

# Guideline for the calculation of extensive green roofs

Date: April 2017

Within the research project

„Ermittlung von Materialeigenschaften und effektiven Übergangsparmetern 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 calculate and plan green roofs – especially on wooden constructions – reliably by the help of the software tool WUFI®.

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

On the basis of the generic model, product-specific approaches for five green roof systems of the company Optigreen 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 already been performed for Holzkirchen and Milan [5].

In the following the procedure as well as the required material data, moisture sources and boundary conditions and also application limits for the developed green roof models are described.

[1] PDF (26,8 MB), Summary, Catalog entry at IRB-Verlag

[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“.

## 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.

### Assembly:

- generic substrate with required thickness

Material directly available in WUFI®

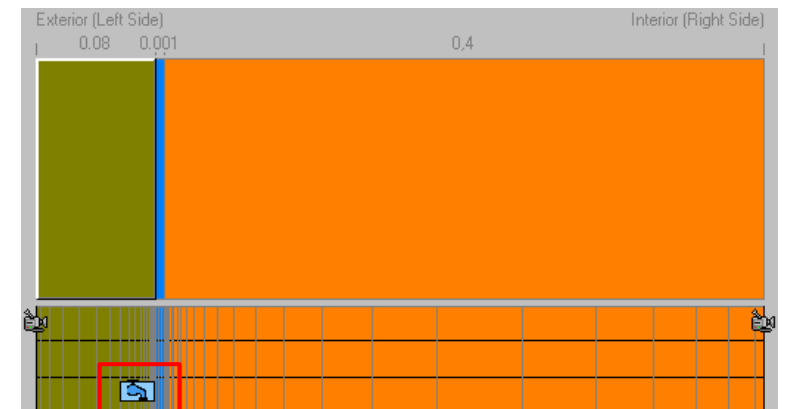
→ Source: Fraunhofer-IBP, Catalog: Green and Gravel Roofs

Note: The models were developed for extensive green roofs with a substrate thickness up to 15 cm.

### Moisture source:

In the lowest 2 cm of the generic substrate:

- spread area: several elements  
*example: 8 cm substrate layer*  
*start depth in layer: 0.06 m / end depth in layer: 0.08 m*
- source type: fraction of diving rain
- fraction: 40 %
- clipping of the source term to the free water saturation



**Moisture Source**

Name: moisture source in the substrate layer

Spread Area

One Element

Several Elements

Whole Layer

Start Depth in Layer [m]: 0.06

End Depth in Layer [m]: 0.08

Source Type

Transient from File

Fraction of Driving Rain

Air Infiltration model IBP

Constant Monthly Moisture Load

Source Term Clipping [kg/m³]

No Clipping

Clipping to max. Water Content

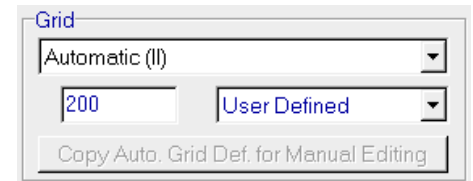
Clipping to Free Water Saturation

User Defined

Fraction [%]: 40

## Suggested grid resolution:

Automatic (II) with 200 elements



Grid

Automatic (II)

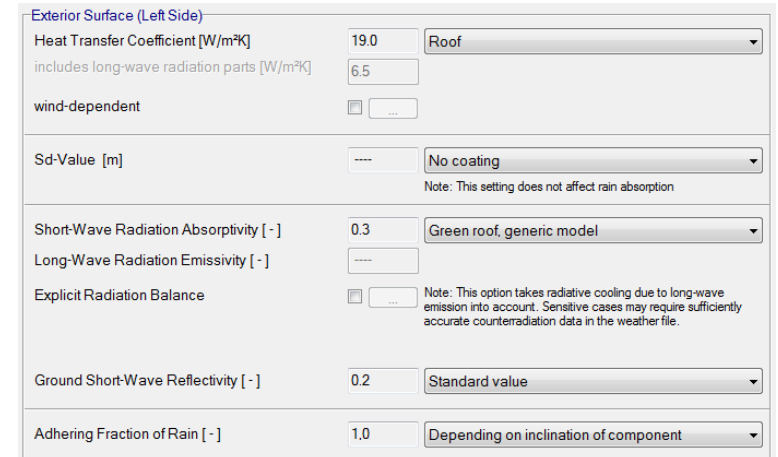
200 User Defined

Copy Auto. Grid Def. for Manual Editing

## Surface transfer parameters on the exterior surface:

- heat transfer coefficient: 19 W/m<sup>2</sup>K  
resp. heat resistance: 0.0526 m<sup>2</sup>K/W  
(depending on the settings in WUFI®)
- short-wave radiation absorptivity:  
Green roof, generic model (a = 0.3)
- explicit radiation balance: not used

Note: After calculation start the warning “Explicit radiation balance disabled but inclination is (e.g.) 2°” appears → this warning can be ignored for the calculation of a green roof with the generic model!



Exterior Surface (Left Side)

Heat Transfer Coefficient [W/m<sup>2</sup>K] 19.0 Roof

includes long-wave radiation parts [W/m<sup>2</sup>K] 6.5

wind-dependent

Sd-Value [m] --- No coating  
Note: This setting does not affect rain absorption

Short-Wave Radiation Absorptivity [-] 0.3 Green roof, generic model

Long-Wave Radiation Emissivity [-] ---

Explicit Radiation Balance  Note: This option takes radiative cooling due to long-wave emission into account. Sensitive cases may require sufficiently accurate counter-radiation data in the weather file.

Ground Short-Wave Reflectivity [-] 0.2 Standard value

Adhering Fraction of Rain [-] 1.0 Depending on inclination of component

## Exterior climate data set:

Required climate data for the calculation with the generic green roof model:

- temperature
- relative humidity of the air
- global radiation (resp. diffuse and direct radiation for pitched roofs)
- precipitation

## 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 already 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 were developed in collaboration with the company.

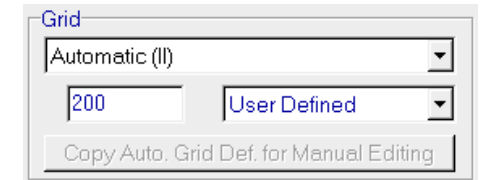
Optigreen-Systems according the product names of the manufacturer:

- Light-weight Roof Solution 1
- Economy Roof Solution 1
- Economy Roof Solution 2
- Pitched Roof 5-45°
- Nature Roof Solution 1

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<sup>®</sup> is explained. Additional information is given in the info-text of each material.

## Suggested grid resolution:

Automatic (II) with 200 elements



Grid

Automatic (II)

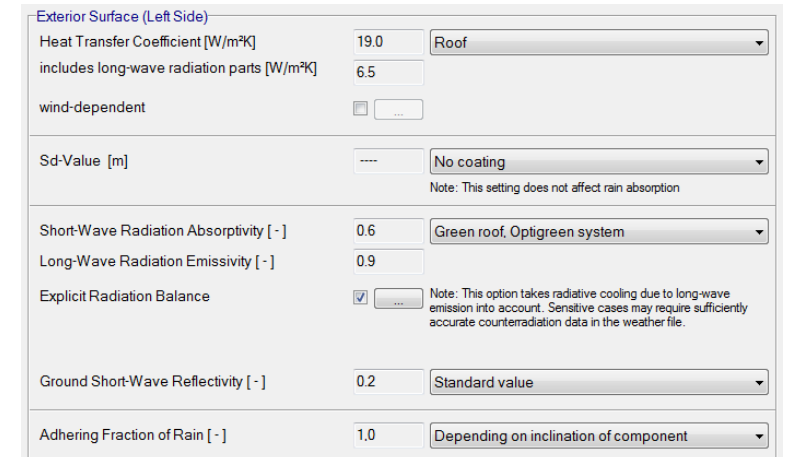
200

User Defined

Copy Auto. Grid Def. for Manual Editing

## Surface transfer parameters on the exterior surface:

- heat transfer coefficient: 19 W/m<sup>2</sup>K  
resp. heat resistance: 0.0526 m<sup>2</sup>K/W  
(depending on the settings in WUFI<sup>®</sup>)
- short-wave radiation absorptivity:  
Green roof, Optigreen system ( $a = 0.6$ )
- long-wave radiation emissivity:  
Green roof, Optigreen system ( $\varepsilon = 0.9$ )
- explicit radiation balance: used



Exterior Surface (Left Side)

Heat Transfer Coefficient [W/m<sup>2</sup>K] 19.0 Roof

includes long-wave radiation parts [W/m<sup>2</sup>K] 6.5

wind-dependent  ...

Sd-Value [m] --- No coating  
Note: This setting does not affect rain absorption

Short-Wave Radiation Absorptivity [-] 0.6 Green roof, Optigreen system

Long-Wave Radiation Emissivity [-] 0.9

Explicit Radiation Balance  ... Note: This option takes radiative cooling due to long-wave emission into account. Sensitive cases may require sufficiently accurate counter-radiation data in the weather file.

Ground Short-Wave Reflectivity [-] 0.2 Standard value

Adhering Fraction of Rain [-] 1.0 Depending on inclination of component

## Exterior climate data set:

Required climate data for the calculation  
with the specific green roof model:

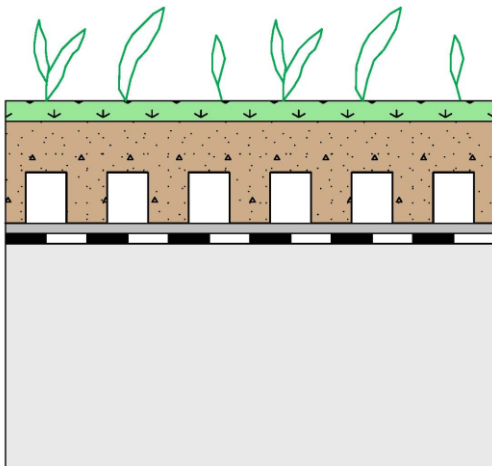
- temperature
- relative humidity of the air
- global radiation (resp. diffuse and direct radiation for pitched roofs)
- atmospheric counter radiation
- precipitation

## 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. 60 mm)
- low weight (approx. 55 kg/m<sup>2</sup>)
- drought-compatible sedum plants (approx. 6-8 species)
- low maintenance (1 time per year)

### System drawing:



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

## Assembly in WUFI®:

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

## Materials directly available in WUFI®

→ Source: Fraunhofer-IBP, Catalog: Green and Gravel Roofs

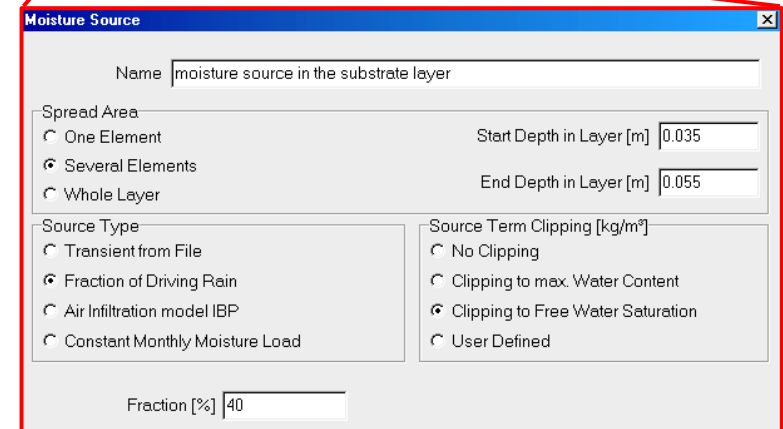
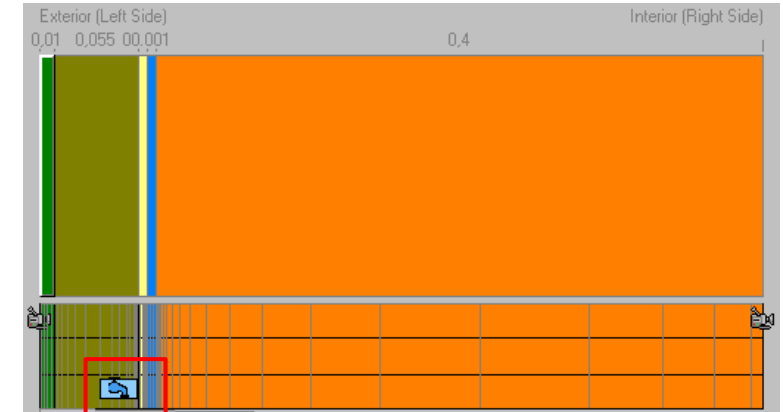
## Note:

The assembly is included into the WUFI “construction-database”.  
To insert click the button “example cases” below the component assembly and choose “Optigreen-System Light-weight Roof Solution 1” in Fraunhofer-IBP source, catalog “Roofs”. After inserting you have to add the substructure to your roof assembly. Before calculation you also need to set the boundary conditions and the moisture source according to this guideline.

## Moisture source:

In the lowest 2 cm of the layer „substrate type L incl. FKD“

- spread area: several elements  
*start depth in layer: 0.035 m / end depth in layer: 0.055 m*
- source type: fraction of diving rain
- fraction: 40 %
- clipping of the source term to the free water saturation

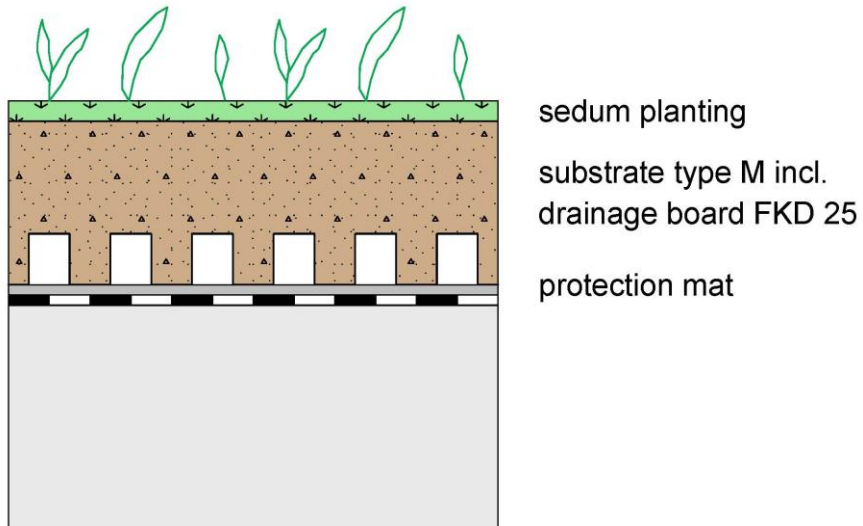


## Optigreen-System Economy Roof Solution 1:

### Description according to the manufacturer:

- double layer, extensive roof greening (from 0-5° roof pitch)
- low layer height (approx. 85 mm)
- low weight (approx. 95 kg/m<sup>2</sup>)
- drought-compatible sedum plants (approx. 6-8 species)
- low maintenance (1 - 2 times per year)

### System drawing:





## Assembly in WUFI®:

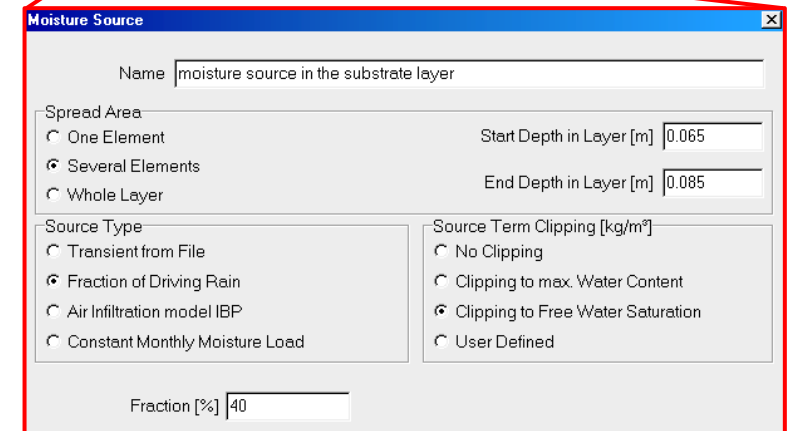
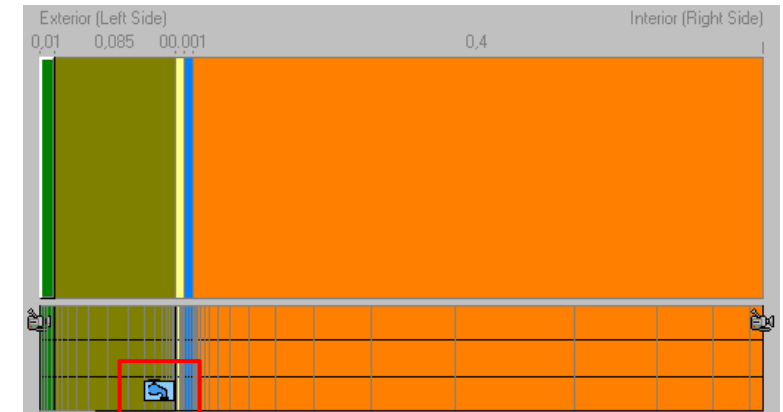
- 1 cm sedum planting  
(material data set: „Optigreen Economy Roof 1 (sedum planting) 1-3.xml“)
- 8.5 cm substrate type M incl. FKD  
(material data set: „Optigreen Economy Roof 1 (substrate type M incl. FKD) 2-3.xml“)
- 0.4 cm protection mat  
(material data set: „Optigreen Economy Roof 1 (protection mat) 3-3.xml“)

Materials directly available in WUFI®

→ Source: Fraunhofer-IBP, Catalog: Green and Gravel Roofs

## Note:

The assembly is included into the WUFI “construction-database”.  
To insert click the button “example cases” below the component assembly and choose “Optigreen-System Economy Roof Solution 1” in Fraunhofer-IBP source, catalog “Roofs”. After inserting you have to add the substructure to your roof assembly. Before calculation you also need to set the boundary conditions and the moisture source according to this guideline.



## Moisture source:

In the lowest 2 cm of the layer „substrate type M incl. FKD“

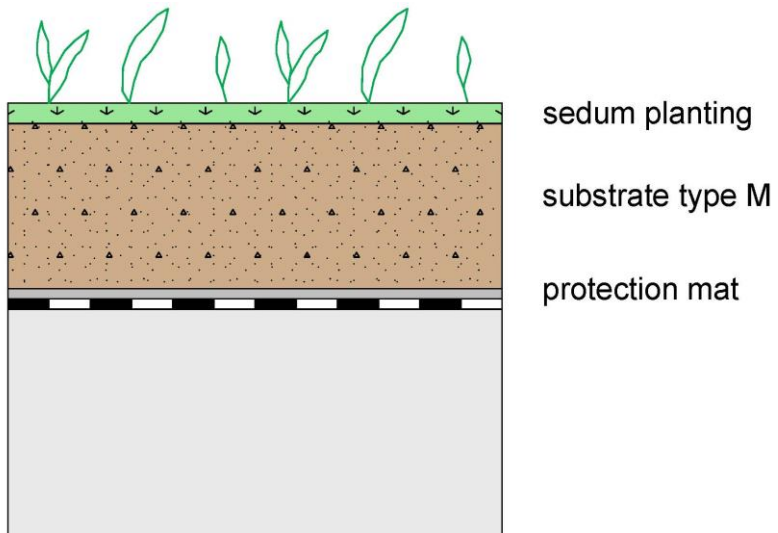
- spread area: several elements  
*start depth in layer: 0.065 m / end depth in layer: 0.085 m*
- source type: fraction of diving rain
- fraction: 40 %
- clipping of the source term to the free water saturation

## Optigrün-System Economy Roof Solution 2:

### Description according to the manufacturer:

- single layer, extensive roof greening (from 0-5° roof pitch)
- low layer height (approx. 80 mm)
- low weight (approx. 100 kg/m<sup>2</sup>)
- drought-compatible sedum plants (approx. 6-8 species)
- low maintenance (1 - 2 times per year)

### System drawing:



## Assembly in WUFI®:

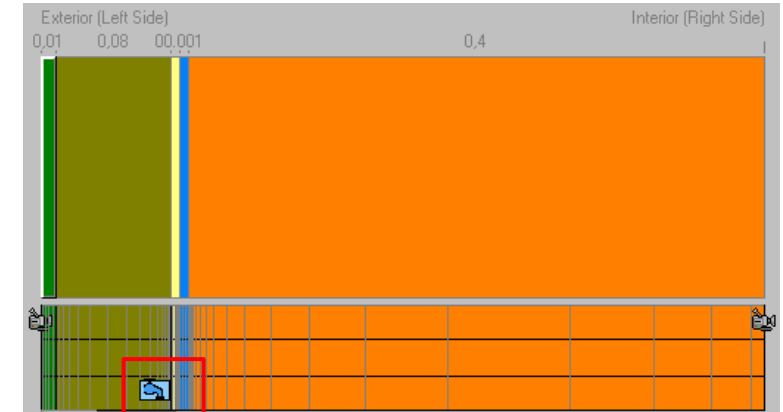
- 1 cm sedum planting  
(material data set: „Optigreen Economy Roof 2 (sedum planting) 1-3.xml“)
- 8 cm substrate type M  
(material data set: „Optigreen Economy Roof 2 (substrate type M) 2-3.xml“)
- 0.4 cm protection mat  
(material data set: „Optigreen Economy Roof 2 (protection mat) 3-3.xml“)

Materials directly available in WUFI®

→ Source: Fraunhofer-IBP, Catalog: Green and Gravel Roofs

## Note:

The assembly is included into the WUFI “construction-database”.  
To insert click the button “example cases” below the component assembly and choose “Optigrün-System Economy Roof Solution 2” in Fraunhofer-IBP source, catalog “Roofs”. After inserting you have to add the substructure to your roof assembly. Before calculation you also need to set the boundary conditions and the moisture source according to this guideline.



**Moisture Source**

Name: moisture source in the substrate layer

Spread Area

One Element Start Depth in Layer [m] 0.06

Several Elements End Depth in Layer [m] 0.08

Whole Layer

Source Type

Transient from File

Fraction of Driving Rain

Air Infiltration model IBP

Constant Monthly Moisture Load

Source Term Clipping [kg/m³]

No Clipping

Clipping to max. Water Content

Clipping to Free Water Saturation

User Defined

Fraction [%] 40

## Moisture source:

In the lowest 2 cm of the layer „substrate type M“

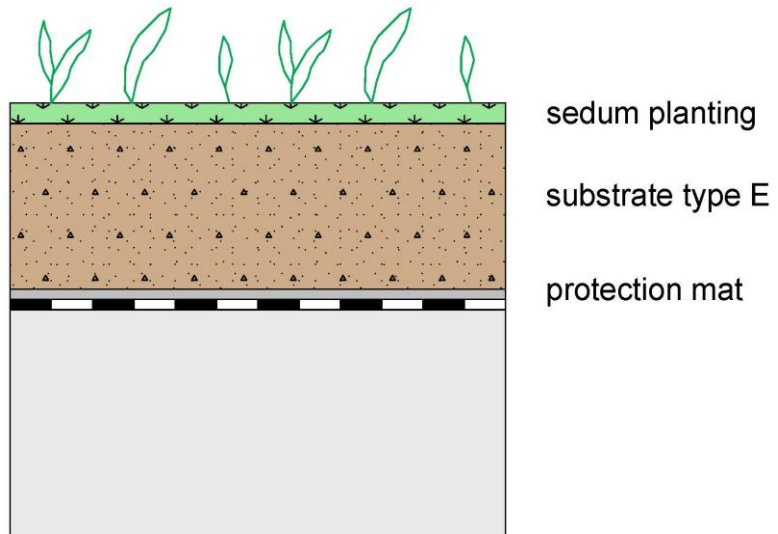
- spread area: several elements  
*start depth in layer: 0.06 m / end depth in layer: 0.08 m*
- source type: fraction of diving rain
- fraction: 40 %
- clipping of the source term to the free water saturation

## Optigreen-System Pitched Roof 5-45°:

### Description according to the manufacturer:

- double layer, extensive pitched roof greening (from 5-45° roof pitch)
- low layer height (approx. 90 mm)
- low weight (approx. 110 kg/m<sup>2</sup>)
- drought-compatible sedum plants (approx. 6-8 species)
- low maintenance (1 time per year)

### System drawing:



## Assembly in WUFI®:

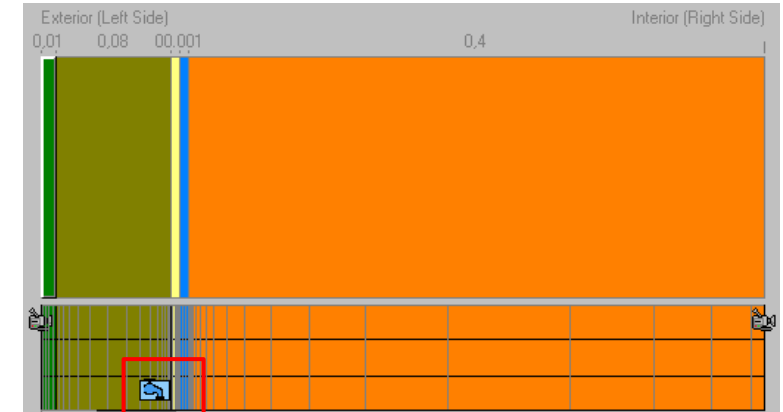
- 1 cm sedum planting  
(material data set: „Optigreen Pitched Roof 5-45° (sedum planting) 1-3.xml“)
- 8 cm substrate type E  
(material data set: „Optigreen Pitched Roof 5-45° (substrate type E) 2-3.xml“)
- 0.4 cm protection mat  
(material data set: „Optigreen Pitched Roof 5-45° (protection mat) 3-3.xml“)

Materials directly available in WUFI®

→ Source: Fraunhofer-IBP, Catalog: Green and Gravel Roofs

## Note:

The assembly is included into the WUFI “construction-database”. To insert click the button “example cases” below the component assembly and choose “Optigreen-System Pitched Roof 5-45°” in Fraunhofer-IBP source, catalog “Roofs”. After inserting you have to add the substructure to your roof assembly. Before calculation you also need to set the boundary conditions and the moisture source according to this guideline.



**Moisture Source**

Name: moisture source in the substrate layer

Spread Area

One Element      Start Depth in Layer [m] 0.06

Several Elements      End Depth in Layer [m] 0.08

Whole Layer

Source Type

Transient from File

Fraction of Driving Rain

Air Infiltration model IBP

Constant Monthly Moisture Load

Source Term Clipping [kg/m³]

No Clipping

Clipping to max. Water Content

Clipping to Free Water Saturation

User Defined

Fraction [%] 40

## Moisture source:

In the lowest 2 cm of the layer „substrate type E“

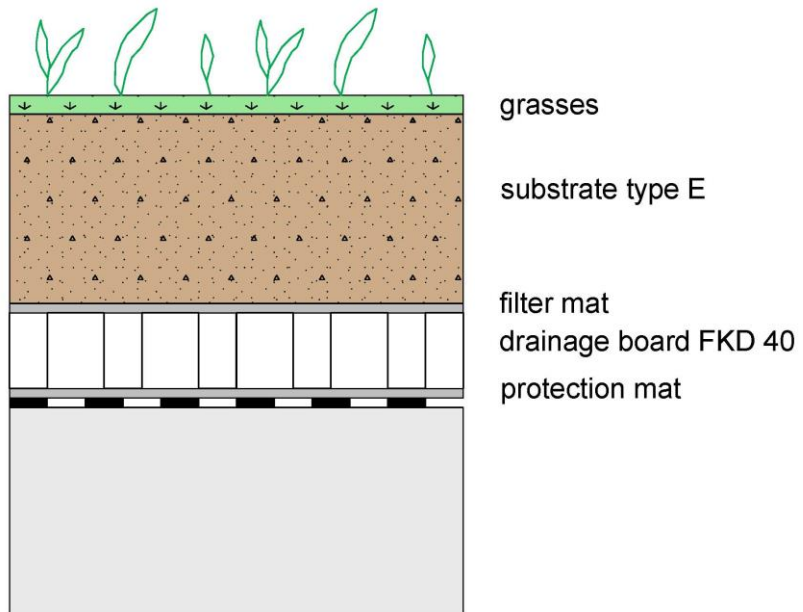
- spread area: several elements  
*start depth in layer: 0.06 m / end depth in layer: 0.08 m*
- source type: fraction of diving rain
- fraction: 40 %
- clipping of the source term to the free water saturation

## 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. 100 mm)
- middle weight (approx. 120 kg/m<sup>2</sup>)
- drought-compatible sedum plants, grasses, herbs (approx. 25 species)
- medium maintenance (2 - 3 times per year)

### System drawing:



## Assembly in WUFI®:

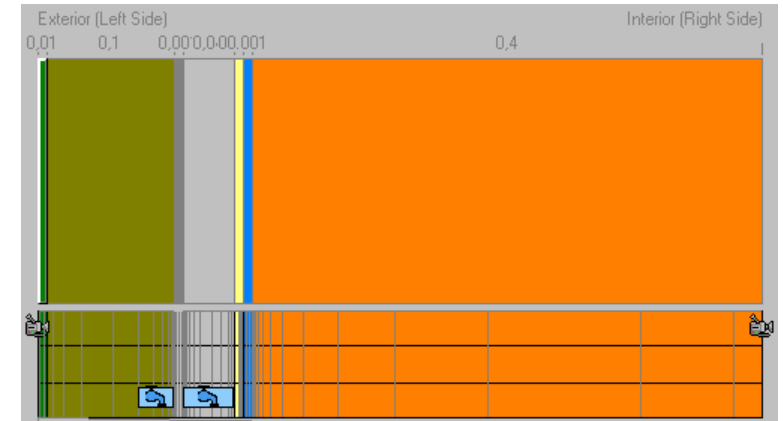
- 1 cm grasses  
(material data set: „Optigreen Nature Roof 1 (grasses) 1-5.xml“)
- 10 cm substrate type E  
(material data set: „Optigreen Nature Roof 1 (substrate type E) 2-5.xml“)
- 0.1 cm filter mat  
(material data set: „Optigreen Nature Roof 1 (filter mat) 3-5.xml“)
- 4 cm drainage board  
(material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

Materials directly available in WUFI®

→ Source: Fraunhofer-IBP, Catalog: Green and Gravel Roofs

### Note:

The assembly is included into the WUFI “construction-database”.  
To insert click the button “example cases” below the component assembly and choose “Optigreen-System Nature Roof Solution 1” in Fraunhofer-IBP source, catalog “Roofs”. After inserting you have to add the substructure to your roof assembly. Before calculation you also need to set the boundary conditions and the moisture source according to this guideline.



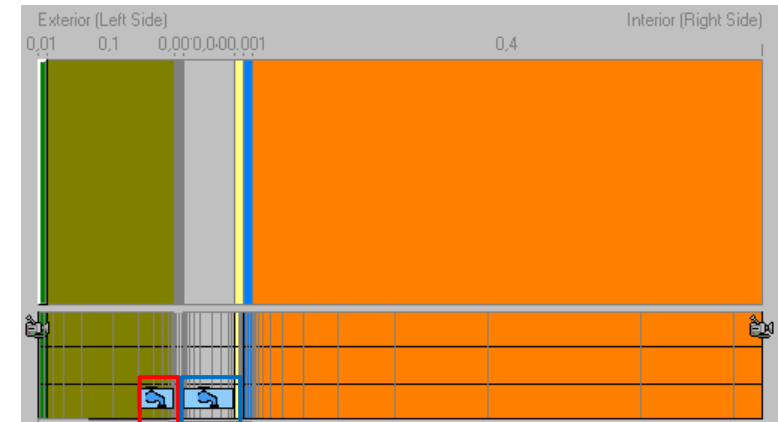
## Moisture source:

In the lowest 2 cm of the layer „substrate type E“

- spread area: several elements  
*start depth in layer: 0.08 m / end depth in layer: 0.1 m*
- source type: fraction of diving rain
- fraction: 40 %
- clipping of the source term to the free water saturation

In the whole layer „drainage board“

- spread area: whole layer
- source type: fraction of diving rain
- fraction: 40 %
- clipping of the source term to the maximal filling volume of the drainage board ( $(8.7 \text{ kg/m}^2) / (0.04 \text{ m}) = 217.5 \text{ kg/m}^3$ )



**Moisture Source**

Name: moisture source in the substrate layer

Spread Area:  
 One Element  
 Several Elements  
 Whole Layer

Start Depth in Layer [m]: 0.08  
End Depth in Layer [m]: 0.1

Source Type:  
 Transient from File  
 Fraction of Driving Rain  
 Air Infiltration model IBP  
 Constant Monthly Moisture Load

Source Term Clipping [kg/m<sup>3</sup>]:  
 No Clipping  
 Clipping to max. Water Content  
 Clipping to Free Water Saturation  
 User Defined

Fraction [%]: 40

**Moisture Source**

Name: moisture source in the drainage board

Spread Area:  
 One Element  
 Several Elements  
 Whole Layer

Source Type:  
 Transient from File  
 Fraction of Driving Rain  
 Air Infiltration model IBP  
 Constant Monthly Moisture Load

Source Term Clipping [kg/m<sup>3</sup>]:  
 No Clipping  
 Clipping to max. Water Content  
 Clipping to Free Water Saturation  
 User Defined 217.5

Fraction [%]: 40