Handling of typical constructions

WUFI® Tutorial
Version: April 2018
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Flat roof (slide 3 ff.)
Pitched roof (slide 11 ff.)
Exterior wall with ETICS (slide 20 ff.)
Exterior wall with interior insulation (slide 28 ff.)
Ventilated timber frame construction (slide 42 ff.)
Basement wall without ground water (slide 54 ff.)
Flat roof

Construction drawing

1 Roofing membrane
2 Exterior insulation
3 Vapor retarder
4 Wooden sheathing
5 Insulation
6 Rafter
7 Vapor retarder
8 Installation layer
9 Gypsum board
10 Simulated cross-section

Construction in WUFI
Flat roof

Please note

- Insert an air infiltration source at the cold side of the construction (at the position where condensation would occur) → source strength depending on the air tightness and height of the connected air column
- Orientation/ Inclination according to planning
- Heat transfer resistance „roof“
- Roofing membrane can be taken in account by using an $s_d$-value on the outer surface (numerical more favorable)
  → if doing so, use no roofing membrane in the construction setup
  → rain water absorption then has to be set to zero („adhering fraction of rain”)
- Short wave radiation absorptivity depending on color of roof surface
- Long wave emissivity depending on the material of the surface
- Switch explicit radiation balance on
Flat roof

Moisture source setup

1. Select layer*

2. Select „Sources, Sinks“

*) Material in which the condensate is expected due to convection which can not be simulated in a 1D program. The infiltration source is either in the inner 5 mm of the wooden sheathing or – if there is no sheathing – in the outer 5 mm of the insulation between the rafters.
Flat roof

Moisture source setup

3. Select „New Moisture Source“
Flat roof

Moisture source setup

- Air Infiltration Model
Flat roof

Result analysis*

- Check total water content (accumulation of moisture in whole construction); must not keep increasing
- Check water content in wooden sheathing
- In a construction without wood-based or moisture sensitive materials:
  Examination of amount of dew water (max. 500 g/m² / 200 g/m² according to DIN 4108 / EN ISO 13788 which equals max. 50 kg/m³ / 20 kg/m³ in outer centimeter of insulation)

  Further check influence of moisture content on the thermal conductivity in the material data table „thermal conductivity, moisture-dependent“

- You may check moisture accumulation in the exterior insulation

*) Note: List not necessarily complete. Depending on boundary conditions additional critical positions may occur → Check in film display
Flat roof

Additional information

- Be careful with bright roofing membranes, the drying potential of the construction is greatly reduced.

- Shading / green roof can be treated by using more elaborate models (more information in the paper Verschattung von Holzflachdächern (only German) and in Guideline for the calculation of extensive green roofs).

- In case of modeling the roofing membrane as $s_d$-value on the exterior surface, this only models the vapor-retarding property of the membrane, not its rain-tightness → don't forget to switch off rain!

- Considering an insulated roof with rafters, usually the cross section through the insulation is relevant.

- Metal roof: Metal layer is taken into account as $sd$-value at the exterior surface, absorptivity and emissivity according to material
  - unsealed seams: effective $sd$-value around 25 m – 75 m
  - sealed seams: effective $sd$-value > 300 m
Content

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Ventilated timber frame construction (slide 42 ff.)

Basement wall without ground water (slide 54 ff.)
Pitched roof

Construction drawing

1. Roofing tiles and battens
2. Weather-protecting membrane
3. Wooden sheathing
4. Insulation
5. Vapor retarder
6. Installation layer
7. Gypsum board

Construction in WUFI
Pitched roof

Please note

- Insert an air infiltration source at the cold side of the construction (at the position where condensation would occur) → source strength depending on the air tightness and height of the connected air column

- Relevant orientation: usually north

- Ventilated roofing is omitted for the calculation → rain water absorption has to be set to zero ("adhering fraction of rain")

- Weather-protection layer can be taken into account by using an $s_d$-value on the outer surface (selectable in the surface transfer coefficient dialog, numerical more favorable) → if doing so use no roofing membrane in the construction setup
Pitched roof

Please note

- Heat transfer coefficients according to table on slide 14 from “Hygrothermal Simulation of ventilated pitched roofs”, value for the long-wave radiation parts is 0 W/m²K.
- Short-wave radiation absorptivity depending on color of roofing tiles, if applicable reduction according to table on slide 14
- Long-wave radiation emissivity depending on the material of roofing tiles
- Switch on explicit radiation balance
### Pitched roof

**Please note**

<table>
<thead>
<tr>
<th></th>
<th>Eaves Position (coldest)</th>
<th>Middle Position</th>
<th>Ridge Position (warmest)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strong ventilation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$a_{k,e} = 30 ,[\text{W/m}^2\text{K}]$</td>
<td>$a_e = a \cdot 0.7$</td>
<td>$a_e = a \cdot 0.9$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a_e = a \cdot 0.7$</td>
<td>$a_e = a$</td>
</tr>
<tr>
<td><strong>Normal ventilation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$a_{k,e} = 19 ,[\text{W/m}^2\text{K}]$</td>
<td>$a_e = a \cdot 0.7$</td>
<td>$a_e = a \cdot 0.9$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a_e = a \cdot 0.7$</td>
<td>$a_e = a$</td>
</tr>
<tr>
<td><strong>Low ventilation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$a_{k,e} = 13.5 ,[\text{W/m}^2\text{K}]$</td>
<td>$a_e = a \cdot 0.75$</td>
<td>$a_e = a \cdot 0.9$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a_e = a \cdot 0.75$</td>
<td>$a_e = a$</td>
</tr>
</tbody>
</table>

with $a_{k,e}$: convective heat transfer coefficient and $a_e$: effective short-wave coefficient of absorption

<table>
<thead>
<tr>
<th>Ventilation Type</th>
<th>Eaves Openings</th>
<th>Ridge Openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly ventilated</td>
<td>Eaves open without any grid etc.</td>
<td>Ridge open with a low flow resistance</td>
</tr>
<tr>
<td>Normal ventilated</td>
<td>Eaves openings with insect protection grid or eave comb</td>
<td>Ridge closed with ridge / arris role</td>
</tr>
<tr>
<td>Low ventilated</td>
<td>Small openings at the eaves</td>
<td>Small openings at the ridge</td>
</tr>
</tbody>
</table>
Pitched roof

Moisture source setup

- Air Infiltration Model

For procedure see „flat roof“
Pitched roof

Surface Transfer setup

- **Heat transfer coefficient „User Defined“**: Here: 19 W/m²K for normal ventilation
- **Long-wave radiation parts**: 0 W/m²K
- **$s_d$-value of the weather-protection layer**: Here: $s_d = 20$ cm
- **Color of roofing tiles**: Here: red tiles ($a = 0.67$)
  - Eaves position ($a_e = a \cdot 0.7 = 0.47$)
- **Switch on explicit radiation balance**

**Assembly/Monitor Positions**

**Exterior Surface (Left Side)**
- Heat Transfer Coefficient [W/m²K]: 19 (User Defined)
- Includes long-wave radiation parts [W/m²K]: 0
- Wind-dependent: 
- Sd-Value [m]: 0.2 (Benutzerdefiniert)
- Short-Wave Radiation Absorptivity [-]: 0.47 (User Defined)
- Long-Wave Radiation Emissivity [-]: 0.9 (User Defined)
- Explicit Radiation Balance: On

**Ground Short-Wave Reflectivity [-]**: 0.20 (Standard value)

**Interior Surface (Right Side)**
- Heat Transfer Coefficient [W/m²K]: 3 (User Defined)
- Sd-Value [m]: 

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Pitched roof

Result analysis*

- Check total water content (accumulation of moisture in whole construction); must not keep increasing
- Check water content in wooden sheathing
- In a construction without wood-based or moisture sensitive materials:
  Examination of amount of dew water (max. 500 g/m² / 200 g/m² according to DIN 4108 / EN ISO 13788 which equals max. 50 kg/m³ / 20 kg/m³ in outer centimeter of insulation)

  Further check influence of moisture content on the thermal conductivity in the material data table „thermal conductivity, moisture-dependent“

*) Note: List not necessarily complete. Depending on boundary conditions additional critical positions may occur → Check in film display
Pitched roof

Additional information

- Heat transfer coefficient according to the latest research results by Kölsch ([Hygrothermal Simulation of ventilated pitched roofs](#))

- In case of modeling the roofing membrane as $s_d$-value on the exterior surface, this only models the vapor-retarding property of the membrane, not its rain-tightness → don't forget to switch off rain!

- Metal roof: Metal layer is taken into account as $s_d$-value at the exterior surface, absorptivity and emissivity according to material
  - unsealed seams: effective $s_d$-value around 25 m – 75 m
  - sealed seams: effective $s_d$-value > 300 m
Content

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Exterior wall with ETICS

Construction drawing

1 Exterior plaster
2 Insulation
3 Plaster
4 Masonry / concrete
5 Interior plaster

Construction in WUFI

Exterior side
Interior side
Exterior wall with ETICS

Please note

- Moisture source behind ETICS: 1 % of driving rain
- Relevant orientations: Prevailing direction of driving rain and north
- Short wave radiation absorptivity depending on color of exterior plaster
- Long wave radiation emissivity for plaster (if not known: 0.9)
- If the short-term hygrothermal behavior of the outer surface is to be evaluated (e.g. dew position), turn on explicit radiation balance
- “Adhering Fraction of Rain” according to inclination and construction type (vertical wall: 0.7)
Exterior wall with ETICS

Moisture source setup

1. Select layer*

2. Select „Sources, Sinks“

*) Driving Rain source is inserted in the outer 5 mm of the layer behind the insulation.
Exterior wall with ETICS

Moisture source setup

3. Select „New Moisture Source“
Exterior wall with ETICS

Moisture source setup

- Fraction of driving rain
Exterior wall with ETICS

Result analysis*

- Check total water content (accumulation of moisture in whole construction); must not keep increasing
- Check water content in the insulation → Possible reduction of insulating capability
- Relative humidity at the interface between exterior plaster and insulation during winter time → risk of frost damage
- At warm and humid sites check relative humidity between insulation and wall (dew water and failure of adhesive may occur)

*) Note: List not necessarily complete. Depending on boundary conditions more critical positions may occur => Check in film display
Exterior wall with ETICS

Additional information

- The prevailing direction of driving rain can be found by using the Climate Analysis dialog (usually west in Middle Europe)

- The moisture source of 1% of the driving rain behind the ETICS is regulated in the ASHRAE Standard 160 and represents critical positions e.g. in the area of window frames
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Exterior wall with interior insulation

Construction drawing

1. Facing brickwork
2. Interior plaster or adhesive
3. Interior insulation
4. Vapor retarder
5. Gypsum board

Construction in WUFI

Exterior side

Interior side
Exterior wall with interior insulation

Please note

- Relevant orientations: Prevailing direction of driving rain and north
- Short-wave radiation absorptivity depending on color of exterior surface
- Long-wave radiation emissivity for exterior surface (if not known: 0.9)
- Explicit radiation balance usually not necessary
- “Adhering fraction of rain” according to inclination and construction type (vertical wall: 0.7)
- If needed: Water-repellent treatment of the exterior surface to reduce rain water absorption
Exterior wall with interior insulation

Water-repellent treatment of façades

Modification of the A-value without influencing other material properties (e.g. $s_d$-value)

Step by step:

1) Split the exterior layer into a surface layer (0.5 – 1.0 cm depending on penetration depth of treatment) and the remaining layer. To do this, duplicate the original layer and then adjust the two thicknesses as needed.

2) Edit the material properties of the new exterior layer:
   - Unlock the material
   - For materials with a default moisture storage function:
     switch “Moisture Storage Function” to “Approximate”
   - Switch “Liquid Transport Coefficients” for suction and redistribution to “generate”
   - Adjust “Water absorption coefficient”

Be careful with the units: $[\text{kg/m}^2\sqrt{\text{s}}]$ is the A-value in $[\text{kg/m}^2\sqrt{\text{h}}]$ divided by 60 !!!
Exterior wall with interior insulation

Water-repellent treatment of façades

1. Select exterior layer
2. Duplicate layer
Exterior wall with interior insulation

Water-repellent treatment of façades

3. Select exterior layer

4. Reduce thickness e.g. 0.01 m
Exterior wall with interior insulation

Water-repellent treatment of façades

5. Select layer

6. Change thickness e.g. original thickness minus 1 cm
Exterior wall with interior insulation

Water-repellent treatment of façades

7. Double click on layer (or click „Material data“)
Exterior wall with interior insulation

Water-repellent treatment of façades

8. Unlock material

9. Select „Liquid Transport Coefficient, Suction“
Exterior wall with interior insulation

Water-repellent treatment of façades

10. Check „Generate“
Exterior wall with interior insulation

Water-repellent treatment of façades

11. Select „Liquid Transport Coefficient, Redistribution“

12. Check „Generate“
Exterior wall with interior insulation

Water-repellent treatment of façades

13. Enter A-value
In this case:
0.5 kg/m²√h / 60
= 0.00833 kg/m²√s
Exterior wall with interior insulation

Result analysis*

- Check total water content (accumulation of moisture in whole construction); must not keep increasing

- Relative humidity at the interface between interior plaster and interior insulation < 95 % r.F.
  → risk of frost damage
  → or: frost-resistance of materials necessary
    (Insulation system plaster, wall materials)

*) Note: List not necessarily complete. Depending on boundary conditions additional critical positions may occur → Check in film display
Exterior wall with interior insulation

Additional information

- An interior insulation reduces the drying potential of a construction due to a lower over-all temperature and a higher diffusion-resistance to the interior side.

- The moisture content at the interface interior plaster / interior insulation usually can be reduced by an enhancement of the protection against driving rain (e.g. by water-repellent treatment, new exterior plaster, paint coat).

- Water-repellent treatment according to WTA:
  - A-value < 0.1 kg/m²√h
  - 50 % increase of the $s_d$-value

- Investigations of an exposed masonry need the knowledge of effective material properties, combining the properties of bricks and mortar.

- A gypsum plaster at the interior surface usually has to be removed before applying an interior insulation.

- Smart vapor retarders are favorable since the drying potential to the inside mainly remains unaffected.
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Ventilated timber frame construction

Construction drawing

1. Planking
2. Battens
3. Counter battens
4. External cladding
5. Insulation
6. Internal Cladding
7. Vapour retarder
8. Gypsum board

Construction in WUFI
Ventilated timber frame construction

Please note

■ Insert Air Change Source in air layer
  → The exchange rate is dependent on construction, surface color and ventilation openings

■ Insert an air infiltration source at the cold side of the construction (at the position where condensation would occur) → source strength depending on the air tightness and height of the wall head

■ Relevant orientation: usually north

■ Short wave radiation absorptivity depending on color of surface

■ Long wave radiation emissivity depending on material of surface

■ If the short-term hygrothermal behavior of the outer surface is to be evaluated (e.g. dew position), turn on explicit radiation balance

■ “Adhering fraction of rain” according to inclination and construction type (vertical wall: 0.7)
Ventilated timber frame construction

Air change source setup

1. Select air layer

2. Select „Sources, Sinks“
Ventilated timber frame construction

Air change source setup

3. Select „New Air Change Source“
Ventilated timber frame construction

Air change source setup
Ventilated timber frame construction

Moisture source setup

1. Select External cladding

2. Select „Sources, Sinks“
Ventilated timber frame construction

Moisture source setup

3. Select „New Moisture Source“
Ventilated timber frame construction

Moisture source setup
Ventilated timber frame construction

Result analysis*

- Check total water content (accumulation of moisture in whole construction); must not keep increasing
- Check water content in the external cladding
- If necessary check moisture content of the insulation

*) Note: List not necessarily complete. Depending on boundary conditions additional critical positions may occur → Check in film display
Ventilated timber frame construction

Additional information

- As the occurring air exchange rates are often not known, it may be useful to vary the air exchange rate to see its influence on the hygrothermal behavior of the construction.
  (Air exchange rates are usually between 10 and 200 1/h)
Ventilated timber frame construction

Additional information

- Examples for air change rates for ventilated facades

<table>
<thead>
<tr>
<th>Guide values for air changes</th>
<th>Flow rate [(m³/h)/m²]</th>
<th>Gap [mm]</th>
<th>ACH [1/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Siding</td>
<td>≈ 1,83</td>
<td>≈ 5</td>
<td>20</td>
</tr>
<tr>
<td>Vinyl Siding</td>
<td>≈ 9,14</td>
<td>≈ 5</td>
<td>200</td>
</tr>
<tr>
<td>Facing brick</td>
<td>≈ 2,74</td>
<td>≈ 25</td>
<td>10</td>
</tr>
<tr>
<td>Stucco (vented)</td>
<td>≈ 1,83</td>
<td>≈ 10</td>
<td>10</td>
</tr>
<tr>
<td>Sheathing flanking flow*</td>
<td>≈ 0,91</td>
<td>≈ 5</td>
<td>10</td>
</tr>
</tbody>
</table>

*The flank flow refers to the leaks in the area on the outer panel.
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Basement wall (without ground water)

Construction drawing

1 Soil
2 Perimeter insulation
3 Concrete wall
4 Interior plaster

Construction in WUFI

XPS Core
XPS Surface Skin

Exterior side
Interior side
Basement wall (without ground water)

Please note

- Material data „Soil (Christian) DIN“ (see Generic Materials)
  Thickness about 0.5 m

- The XPS perimeter insulation is build up three layers: core and outer surface skins
  (thickness 1 cm).

- Heat transfer resistance „Basement“

- No radiation absorptivity / emissivity

- No rain water absorption

- Outdoor climate:
  - Soil temperature from the climate „Holzkirchen-IBP Year 1991“
  - Sinus curve according to the diagram on slide 56
    with constant relative humidity of 99 % or 100 % RH

- Set interior climate depending on utilization
Basement wall (without ground water)

Soil temperature setup (from climate Holzkirchen)

1. Select climate file „Holzkirchen; Fraunhofer-IBP; Year 1991“
2. Select „Details…“
Basement wall (without ground water)

Soil temperature setup (from climate Holzkirchen)

3. Select ground temperature at 50 cm or 1 m depth

4. Enter Constant Relative Humidity of 99 % or 100 %
Basement wall (without ground water)

Soil temperature setup (from diagram)

Average soil temperature for each month depending on the depth of the soil

Example for a depth of 3 m:
Minimum of about 7 °C in March and
Maximum of about 12 °C in September

Basement wall (without ground water)

Soil temperature setup (from diagram)

1. Sine Curves
2. Select „User Defined“
3. Enter Mean Value, Amplitude and Day of Maximum
4. Relative Humidity constant 99 % or 100 %
Basement wall (without ground water)

Result analysis*

- Check total water content (accumulation of moisture in whole construction); must not keep increasing
- Check water content of insulation
- Check water content in masonry / concrete

*) Note: List not necessarily complete. Depending on boundary conditions additional critical positions may occur → Check in film display
The climate file from Holzkirchen 1991 contains measured temperatures in the ground at 50 cm and 100 cm depth.

Furthermore one can use temperature values from the literature and implement them as sinusoidal curve (slide 56).

By inserting a soil layer, the interaction between construction and soil can be taken into account in the simulation.
Consideration of water in the soil:

- Material data containing moisture storage function and moisture transport coefficients „Soil (Christian) FSP“ must be used. Further soil materials can be found in the “North American Database in the “Soil” section.

- The soil has to be saturated during the calculation period (check water content after calculation).

- Create a climate file, which contains rain for each time step (with CreateClimateFile.xls).

- Adhering Fraction of Rain (in „Surface Transfer Coefficient“) must be set to 1.

- Pressurized water can not be taken into account!
Handling of typical constructions