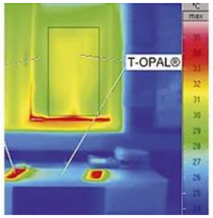
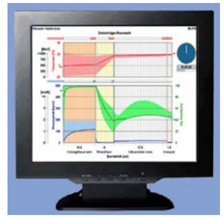
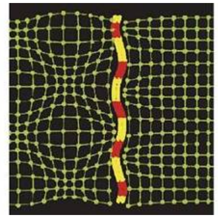




WUFI®

Guideline for the Calculation of Gravel Roofs

Version: July 2021

Fraunhofer
IBP

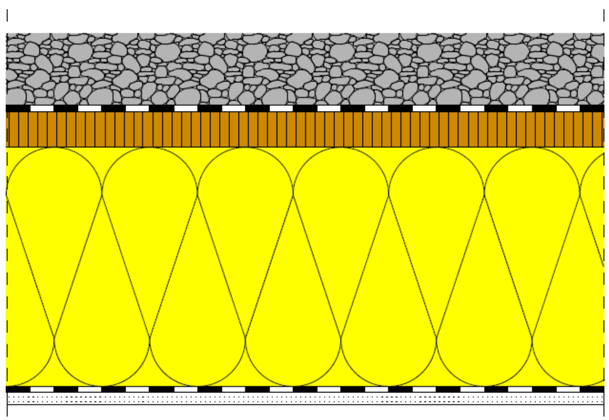
Content

Gravel Roof Material Data in the WUFI® - Material Database

„Generic Gravel“

The **hygrothermal material properties** of a gravel layer have been **adapted by recalculations of field tests and measurements** which were performed on gravel roofs in Holzkirchen, Gräfelfing (both Southern Germany) and Milan (Italy).

In the gravel layer there is **no capillary transport** – the **rainwater** which runs through the gravel layer **has to be modelled by a moisture source**. The moisture source is spread over the whole layer with the exception of the outermost element – by adding the moisture source in the outermost element numerical problems and differences in the balances may be caused.



Modelling: Component Assembly und Grid Setting

Component – Assembly/Monitor Positions

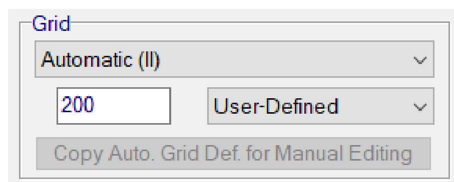
Generic Gravel Layer

The generic gravel layer has to be applied in the required 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 structure in the simulation (eg. insulated cavity) axis.

Grid Structure



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

Modelling: Moisture Source in the Gravel

Component - Assembly/Monitor Positions

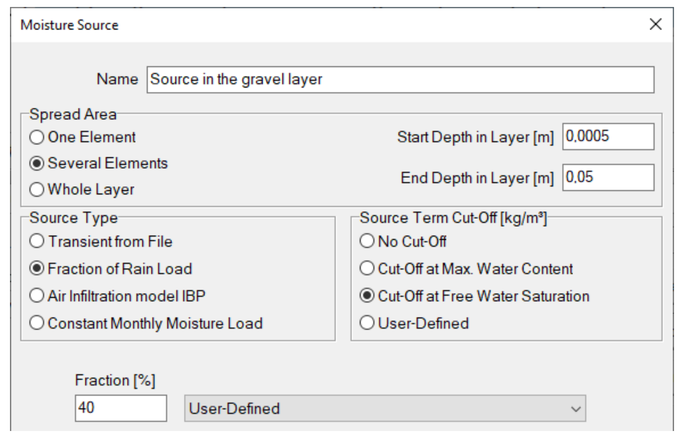
Moisture Source in the Gravel Layer

To account for rainwater flowing through the gravel layer, a moisture source is applied throughout the whole layer except for the outermost element.

Note: By adding the moisture source in the outermost element numerical problems and differences in the balances can be caused.

Source Settings:

- Spread Area: several elements
  example: 5 cm thick gravel layer
  start depth in layer: 0,0005 m /
  end depth in layer: 0,05 m
- Source Type: Fraction of driving rain
- Fraction: 40 % (User-Defined)
- Cut-Off of the source term at free water saturation



Component - Assembly/Monitor Positions

Moisture Source - Infiltration (only for wooden structures)

According to DIN 68800 [2], the amount of moisture that convectively enters the construction as a function of the air tightness must always be assessed for wooden structures and can be taken into account in the simulation using the infiltration model of the IBP.

The moisture source must be placed in the component assembly at the position where the condensation water will occur 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

Modelling: Infiltration Source

Component - Assembly/Monitor Positions

Moisture Source - Infiltration (only for wooden structures)

The amount of moisture entered during cold periods 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 [2].

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

Modelling: Orientation / Inclination

Component - Orientation

Orientation

The relevant orientation for the Northern hemisphere is usually North, as here the lowest radiation gains occur. However, the orientation is only of minor importance for very low roof pitches.

Roof Inclination

The inclination of the roof must be specified according to the planned roof inclination.

Modelling: Surface Transfer Coefficients

Component – Surface Transfer Coefficients

Heat Transfer Coefficient

Exterior Surface

The heat transfer coefficient at the exterior surface of gravel roofs is assumed to be 19 W/m²K.

Interior Surface

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

Modelling: Surface Transfer Coefficients

Component – Surface Transfer Coefficients

Short-Wave Radiation Absorptivity

The short-wave radiation absorptivity for medium grey gravel is 0.5 (based on recalculations of field tests on gravel roofs).

Long-Wave Radiation Emissivity

The long-wave radiation emissivity for gravel roofs is 0.93 (based on recalculations of field tests on gravel roofs).

For roofs, the explicit radiation balance must always be switched on due to the large field of view to the sky, in order to take into account the overcooling due to long-wave radiation.

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.

Control

Calculation Period / Profiles:

It is recommended to start the calculation on October 1, because the component usually moistens up further in the following winter months before drying out possibly starts in spring. This start date is therefore usually an extra stressing of the component.

The calculation time depends the time the construction needs to reach steady state conditions. Usually a calculation time of 5 years is sufficient.

Numerics:

For numerics the default settings can be used.

Climate

Outdoor Climate:

A climate appropriate for the building location should be used. For the application of the gravel roof model, climate data containing long-wave radiation and rain data are furthermore necessary.

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

Modelling: Climate

Climate

Indoor Climate:

By default, we recommend the indoor climate with medium moisture load + 5% according to DIN 4103-3 Appendix D [3] and WTA Guideline 6-2 [5] for the design.

Alternatively, depending on the use of the building, the indoor climate according to EN 15026 [6] with medium or high moisture load or other conditions applicable to the building as well as constant or measured conditions can be applied.

Notes on the Evaluation of Gravel Roofs

Calculation Quality

Status of Last Calculation

Status of Calculation

Calculation: Time and Date	05.05.2021 10:14:01
Computing Time	6 min,57 sec.
Begin / End of calculation	01.10.2021 / 01.10.2031
No. of Convergence Failures	154

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[kg/m²]	0,0 -1112,94
Integral of fluxes, right side (kr,dr)	[kg/m²]	3,5E-7 0,47
Balance 1	[kg/m²]	2,79
Balance 2	[kg/m²]	2,79

- The differences in the balances should remain as small as possible.

- Ideally, the number of convergence failures should also remain small.
  In the case of gravel roofs, however, a higher number of convergence failures may occur due to the large amounts of moisture in the gravel roof structure (driving rain source).

- If the water content curves in the layers of the underlay construction do not show any abnormalities (e.g. abrupt jumps, peaks...), the results are usually acceptable.

Notes on the Evaluation of Gravel Roofs

Gravelled 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: Gravel Roofs

Notes on the Evaluation of Gravel 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.

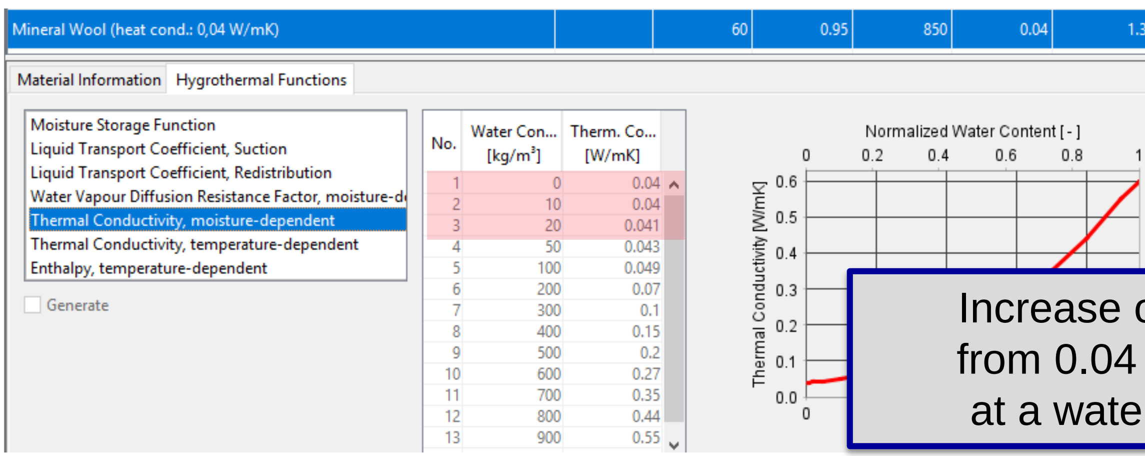
- Moisture leads to an increase in thermal conductivity - but this increase usually remains so small (see next slide) that it appears negligible even for typical service lives of 25 years.
- In rigid-foam insulation, moisture remains in the pore structure of the material - i.e. usually without any further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

Notes on the Evaluation of Gravel 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.

Literature

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

[2] 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.

[3] 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.

[4] Research Report: Energieoptimiertes Bauen: Klima- und Oberflächenübergangsbedingungen für die hygrothermische Bauteilsimulation. IBP-Bericht HTB-021/2016. Carried out on behalf of Project Management Jülich (PTJ UMW). July 2016.

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

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