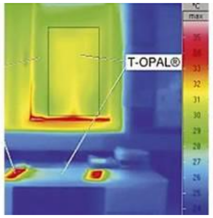
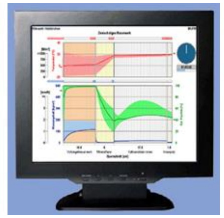
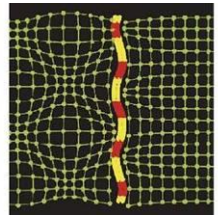




WUFI®

Guideline for the Calculation of extensive Green Roofs (Optigreen)

Date: July 2021

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 program "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 different product-specific models were developed in order to simulate and design green roofs – especially on wooden constructions – reliably by 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 the five Optigreen-Systems with WUFI® were developed in collaboration with the company.

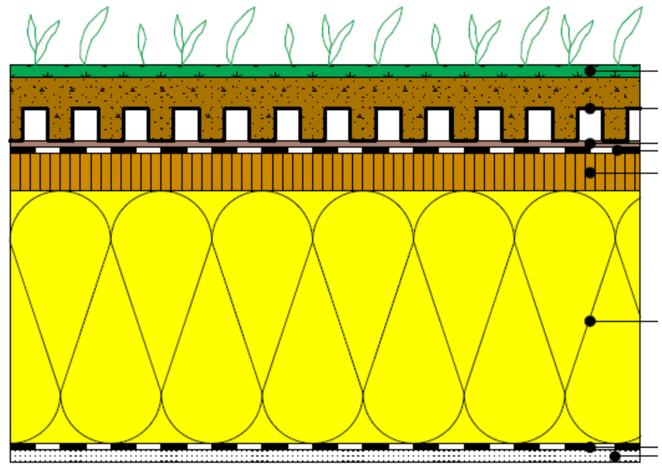
Application of the Specific Green Roof Models

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 19
- Economy Roof Solution 1: slide 22
- Economy Roof Solution 2: slide 25
- Pitched Roof 5-45°: slide 28
- Nature Roof Solution 1: slide 31



Input: Component Assembly and Grid Setting

Component – Assembly/Monitor Positions

<u>Optigreen-Systems</u>

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

On the other hand, the assemblies are also in the Construction Database. To insert them, click the “Example Cases" button under the component assembly. Then select the respective assembly under *Fraunhofer-IBP → Roofs*.

After inserting, add the substructure to the assembly. Afterwards, the boundary conditions and the moisture sources must be defined according to this guideline.

Input: Component Assembly and Grid Setting

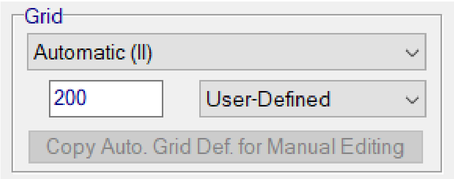
Component – Assembly/Monitor Positions

Underlaying Roof Assembly

The underlaying layers are to be entered according to the assembly in the compartment axis.

Grid Structure

The following grid setting is recommended for green roofs:
Automatic (II) with 200 elements (User-Defined)



Input: Moisture Source in the Substrate

Component - Assembly/Monitor Positions

Moisture Source in the Substrate resp. Drainage Layer

The moisture sources to be applied in the individual layers are explained in the description of the respective Optigreen-Systems.
(slide 19 et seq.)

Input: Infiltration Source

Component - Assembly/Monitor Positions

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/Monitor Positions

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: Orientation / Inclination

Component - Orientation

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

Component – Surface Transfer Coefficients

Heat Transfer Coefficient

Exterior Surface

The heat transfer coefficient at the exterior surface is 19 W/m²K according to the specific green roof model [1].

Interior Surface

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

Input: Surface Transfer Coefficients

Component – Surface Transfer Coefficients

Short-Wave Radiation Absorptivity

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

Long-Wave Radiation Emissivity

The long-wave radiation emissivity is 0.9.

The explicit radiation balance 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.

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 each individual layer.

Input: Control

Control

Calculation Period / Profiles:

It is recommended to start the calculation on October 1, because the component usually becomes even more humid during the following winter months before drying out possibly 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.

Numerics:

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

Climate

Outdoor Climate:

A climate suitable for the building location should be used. However, locations that contain long-wave radiation and rain data are necessary for the use of the specific green roof model.

The Hygrothermal Reference Years (HRY), which were created for 11 locations in Germany as part of a research project [9], are useful here. These locations are typical for the respective climatic region.
More detailed information can be found in
WUFI®-Help (F1) → Topic: Hygrothermal Reference Years

The location Holzkirchen is considered critically representative for Germany for many application fields. However, especially when evaluating roofs, locations with less radiation may be less favorable.

Input: Climate

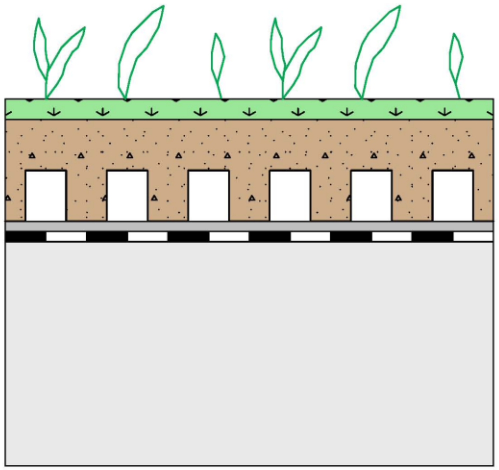
Climate

Indoor Climate:

By default, we recommend the indoor climate with medium moisture load + 5% according to WTA Guideline 6-2 [10] for the design.

Alternatively, depending on the use of the building, the indoor climate according to EN 15026 [11] with medium or high moisture load or, for example, constant or measured conditions can be used.

Optigreen-System Light-weight Roof Solution 1



sedum planting
substrate type L incl.
drainage board FKD 25
protection mat

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

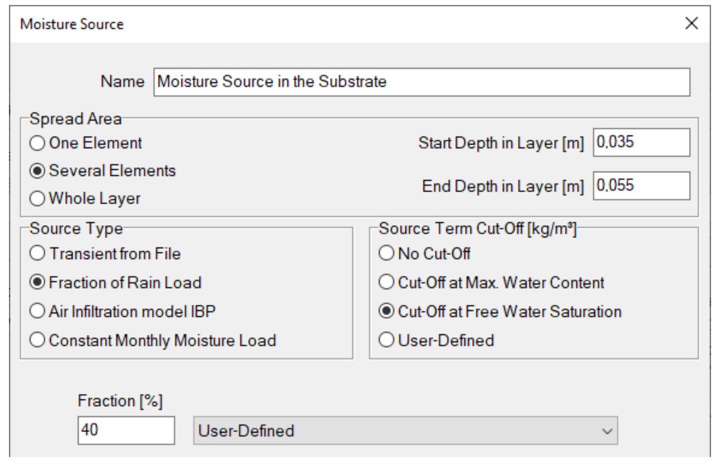
Assembly in WUFI®:

- 1 cm sedum planting
  (material data set: „Optigreen Light-weight Roof 1 (sedum planting) 1-3")
- 5.5 cm substrate type L incl. FKD
  (material data set: „Optigreen Light-weight Roof 1 (substrate type L incl. FKD) 2-3")
- 0.1 cm protection mat
  (material data set: „Optigreen Light-weight Roof 1 (protection mat) 3-3")

Optigreen-System Light-weight Roof Solution 1

Moisture Source in the Substrate Layer

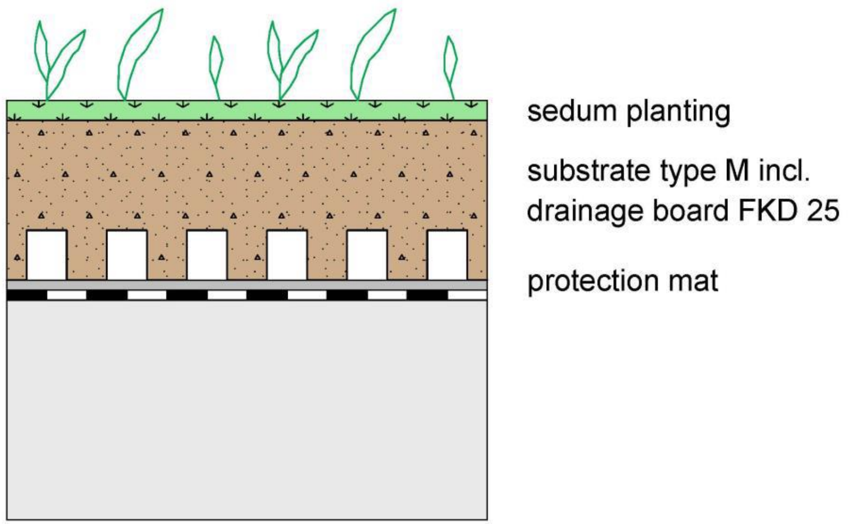
In order to take the precipitation flowing through the substrate layer into account in the calculation, a moisture source is to be considered in the lower 2 cm of the substrate layer. This should inset 40 % of the precipitation, limited to the free water saturation, into the substrate layer during a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



Settings:

- Spread Area: several elements
  start depth in layer: 0.035 m /
  end depth in layer: 0.055 m
- Source Type: Fraction of driving rain
- Fraction: 40 % (User-Defined)
- Cut-Off of the source term at free water saturation

Optigreen-System Economy Roof Solution 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 Solution 1

Assembly in WUFI®:

- 1 cm sedum planting
  (material data set: „Optigreen Economy Roof 1 (sedum planting) 1-3“)

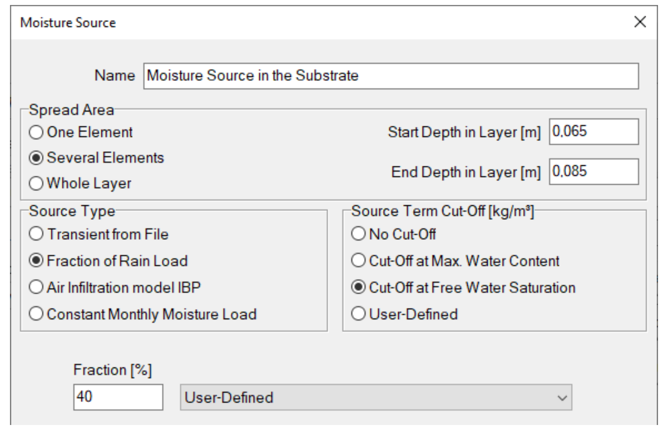
- 8.5 cm substrate type M incl. FKD
  (material data set: „Optigreen Economy Roof 1 (substrate type M incl. FKD) 2-3“)

- 0.1 cm protection mat
  (material data set: „Optigreen Economy Roof 1 (protection mat) 3-3“)

Optigreen-System Economy Roof Solution 1

Moisture Source in the Substrate Layer

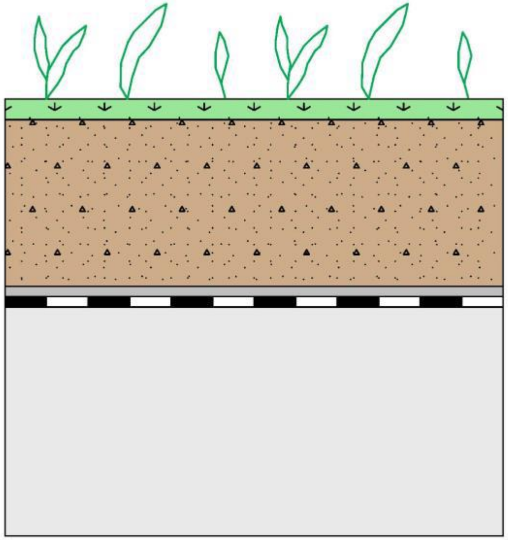
In order to take the precipitation flowing through the substrate layer into account in the calculation, a moisture source is to be considered in the lower 2 cm of the substrate layer. This should inset 40 % of the precipitation, limited to the free water saturation, into the substrate layer during a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



Settings:

- Spread Area: several elements
  start depth in layer: 0.065 m /
  end depth in layer: 0.085 m
- Source Type: Fraction of driving rain
- Fraction: 40 % (User-Defined)
- Cut-Off of the source term at free water saturation

Optigreen-System Economy Roof Solution 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 Solution 2

Assembly in WUFI®:

- 1 cm sedum planting
  (material data set: „Optigreen Economy Roof 2 (sedum planting) 1-3“)

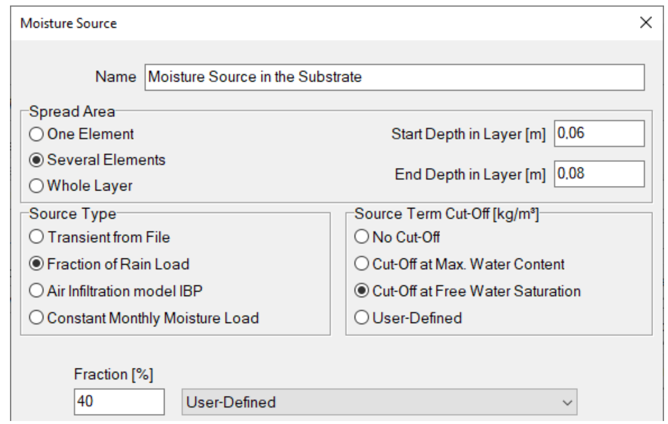
- 8 cm substrate type M
  (material data set: „Optigreen Economy Roof 2 (substrate type M) 2-3“)

- 0.1 cm Schutzvlies
  (material data set: „Optigreen Economy Roof 2 (protection mat) 3-3“)

Optigreen-System Economy Roof Solution 2

Moisture Source in the Substrate Layer

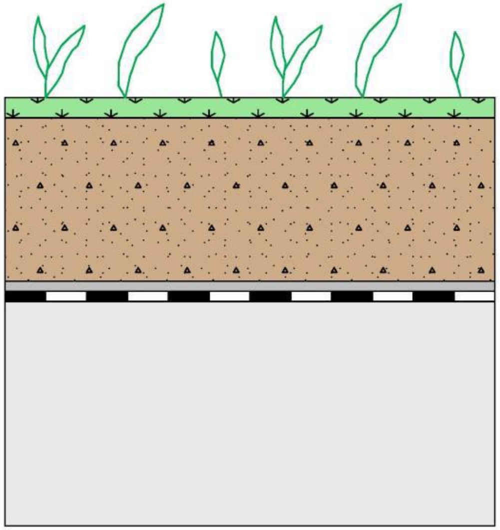
In order to take the precipitation flowing through the substrate layer into account in the calculation, a moisture source is to be considered in the lower 2 cm of the substrate layer. This should inset 40 % of the precipitation, limited to the free water saturation, into the substrate layer during a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



Settings:

- Spread Area: several elements
  start depth in layer: 0.06 m /
  end depth in layer: 0.08 m
- Source Type: Fraction of driving rain
- Fraction: 40 % (User-Defined)
- Cut-Off of the source term at free water saturation

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®:

- 1 cm sedum planting
  (material data set: „Optigreen Pitched Roof 5-45° (sedum planting) 1-3")

- 8 cm substrate type E
  (material data set: „Optigreen Pitched Roof 5-45° (substrate type E) 2-3")

- 0.1 cm protection mat
  (material data set: „Optigreen Pitched Roof 5-45° (protection mat) 3-3")

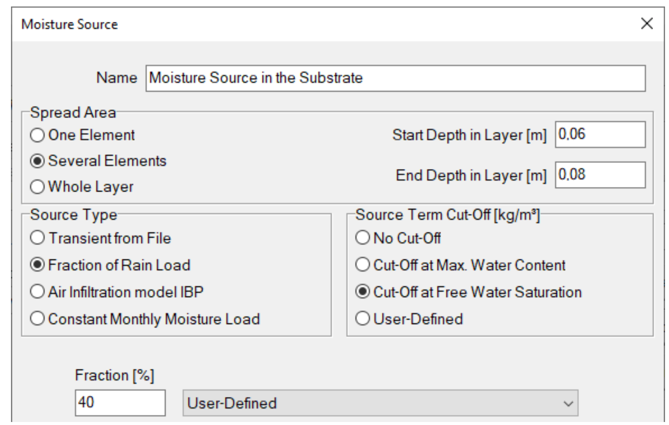
Optigreen-System Pitched Roof 5-45°

Moisture Source in the Substrate Layer

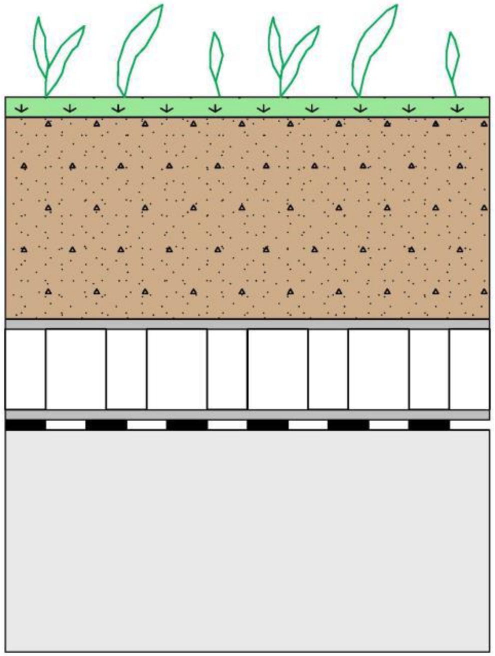
In order to take the precipitation flowing through the substrate layer into account in the calculation, a moisture source is to be considered in the lower 2 cm of the substrate layer. This should inset 40 % of the precipitation, limited to the free water saturation, into the substrate layer during a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

Settings:

- Spread Area: several elements
  start depth in layer: 0.06 m /
  end depth in layer: 0.08 m
- Source Type: Fraction of driving rain
- Fraction: 40 % (User-Defined)
- Cut-Off of the source term at free water saturation



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)
- middle 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®:

- 1 cm grasses
  (material data set: „Optigreen Nature Roof 1 (grasses) 1-5“)
- 10 cm substrate type E
  (material data set: „Optigreen Nature Roof 1 (substrate type E) 2-5“)
- 0.1 cm filter mat
  (material data set: „Optigreen Nature Roof 1 (filter mat) 3-5“)
- 4 cm drainage board
  (material data set: „Optigreen Nature Roof 1 (drainage board) 4-5“)
- 0.1 cm protection mat
  (material data set: „Optigreen Nature Roof 1 (protection mat) 5-5“)

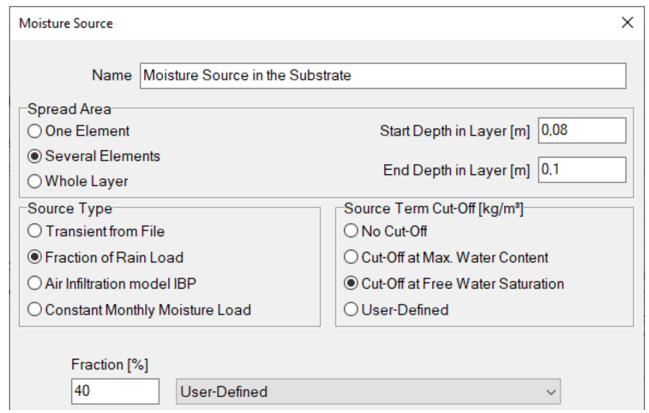
Optigreen-System Nature Roof Solution 1

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 inset 40 % of the precipitation, limited to the free water saturation, into the substrate layer during a rain event.

Settings:

- Spread Area: several elements
  start depth in layer: 0.08 m /
  end depth in layer: 0.1 m
- Source Type: Fraction of driving rain
- Fraction: 40 % (User-Defined)
- Cut-Off of the source term at free water saturation

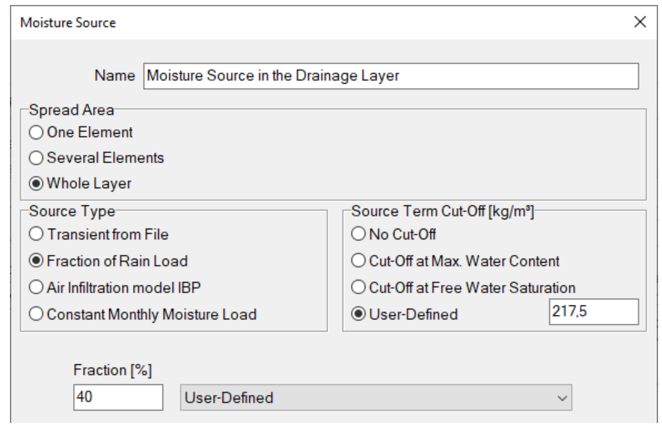


Fraunhofer IBP

Optigreen-System Nature Roof Solution 1

Moisture Source in the Drainage Layer

If a drainage element is present, an additional moisture source is placed in the entire drainage and storage layer with also 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.

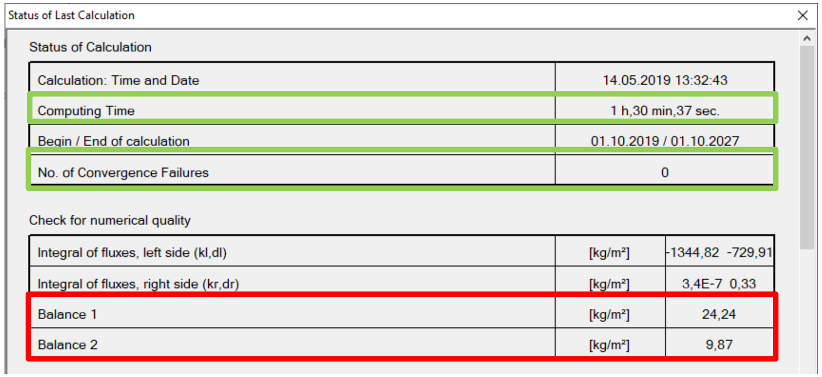


Settings:

- Spread Area: whole layer
- Source Type: Fraction of driving rain
- Fraction: 40 % (User-Defined)
- Limitation of the source value to the maximum filling volume of the drainage element
  (8.7 kg/m²) / (0.04 m) = 217.5 kg/m³

Notes on the Evaluation of Green Roofs

Calculation Quality



Status of Last Calculation

Status of Calculation

Calculation: Time and Date	14.05.2019 13:32:43
Computing Time	1 h,30 min,37 sec.
Begin / End of calculation	01.10.2019 / 01.10.2027
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[kg/m²]	-1344,82 -729,91
Integral of fluxes, right side (kr,dr)	[kg/m²]	3,4E-7 0,33
Balance 1	[kg/m²]	24,24
Balance 2	[kg/m²]	9,87

- Long calculation times are not unusual for green roofs.
- The number of convergence failures should be very low or equal to zero by activating the “Adaptive Time Step Control”.
- In general, the balance differences should remain as small as possible. 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 sublying structure.
- If the water content curves in the layers of the sublying 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 Leitfaden zur Berechnung von Flachdächern (so far only available in German)

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

Example cased described in detail from input to evaluation can be found here:
Example Cases WUFI® Pro: Green Roofs (Optigreen)

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.

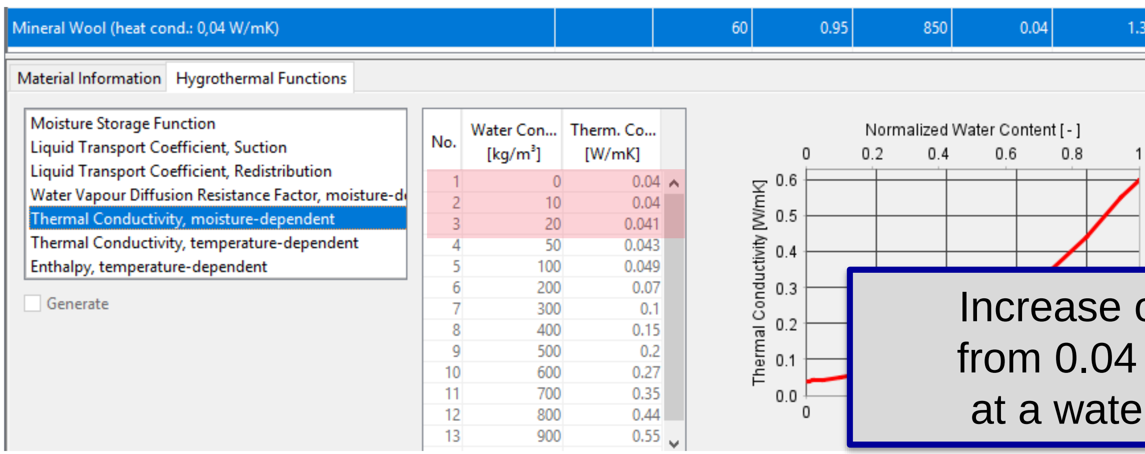
- Moisture leads to an increase in thermal conductivity - but this increase usually remains so small (see next slide) that it appears negligible even for typical service lives of 25 years.
- In rigid-foam insulation, moisture remains in the pore structure of the material - i.e. usually without any further consequences for the material or construction.
- In fiber 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

<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.



No.	Water Con... [kg/m³]	Therm. Co... [W/mK]
1	0	0.04
2	10	0.04
3	20	0.041
4	50	0.043
5	100	0.049
6	200	0.07
7	300	0.1
8	400	0.15
9	500	0.2
10	600	0.27
11	700	0.35
12	800	0.44
13	900	0.55

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 at and check 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 are 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.

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[6] DIN 68800: Wood preservation. Beuth Verlag, Berlin 2012.

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[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. October 2018.

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

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