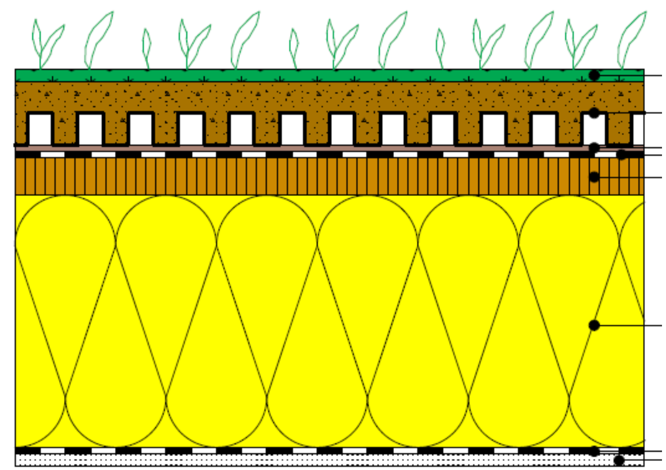
Application of the Specific Green Roof Models

First the input data which are identical for the five approaches are given.

Then each of the systems is described briefly and the procedure for the calculation with WUFI® is explained.

Optigreen-Systems according to the product names of the manufacturer:

- Light-weight Roof Solution 1: slide 20
- Economy Roof Solution 1: slide 22
- Economy Roof Solution 2: slide 24
- Pitched Roof 5-45°: slide 26
- Nature Roof Solution 1: slide 28



Input: Component Assembly and Grid Setting

Component – Assembly

<u>*Optigreen-Systems*</u>

The layer structure of the specific green roof models is explained in the description of the respective Optigreen-Systems.
The materials are available in the WUFI® - Material Database under *Fraunhofer-IBP*→ *Green and Gravel Roofs*.

The systems are applied to the component assembly with the layer structure and respective layer thicknesses specified by the manufacturer.
The specific green roof models are also explained in the description of the respective Optigreen-Systems.

Finally, the moisture sources and boundary conditions must be set in accordance with this guideline.

Input: Component Assembly and Grid Setting

Component – Assembly

Underlying Roof Assembly

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

Grid Setting

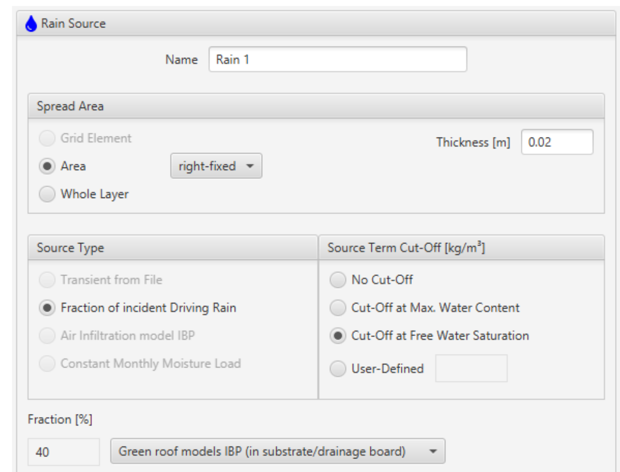
Recommended grid setting:
Automatic (II) with 200 elements (default setting)

Input: Moisture Source in the Substrate

Component - Assembly

Moisture Source in the Substrate Layer

In order to take the precipitation flowing through the substrate layer into account in the calculation, a moisture source is to be considered in the lower 2 cm of the substrate layer. This should introduce 40 % of the precipitation, limited to the free water saturation, into the substrate layer during a rain event.



Settings:

- Spread Area:
  Area – right fixed; thickness: 0.02 m
- Source Type:
  Fraction of incident driving rain
- Source Term Cut-Off:
  Cut-Off at Free Water Saturation
- Fraction: 40 % (Green roof models IBP)

Input: Moisture Source in the Drainage Layer

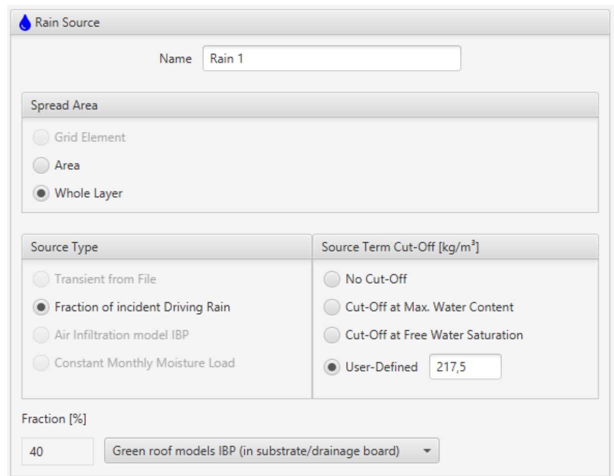
Component - Assembly

<u>Moisture Source in the Drainage Layer (only for the system “Nature Roof”)</u>

If a drainage element is present, an additional moisture source is placed in the entire drainage and storage layer also with 40 % of the precipitation. This moisture source is limited to the maximum filling volume specified by the manufacturer. In this way, the drainage function is reflected in the calculation, since excess water is not taken into account.

<u>Settings:</u>

- Spread Area: Whole Layer
- Source Type:
  Fraction of incident driving rain
- Source Term Cut-Off: User-Defined
  Limitation of the source value to the max. filling volume of the drainage element
  (8.7 kg/m²) / (0.04 m) = 217.5 kg/m³
- Fraction: 40 % (Green roof models IBP)



Input: Infiltration Source

Component - Assembly

Moisture Source - Infiltration (only for wooden structures)

According to DIN 68800 [6], the amount of moisture that convectively enters the construction as a function of the air tightness must always be assessed for wooden structures and is taken into account in the simulation using the infiltration model of the IBP.

The moisture source must be located in the component assembly at the position where the condensation water will precipitate in practice – usually this is in front 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

Input: Infiltration Source

Component - Assembly

Moisture Source - Infiltration (only for wooden structures)

The amount of moisture entered in winter 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 [7].

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

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

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) – Climate

Orientation

The relevant orientation is usually North, as this is where the lowest radiation gains occur. However, the orientation is only of minor importance for very flat sloping roofs.

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 is 19 W/m^2K according to the specific green roof model [1].

Radiation

Selection (drop-down menu): Roof → Green roof, Optigreen system

According to the specific green roof model in [1], the short-wave radiation absorptivity is 0.6 and the long-wave radiation emissivity is 0.9.

The radiative overcooling must always be activated for roofs due to the large field of view to the sky, in order to take into account the undercooling due to long-wave radiation.

Rain

Rain must be taken into account when simulating green roofs.

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 [8].

Input: Control

Control

<u>Period of Calculation:</u>

It is recommended to start the calculation on October 1, because the component usually becomes even more humid during the following winter months before the drying period starts in spring. This start date is therefore usually an unfavorable case.

The calculation time depends on when the construction reaches the steady-state condition. Green roofs usually require a calculation time of about 10-15 years.

Input: Control

Control

Adaptive Time Step Control:

Due to the difficult moisture balance in the substrate layer, the calculation of green roofs should be performed with "Adaptive Time Step Control".

The following setting is recommended:

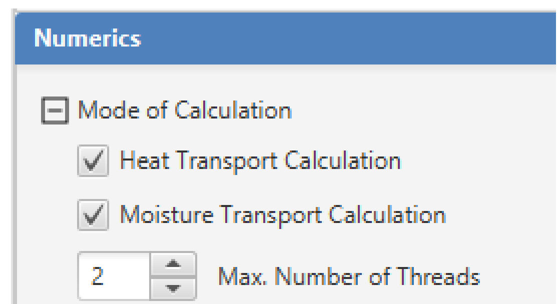
- Steps: 3
- Max. Stages: 10

Numerics:

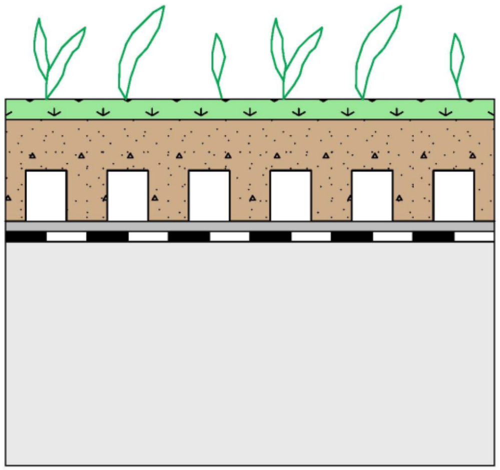
It is recommended to use 2 CPU cores when simulating green roofs.

→ Mode of Calculation

→ Max. Number of Threads: 2



Optigreen-System Light-weight Roof Solution 1



Description according to the manufacturer:

- double layer, extensive roof greening (from 0-5° roof pitch)
- low layer height (approx. 6 cm)
- low weight (approx. 55 kg/m²)
- drought-tolerant sedum plants (approx. 6-8 species)
- low maintenance (1 time per year)

Optigreen-System Light-weight Roof Solution 1

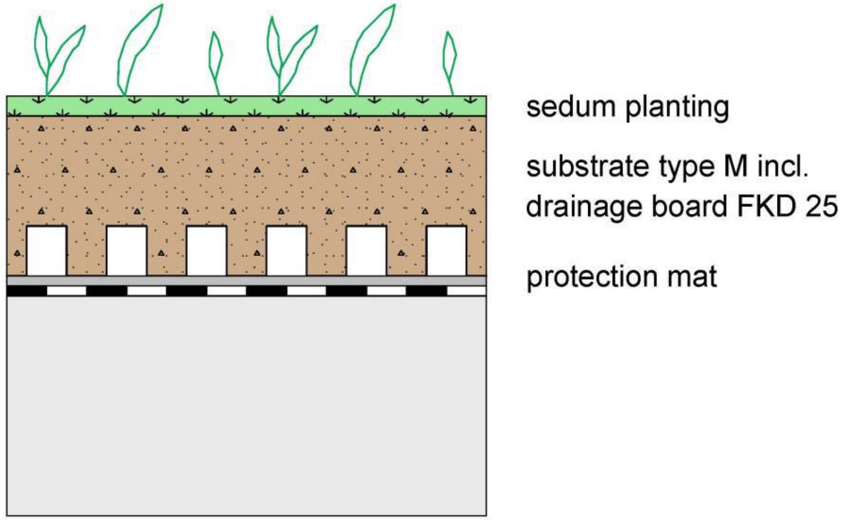
Assembly in WUFI®:

Material data set (system): “Optigreen Light-weight Roof Solution 1”

Consisting of the following layers:

- 1 cm Sedum planting
- 5.5 cm Substrate type L incl. drainage board
- 0.1 cm Protection mat

Optigreen-System Economy Roof 1



Description according to the manufacturer:

- double layer, extensive roof greening (from 0-5° roof pitch)
- low layer height (approx. 8.5 cm)
- low weight (approx. 95 kg/m²)
- drought-tolerant sedum plants (approx. 6-8 species)
- low maintenance (1 - 2 times per year)

Optigreen-System Economy Roof 1

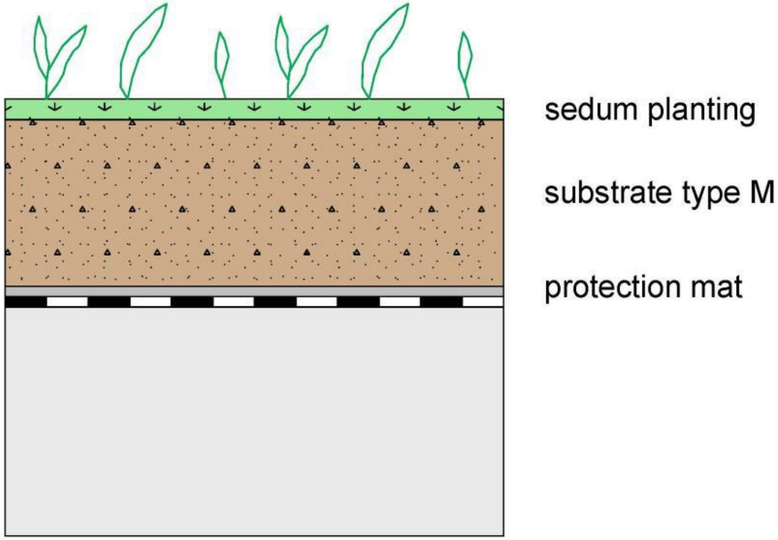
Assembly in WUFI®:

Material data set (system): “Optigreen Economy Roof 1”

Consisting of the following layers:

- 1 cm Sedum planting
- 8.5 cm Substrate type M incl. drainage board
- 0.1 cm Protection mat

Optigreen-System Economy Roof 2



Description according to the manufacturer:

- single layer, extensive roof greening (from 1-5° roof pitch)
- low layer height (approx. 8 cm)
- low weight (approx. 100 kg/m²)
- drought-tolerant sedum plants (approx. 6-8 species)
- low maintenance (1 - 2 times per year)

Optigreen-System Economy Roof 2

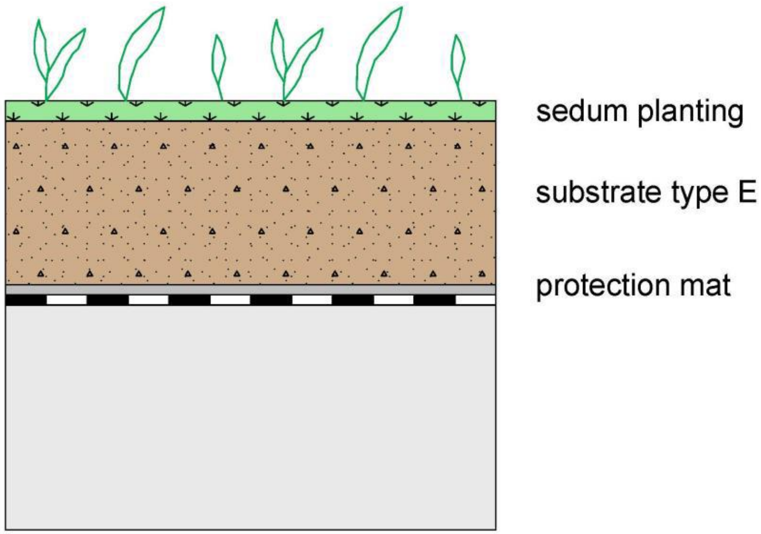
Assembly in WUFI®:

Material data set (system): “Optigreen Economy Roof 2”

Consisting of the following layers:

- 1 cm Sedum planting
- 8 cm Substrate type M
- 0.1 cm Protection mat

Optigreen-System Pitched Roof 5° - 45°



Description according to the manufacturer:

- double layer, extensive roof greening (from 5-45° roof pitch)
- low layer height (approx. 9 cm)
- low weight (approx. 110 kg/m²)
- drought-tolerant sedum plants (approx. 6-8 species)
- low maintenance (1 time per year)

Optigreen-System Pitched Roof 5° - 45°

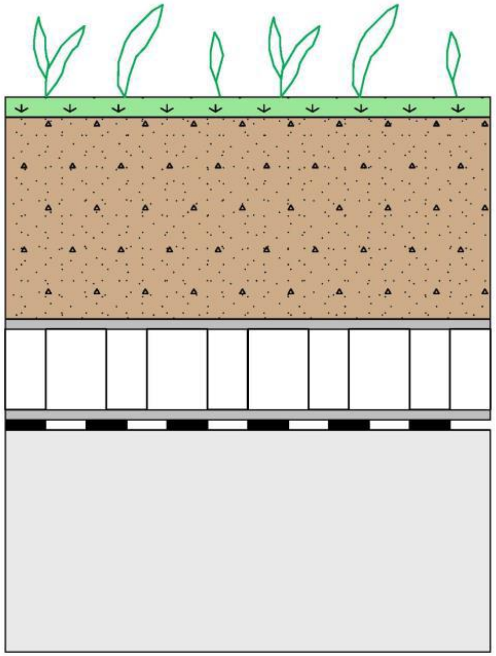
Assembly in WUFI®:

Material data set (system): "Optigreen Pitched Roof 5° - 45°"

Consisting of the following layers:

- 1 cm Sedum planting
- 8 cm Substrate type E
- 0.1 cm Protection mat

Optigreen-System Nature Roof Solution 1



Description according to the manufacturer:

- multi-layer, extensive roof greening (from 0-5° roof pitch)
- medium layer height (approx. 10 cm)
- medium weight (approx. 120 kg/m²)
- drought-tolerant sedum plants, grasses, herbs (approx. 25 species)
- medium maintenance (2 - 3 times per year)

Optigreen-System Nature Roof Solution 1

Assembly in WUFI®:

Material data set (system): "Optigreen Nature Roof Solution 1"

Consisting of the following layers:

- 1 cm Grasses
- 10 cm Substrate type E
- 0.1 cm Filter mat
- 4 cm Drainage board
- 0.1 cm Protection mat

Notes on the Evaluation of Green Roofs

Calculation Quality

- Long calculation times are not unusual for green roofs.

- The balance differences should remain as small as possible.

Status of Calculation

Calculation: Time and Date	May 11, 2026, 10:15 AM
Start / end of the computed time period	Oct 1, 2026 / Oct 1, 2034
Calculation Period	0:01:28.302
Currently simulated time step	Oct 1, 2034, 12:00 AM

Check for numerical quality

No. of Convergence Failures		**104**	
Sum of diffusive fluxes (left/right)	[kg/m²]	-362.132	-0.245
Sum of capillary fluxes (left/right)	[kg/m²]	-726.990	0.000
Balance (mass vs. sum of surface-fluxes)	**[kg/m²]**	**15.292**	**15.371**

- The number of convergence failures is not a decisive factor, but a high number indicates that convergence is difficult. It is important that the balances do not differ too greatly. In the case of green roofs, however, larger balance differences can occur due to the large amounts of moisture in the green roof structure (driving rain source). These usually occur in the green roof layers and often have no or only a marginal effect on the underlying structure.

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

Notes on the Evaluation of Green Roofs

Greened 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 Green 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.

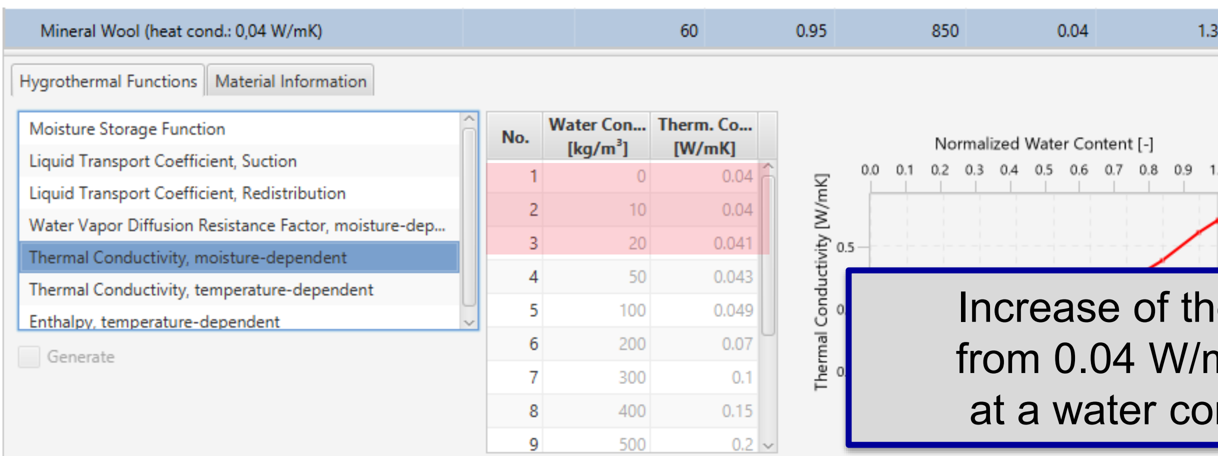
- Moisture leads to an increase in thermal conductivity - but this increase usually remains so small (see next slide) that it appears negligible even for typical service lives of 25 years.
- In rigid-foam insulation, moisture remains in the pore structure of the material - i.e. usually without any further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

Notes on the Evaluation of Green Roofs

Additional evaluation in the case of an additional insulation

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.

Important Notes / Rules for Construction Practice

- **Additional insulation** of the exterior sheathing **is useful** and recommended for insulation thicknesses above about 15 - 20 cm.
- **Moisture-variable vapour retarders** in combination with diffusion-open interior sheathing improve drying and moisture balance and should therefore be **preferred**.
- **Caution** should be exercised **in shaded areas** and locations with low radiation, as the low drying potential is further reduced.
- **Install** materials **as dry as possible** – drying out after installation is only possible very slowly.
- Aim for and verify for **good airtightness.**
- **No drying possible upwards** through the greening layer – but moisture entry from above is possible. Therefore, **diffusion-resistant roofing membranes** perform more favourably (**s_d-values ≥ 300 m** recommended)!
- Insulation over the rafters is always uncritical!!

Literature

[1] Schafaczek B., Zirkelbach D.: Ermittlung von Materialeigenschaften und effektiven Übergangsparametern von Dachbegrünungen zur zuverlässigen Simulation der hygrothermischen Verhältnisse in und unter Gründächern bei beliebigen Nutzungen und unterschiedlichen Standorten. Forschungsinitiative Zukunft Bau, Band F 2863, Fraunhofer IRB Verlag 2013.

[2] Winter, S.; Fülle, C.; Werther, N.: Forschungsprojekt MFPA Leipzig und TU München (Z 6 – 10.08.18.7-07.18). „Flachdächer in Holzbauweise“. 2007-2010.

[3] Teibinger, M.; Nusser, B.: Ergebnisse experimenteller Untersuchungen an flachgeneigten Hölzernen Dachkonstruktionen. Herausgegeben von Holzforschung Austria, Wien. (Forschungsbericht, HFA-Nr.: P412), 2010.

[4] Minke, G.; Otto, F.; Gross, R.: Ermittlung des Wärmedämmverhaltens von Gründächern. Abschlussbericht, AZ 24242-25. ZUB Kassel. Juli 2009.

[5] Fiori, M.; Paolini, R.: Politecnico di Milano, Dipartimento di Architettura, Ingegneria delle costruzioni e Ambiente costruito. The green roof monitoring is funded by the Italian Ministry of Research, project PRIN SENSE „Smart Building Envelope for Sustainable Urban Environment“.

[6] DIN 68800-2: Wood preservation - Part 2: Preventive constructional measures in buildings. Beuth Verlag, February 2022.

[7] 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.

[8] DIN 4108-3: Thermal protection and energy economy in buildings – Part 3: Protection against moisture subject to climate conditions – Requirements, calculation methods and directions for planning and construction. Beuth Verlag, March 2024.

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

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

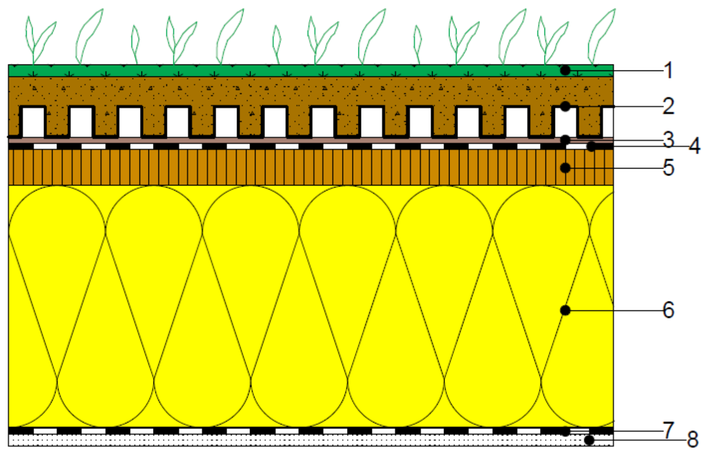
[11] EN 15026: Hygrothermal performance of building components and building elements – Assessment of moisture transfer by numerical simulation. Beuth Verlag, December 2023.

Example: Extensive green roof on lightweight construction

On the basis of an example case with the lightweight substrate, 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.

<u>Example:</u>
extensive green roof on lightweight construction with „Optigreen Light-weight Roof 1“



1 Sedum Planting
2 Substrate incl. Drainage Board (FKD)
3 Protection Mat
4 Roofing Membrane (s_d = 300 m)
5 Oriented Strand Board
6 Mineral Wool Insulation
7 Moisture-variable Vapour Retarder
8 Gypsum Board

Fraunhofer IBP

Example: Assembly

Assembly (from outside to inside):

• Optigreen Light-weight Roof 1 (sedum planting) 1-3	0.01	m
• Optigreen Light-weight Roof 1 (substrate type L incl. FKD) 2-3	0.055	m
• Optigreen Light-weight Roof 1 (protection mat) 3-3	0.001	m
• Roofing Membrane (s_d = 300m)	0.001	m
• Oriented Strand Board (density 615 kg/m³)	0.022	m
• Mineral Wool (heat cond.: 0,04 W/mK)	0.18	m
• Moisture-variable Vapour Retarder (Vario KM Duplex)	0.001	m
• Gypsum Board	0.0125	m

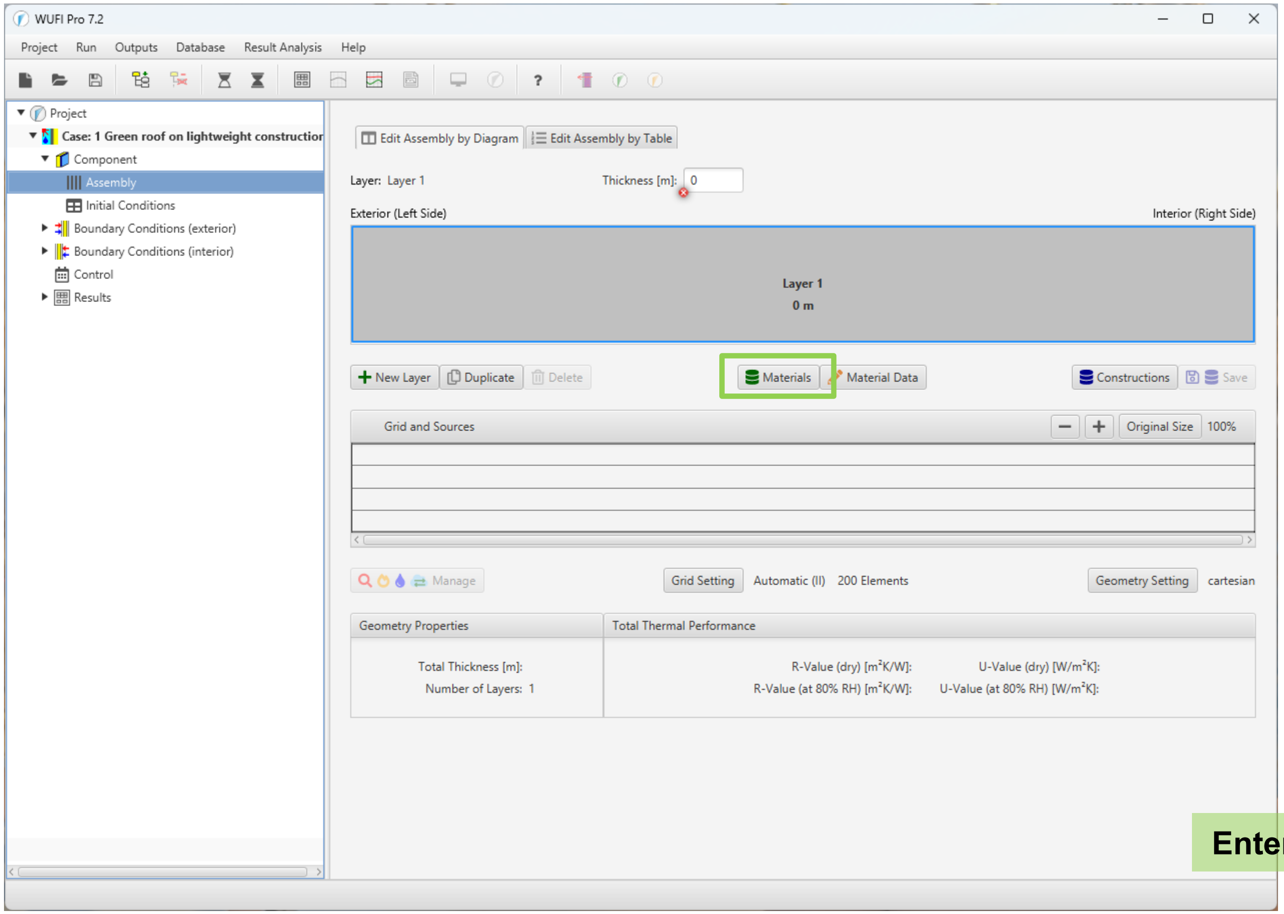
Example: Boundary Conditions

Boundary Conditions:

- Flat roof (3° to the North)
- Radiation according to “Green roof: Optigreen system”
  Short-wave absorptivity: 0.6
  Long-wave emissivity: 0.9
  Consideration of radiative overcooling!
- 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: Component Assembly

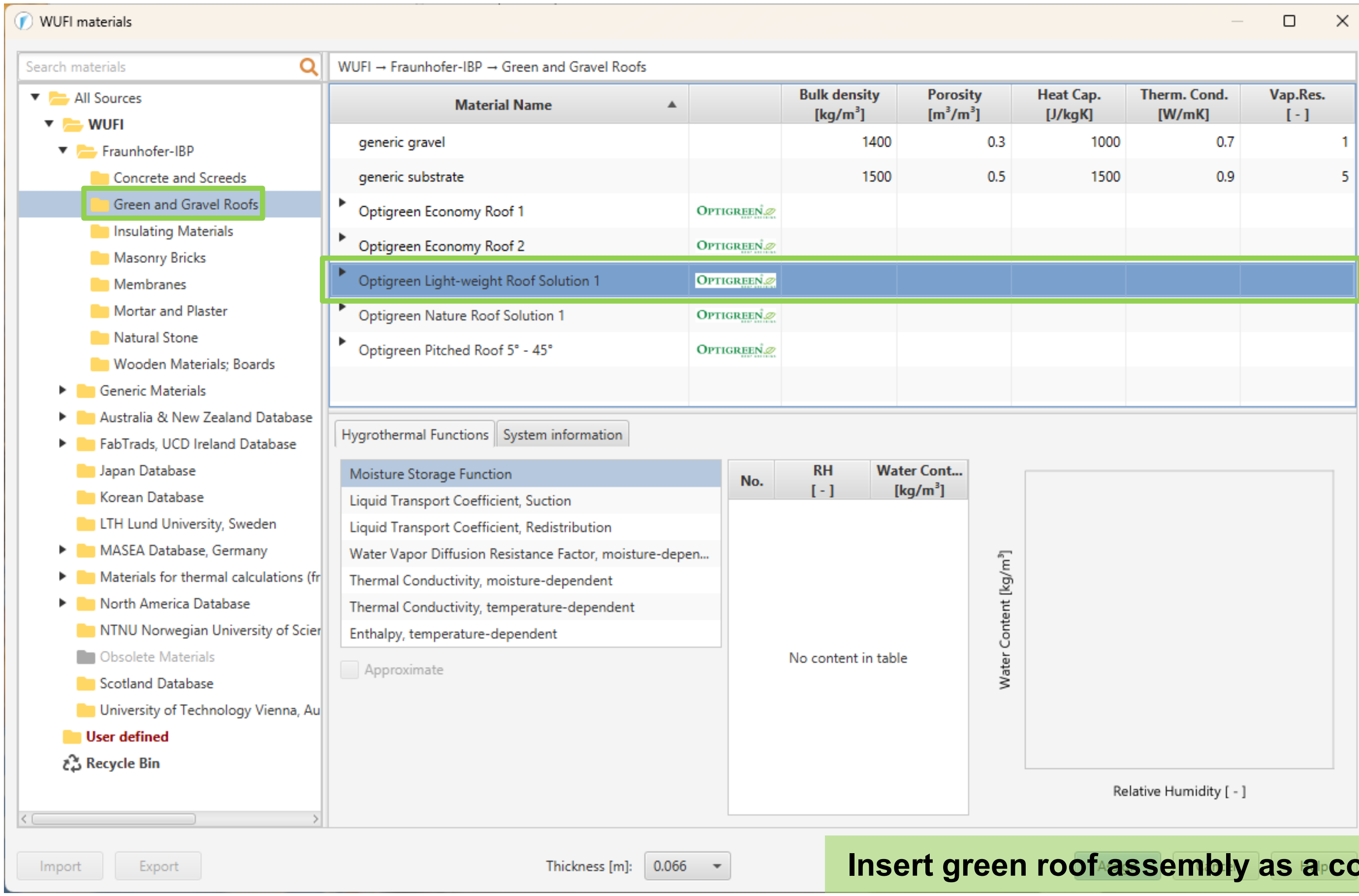
Input: Component – Assembly



Enter green roof assembly

Example: Component Assembly

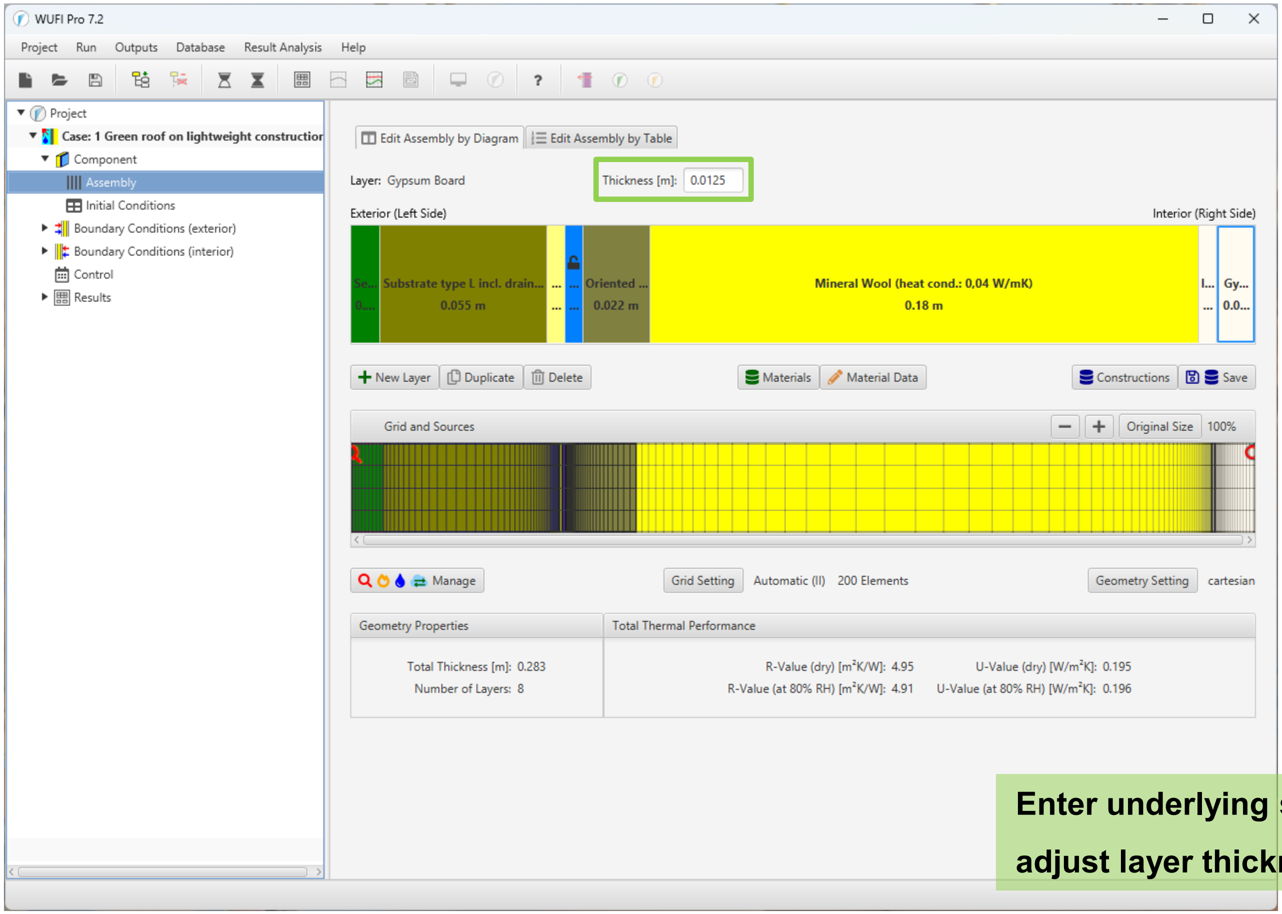
<u>Input:</u> Component – Assembly



Insert green roof assembly as a complete system

Example: Component Assembly

Input: Component – Assembly



Enter underlying structure

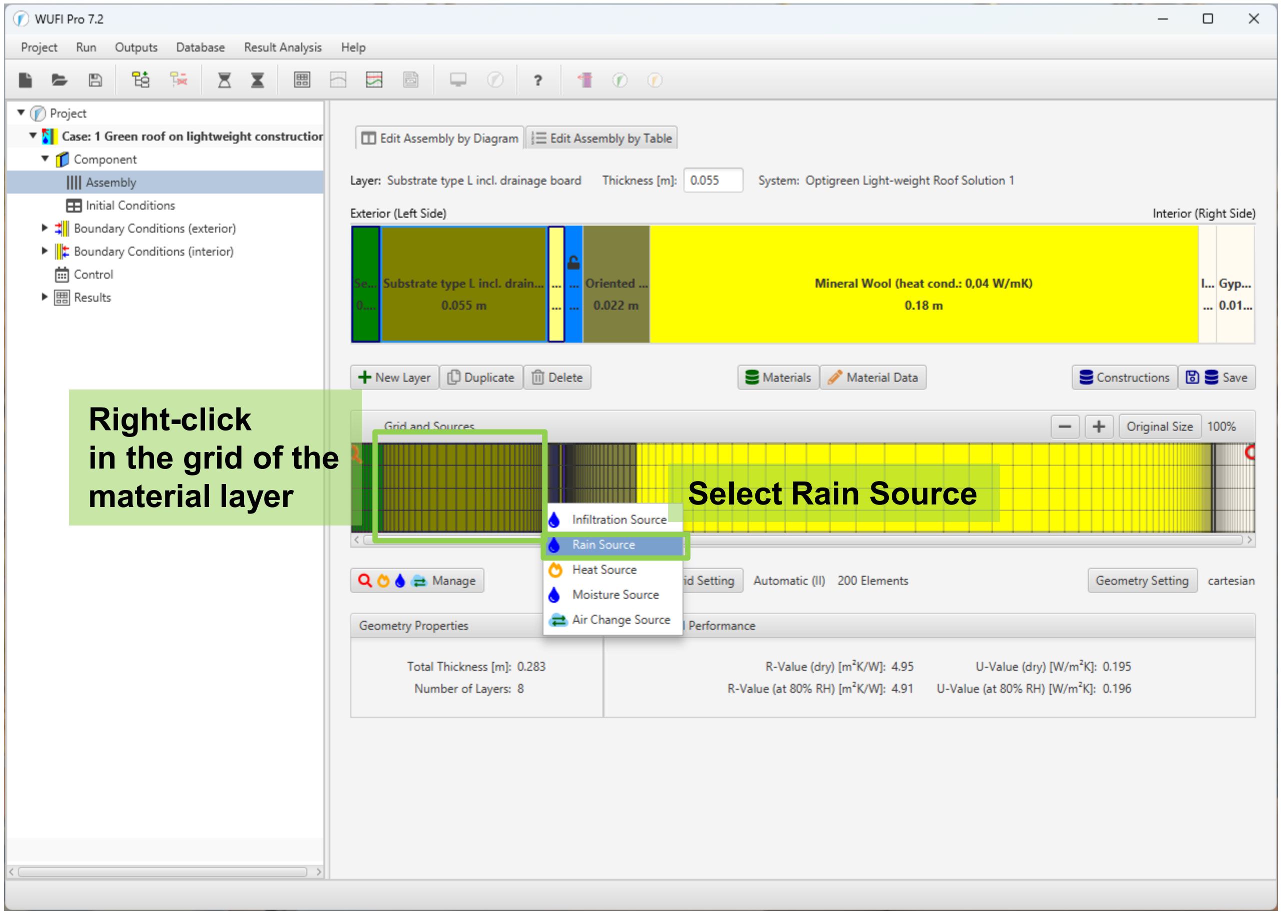
adjust layer thicknesses if necessary

Fraunhofer IBP

Example: Moisture Source in the Substrate Layer

<u>Input:</u> Component – Assembly

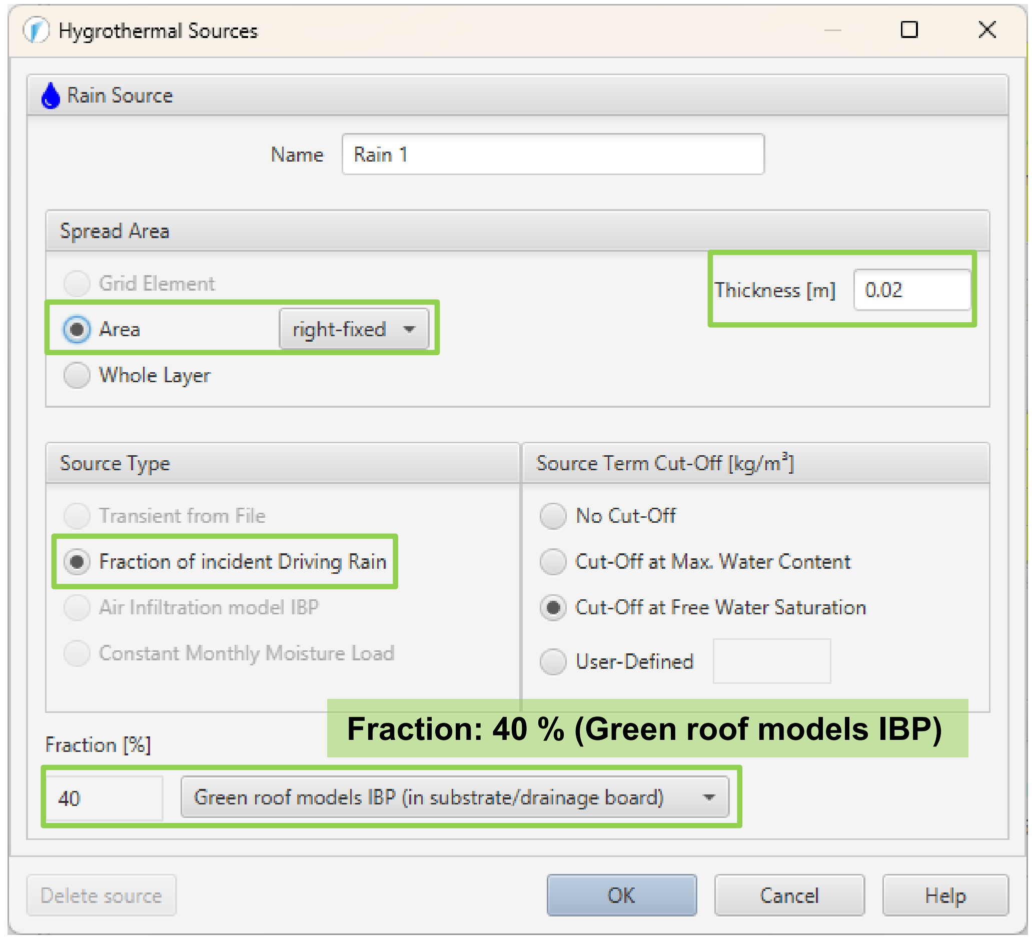
Insert moisture source in the layer “Substrate Type L incl. FKD“



Example: Moisture Source in the Substrate Layer

Input: Component – Assembly

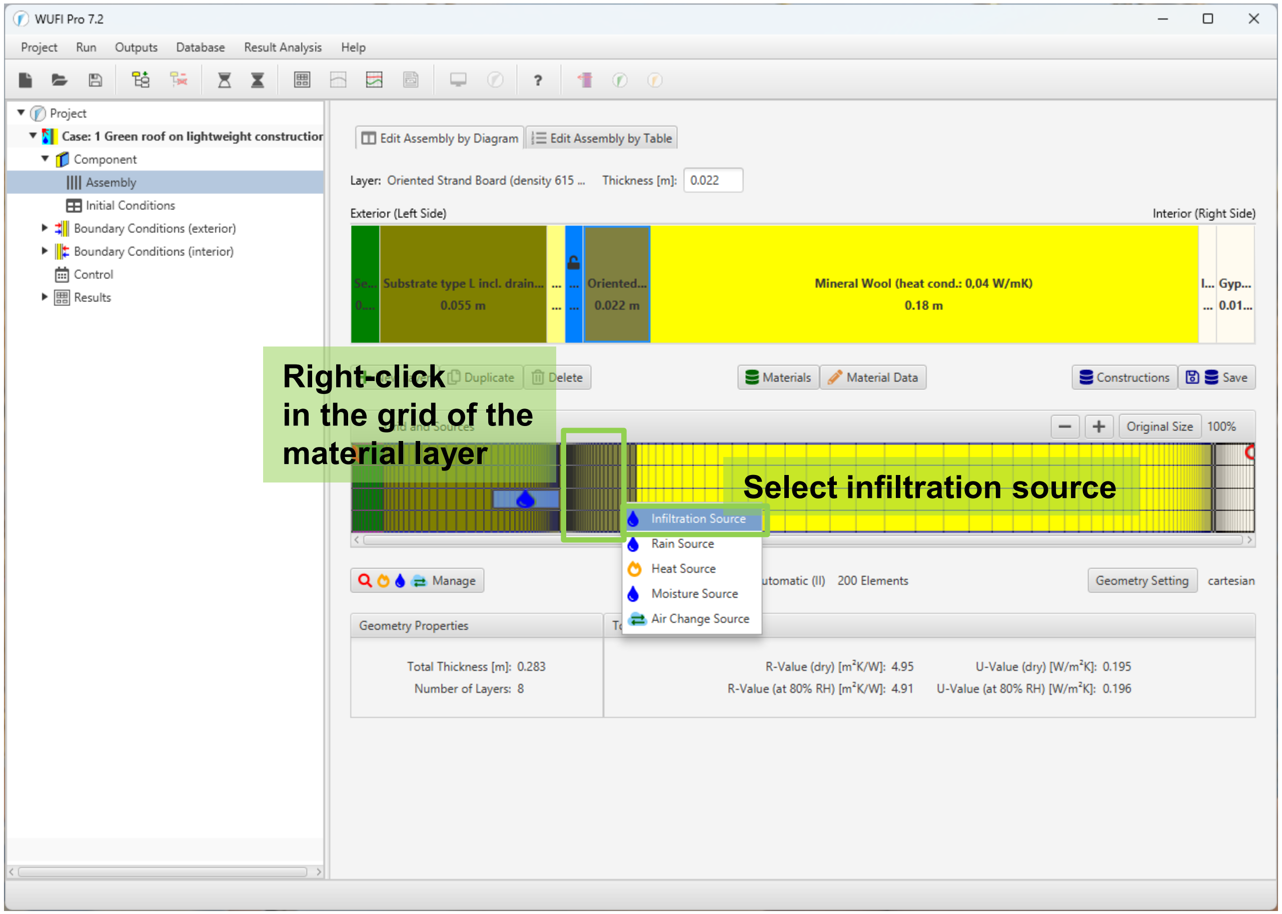
Moisture source in the lowest 2 cm of the substrate layer.



Example: Infiltration Source

Input: Component – Assembly

Infiltration source according to DIN 68800 in the OSB

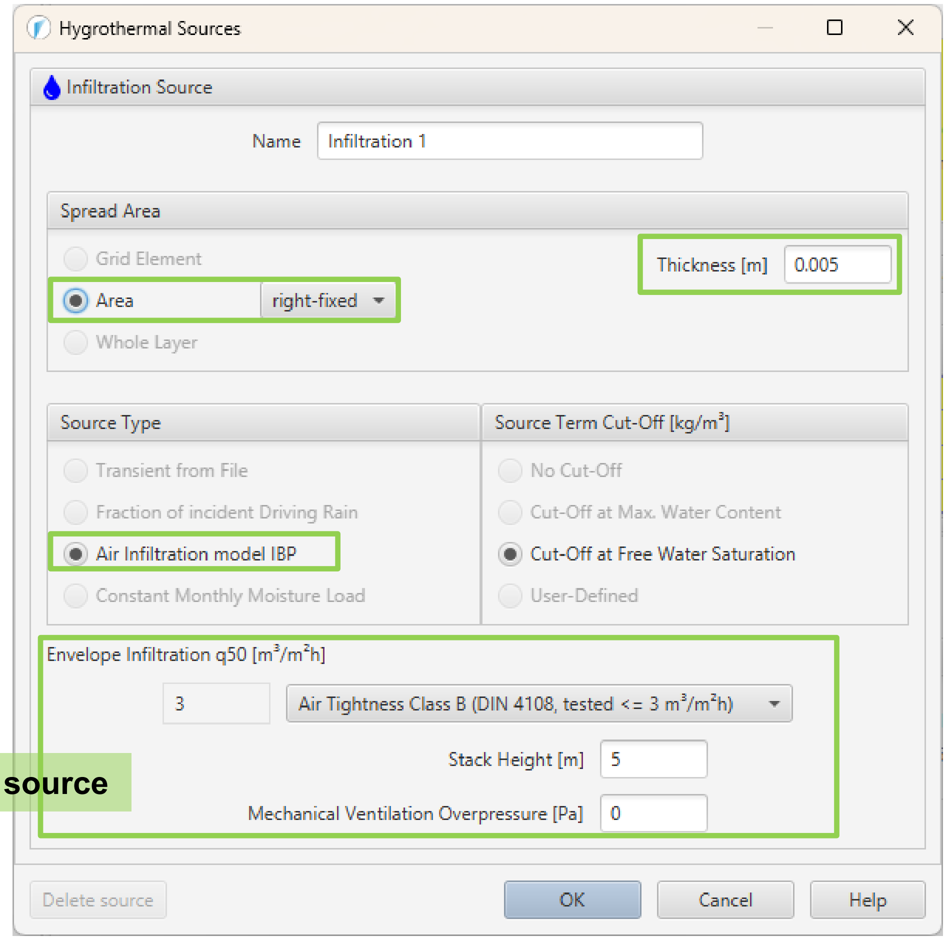


Fraunhofer IBP

Example: Infiltration Source

<u>Input:</u> Component – Assembly

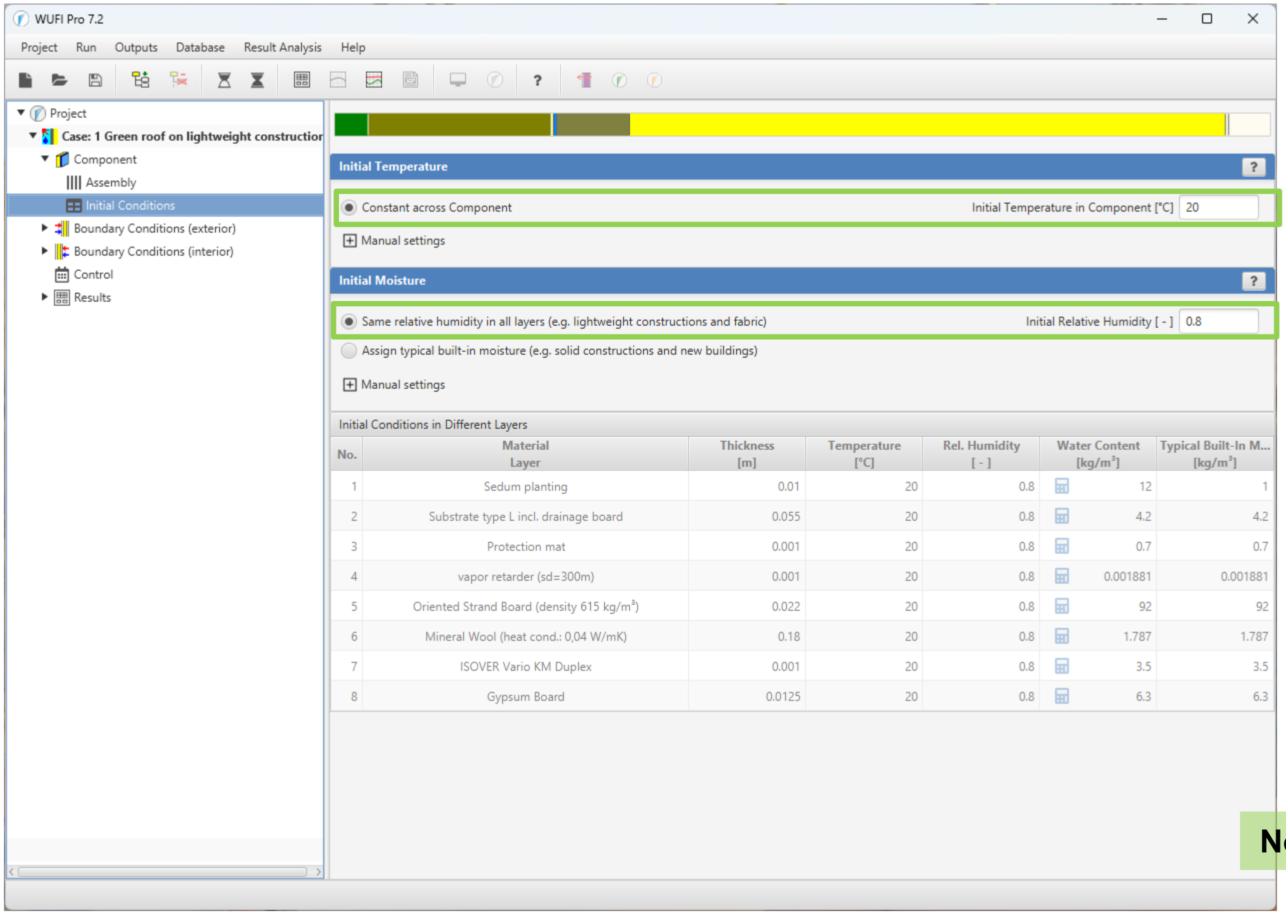
Moisture Source in the interior 5 mm of the OSB.



Adjust infiltration source

Example: Initial Conditions

__Input:__ Component – Initial Conditions

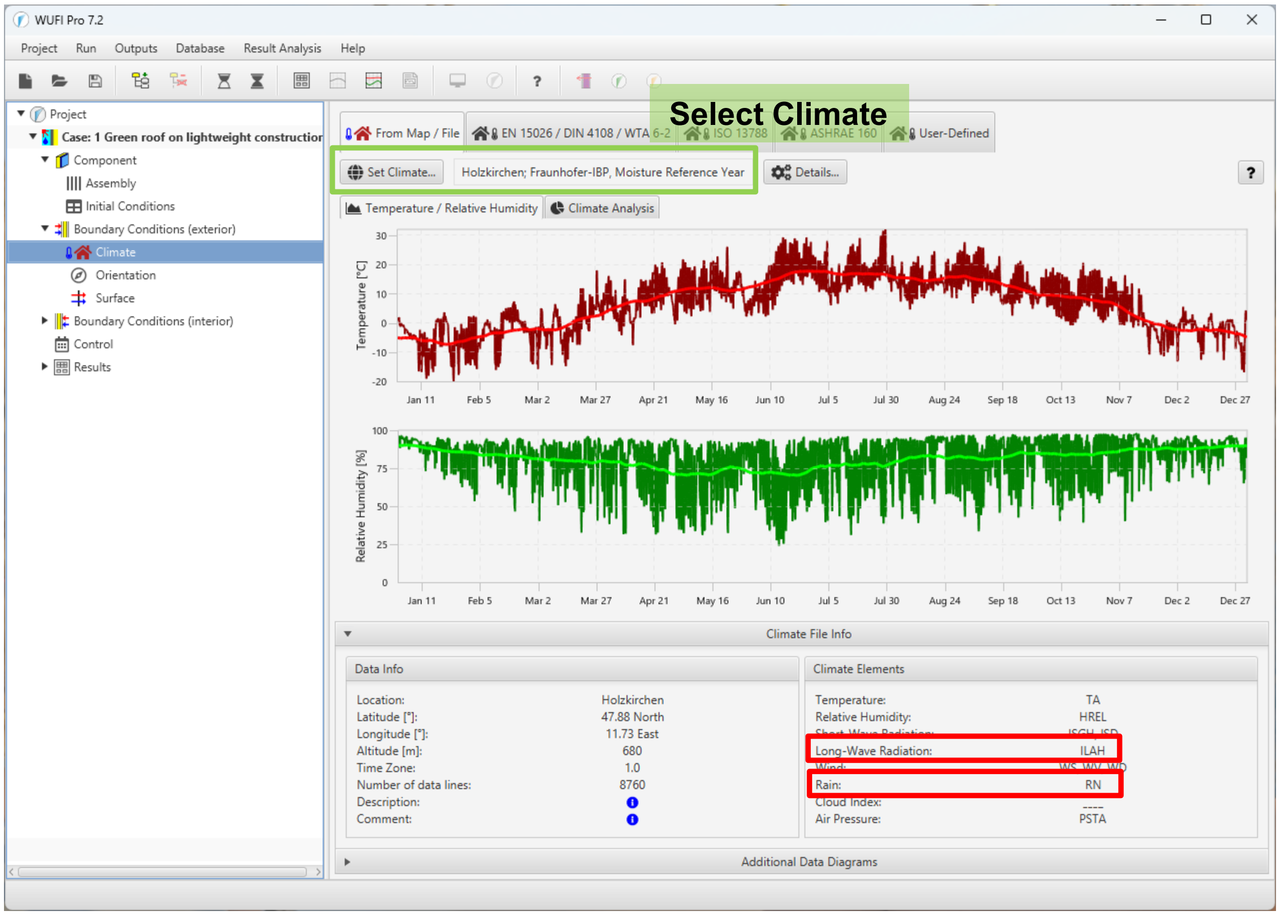


No.	Material Layer	Thickness [m]	Temperature [°C]	Rel. Humidity [-]	Water Content [kg/m³]	Typical Built-In M... [kg/m³]
1	Sedum planting	0.01	20	0.8	12	1
2	Substrate type L incl. drainage board	0.055	20	0.8	4.2	4.2
3	Protection mat	0.001	20	0.8	0.7	0.7
4	vapor retarder (sd=300m)	0.001	20	0.8	0.001881	0.001881
5	Oriented Strand Board (density 615 kg/m³)	0.022	20	0.8	92	92
6	Mineral Wool (heat cond.: 0,04 W/mK)	0.18	20	0.8	1.787	1.787
7	ISOVER Vario KM Duplex	0.001	20	0.8	3.5	3.5
8	Gypsum Board	0.0125	20	0.8	6.3	6.3

No changes required

Example: Outdoor Climate

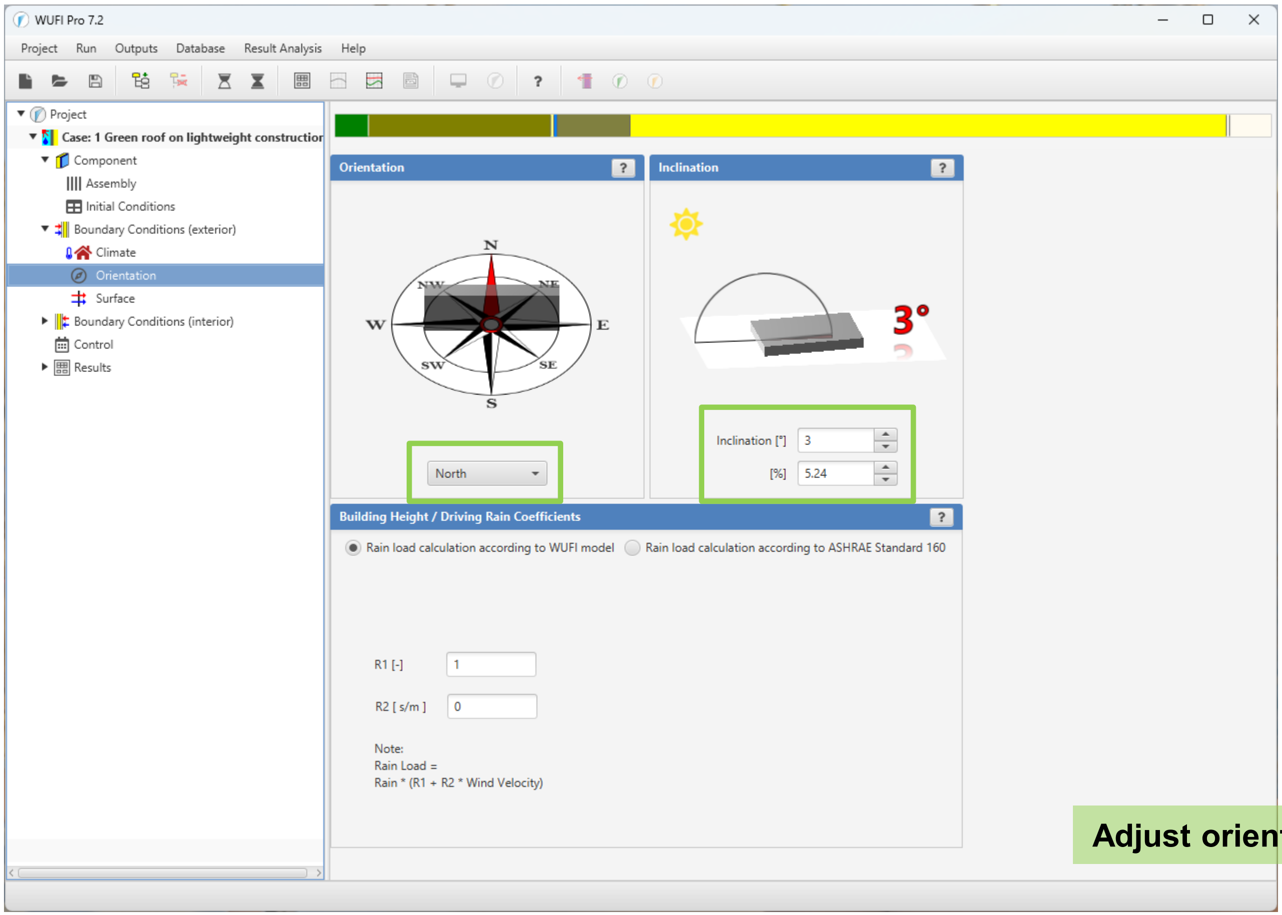
Input: Boundary Conditions (exterior) – Climate



Note:
For the application of the model "green roof, Optigreen system", climate data with long-wave radiation and rain data are necessary!

Example: Orientation / Inclination

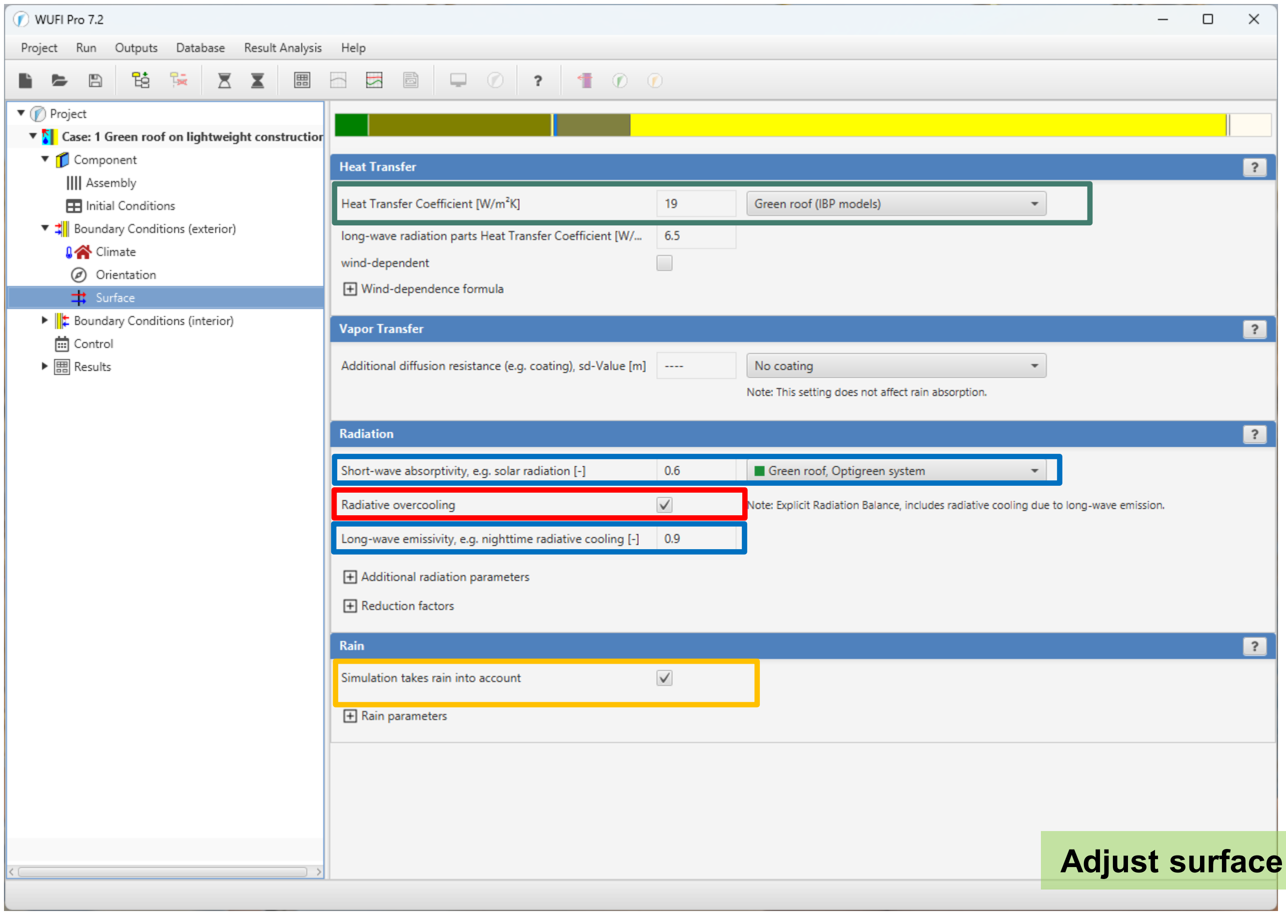
Input: Boundary Conditions (exterior) – Orientation



Adjust orientation and inclination

Example: Surface Transfer Coefficients

Input: Boundary Conditions (exterior) – Surface



Heat transfer coefficient (from list: green roof)

Absorption (from list: green roof, Optigreen system)

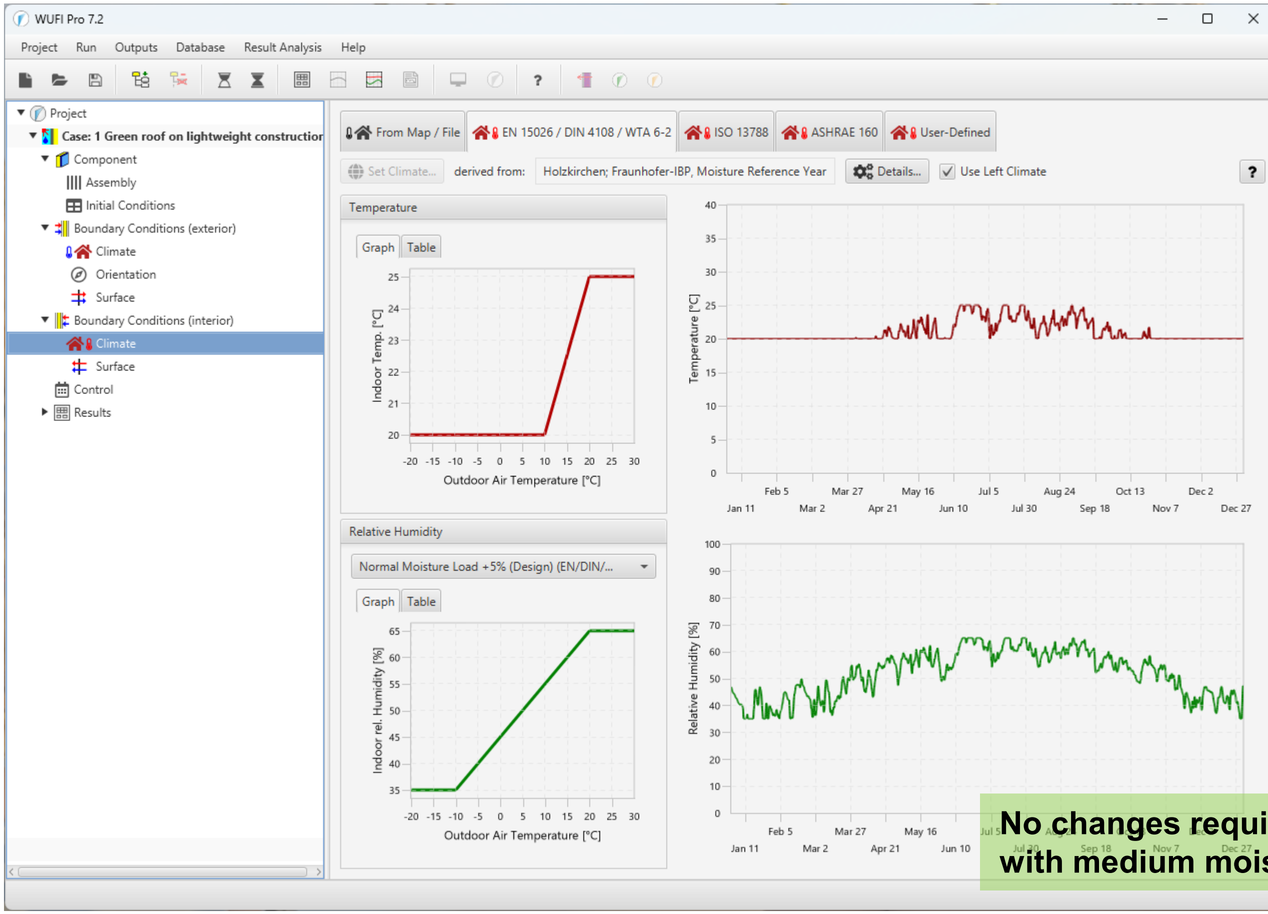
USE of the radiative overcooling

Rain is taken into account

Adjust surface transfer coefficients!

Example: Indoor Climate

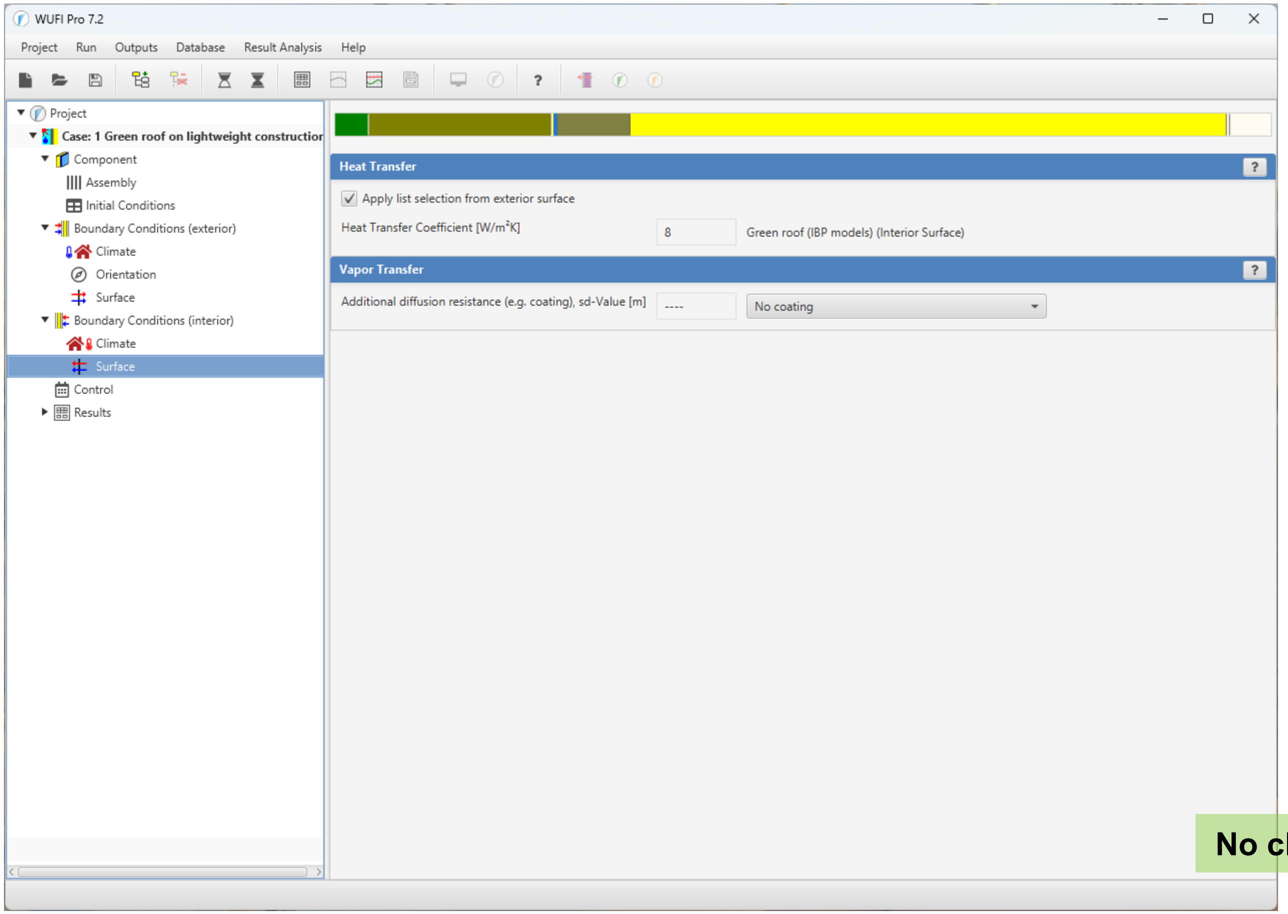
<u>Input:</u> Boundary Conditions (interior) – Climate



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

Example: Surface Transfer Coefficients (interior)

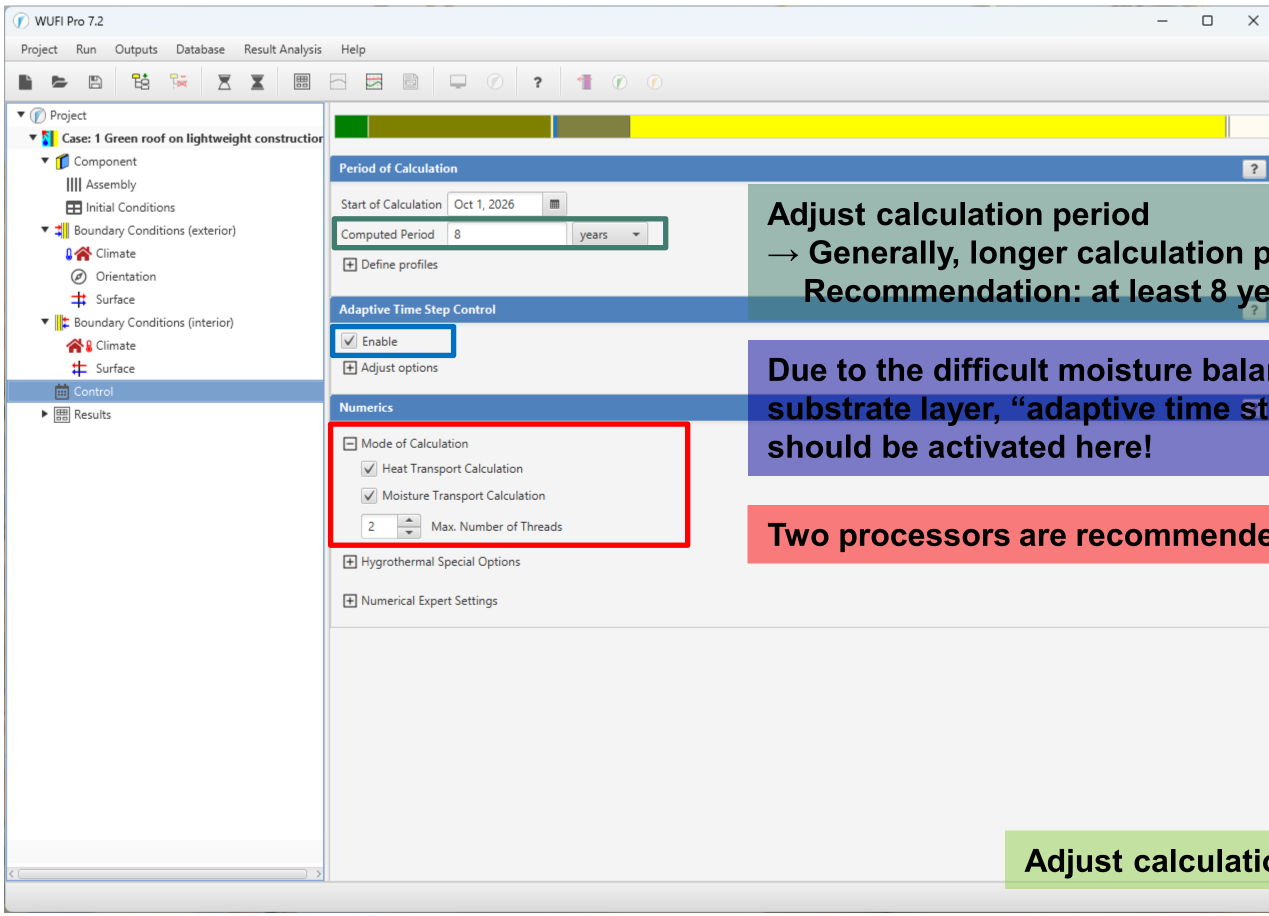
Input: Boundary Conditions (interior) – Surface



No changes required

Example: Period of Calculation and Numerics

Input: Control



Adjust calculation period
→ Generally, longer calculation periods are required
Recommendation: at least 8 years

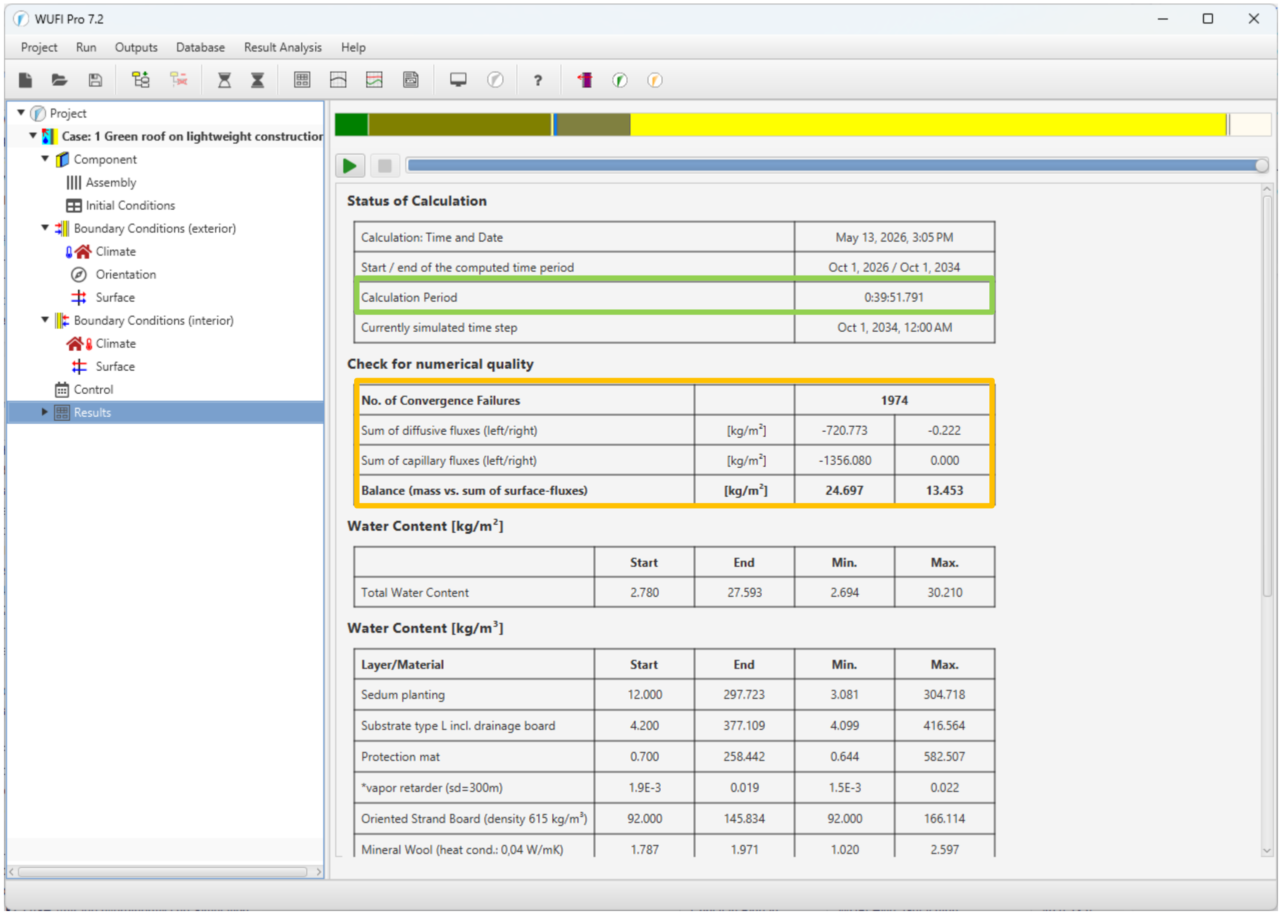
Due to the difficult moisture balance in the substrate layer, "adaptive time step control" should be activated here!

Two processors are recommended for this calculation!

Adjust calculation period and numeric settings

Example: Check for Numerical Quality

Results:



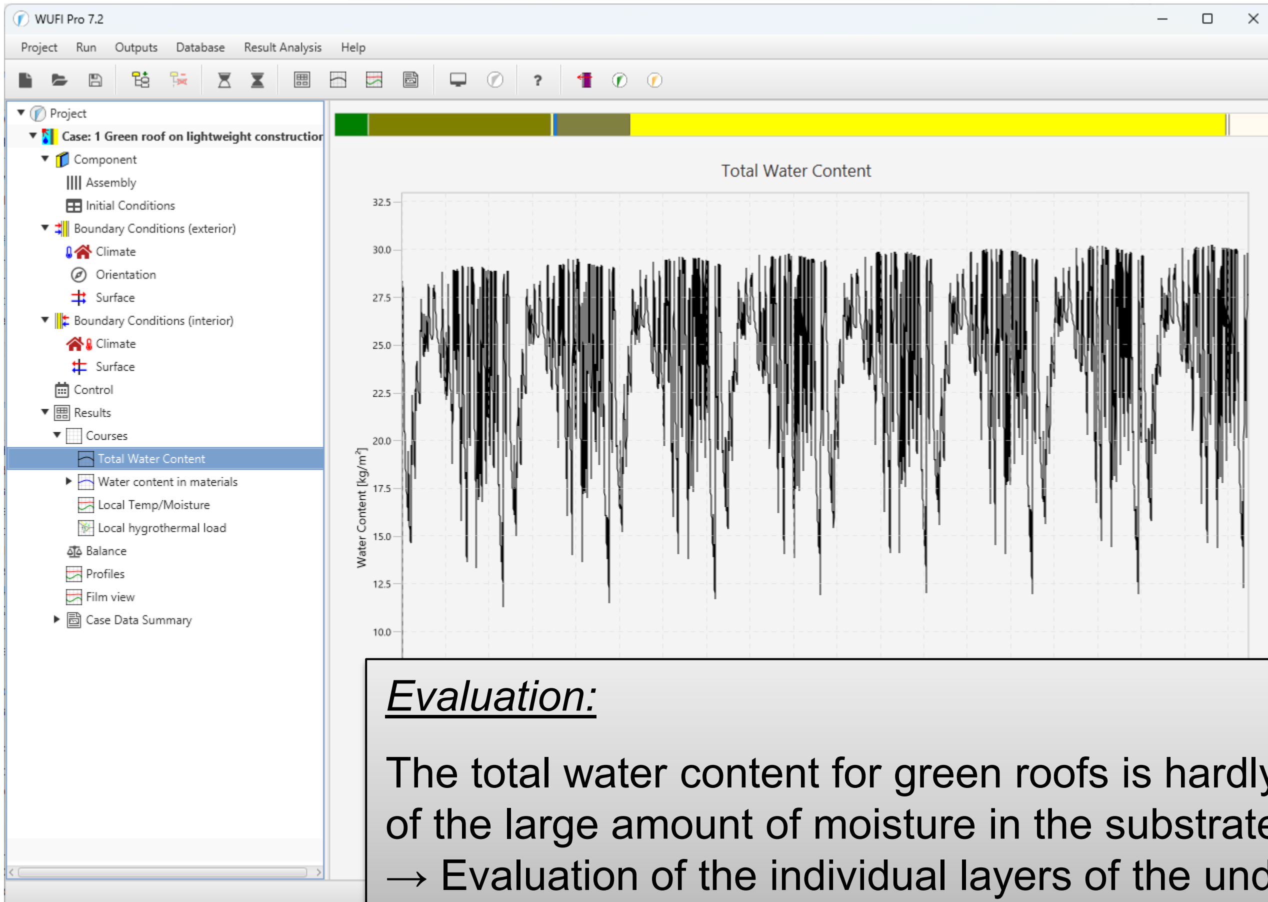
In the case of green roofs, long calculation times are not uncommon!

Due to the large amounts of water absorbed by the green roof, significant discrepancies in the balances can occur.

These balance failures usually occur in the green roof layers and often have little or no effect on the substructure (check the course of the substructure!).

Example: Evaluation of Total Water Content

Evaluation:
Total water content

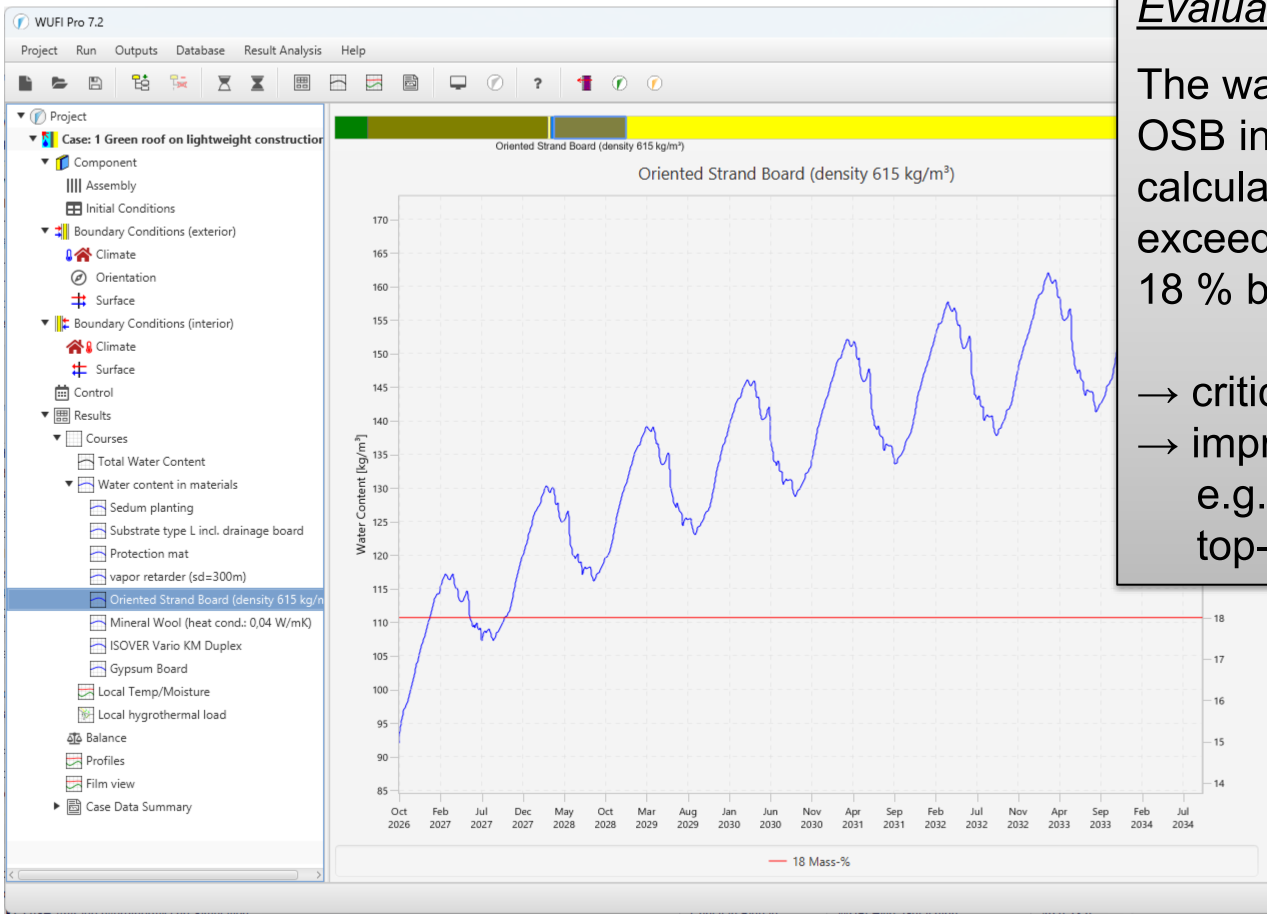


Evaluation:

The total water content for green roofs is hardly conclusive because of the large amount of moisture in the substrate layer.
→ Evaluation of the individual layers of the underlying construction

Example: Evaluation of Wood Moisture

<u>Evaluation:</u>
Water content in the OSB



<u>Evaluation:</u>

The water content in the OSB increases over the calculation period and exceeds the limit value of 18 % by mass.

→ critical
→ improvement,
e.g. by an additional top-side insulation