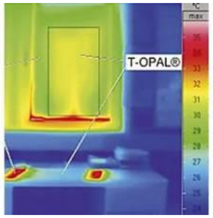
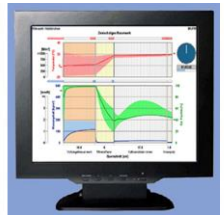
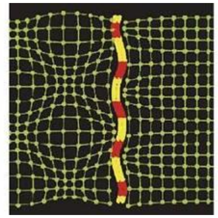




WUFI®

Guideline for the Calculation of extensive Green Roofs (generic)

Version: 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.

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].

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

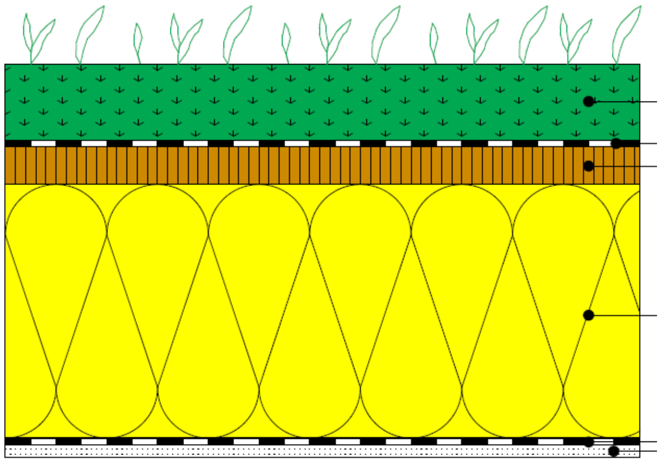
Application of the Generic Green Roof Model

The **generic green roof model** should be used if **no detailed information about the substrate type** or **no measured data for the atmospheric counter radiation** are available.

In this model **the long-wave radiation is considered in a simplified way by the reduced short-wave radiation absorptivity**.

This is acceptable if the radiation conditions are comparable to the one at the examined locations.

Other radiation conditions
(especially due to clearly different clouding)
should be considered by a detailed
calculation of the long-wave radiation losses.



Input: Component Assembly and Grid Setting

Component – Assembly/Monitor Positions

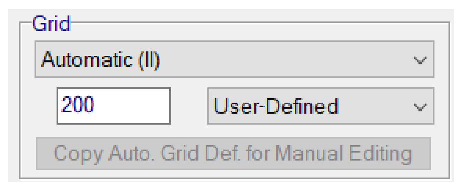
Generic Substrate

The generic substrate is to be applied in the required thickness (up to a maximum of about 15 cm substrate layer thickness).
The material is directly available in the WUFI® - Material Database under *Fraunhofer-IBP* → *Green and Gravel Roofs*.

Underlying Roof Assembly

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

Grid Structure



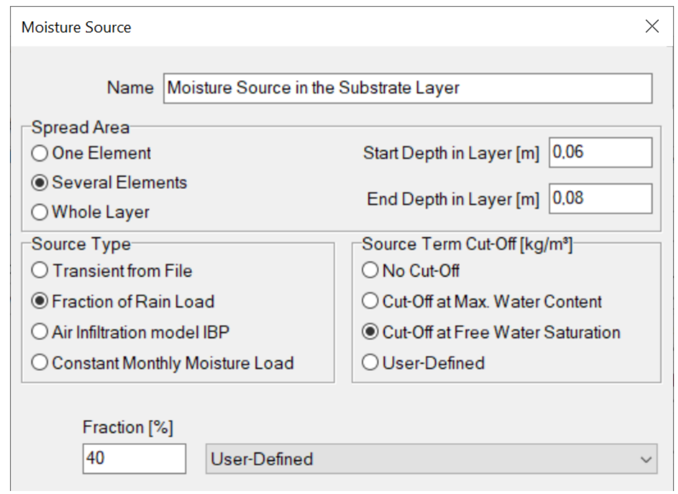
The following grid setting is recommended for green roofs:
Automatic (II) with 200 elements (User-Defined)

Input: Moisture Source in the Substrate

Component - Assembly/Monitor Positions

Moisture Source in the Substrate 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
  example: 8 cm thick substrate layer
  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

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 generic 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 generic green roof model in [1], the long-wave radiation is taken into account in a simplified way by using a reduced short-wave radiation absorptivity.

This is assumed to be a rather low value of 0.3.

Long-Wave Radiation Emissivity

The long-wave radiation emissivity is not applied for generic green roofs. The explicit radiation balance is also not used.

Input: Initial Conditions

Component – Initial Conditions

Initial Temperature und 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 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.

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

Input: Climate

Climate

<u>*Outdoor Climate:*</u>

A climate suitable for the building location should be used. However, locations that contain rain data are necessary for the use of the generic 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.

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.

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

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.

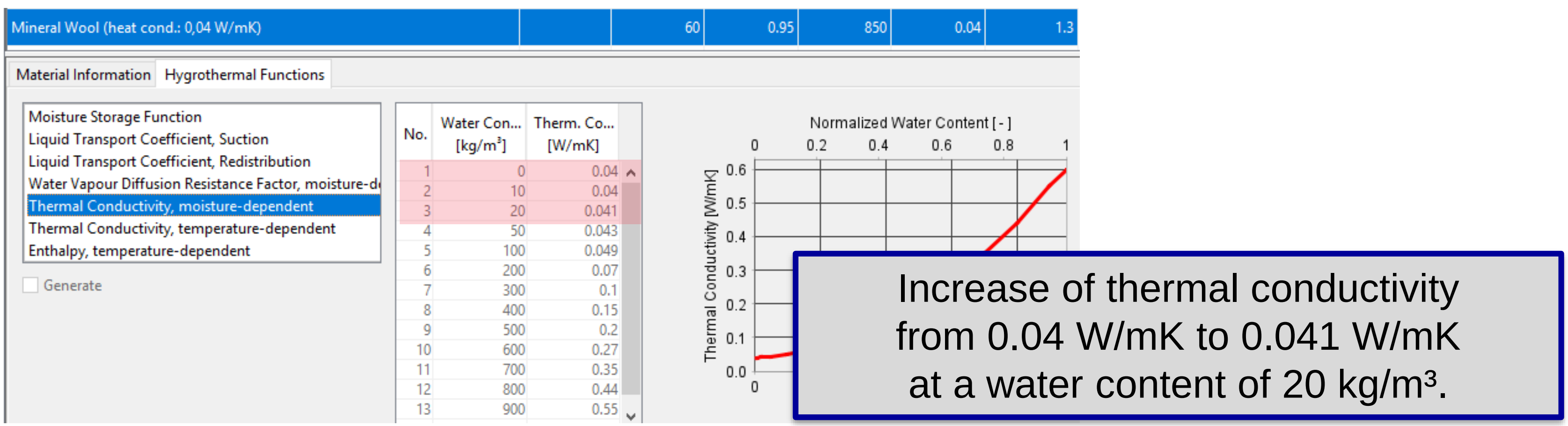
- Moisture leads to an increase in thermal conductivity - but this increase usually remains so small (see next slide) that it appears negligible even for typical service lives of 25 years.
- In rigid-foam insulation, moisture remains in the pore structure of the material - i.e. usually without any further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



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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[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.