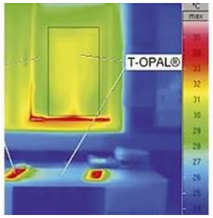
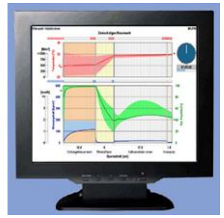
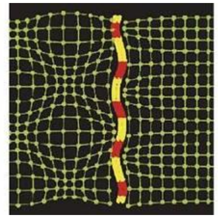




WUFI®

Guideline for Using the Air Infiltration Source in WUFI®

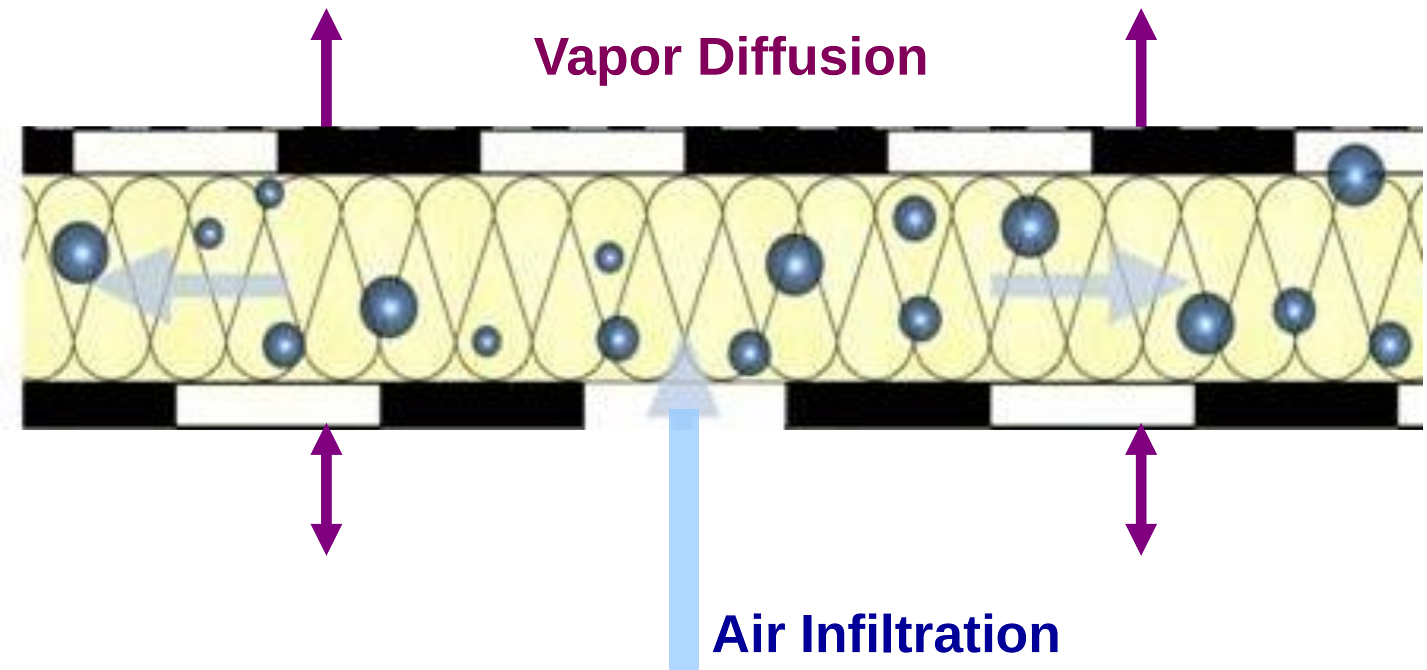
Date: July 2024

Fraunhofer IBP

Content

Damage caused by Air Infiltration

Moisture entry by air infiltration due to small, unavoidable leakages.

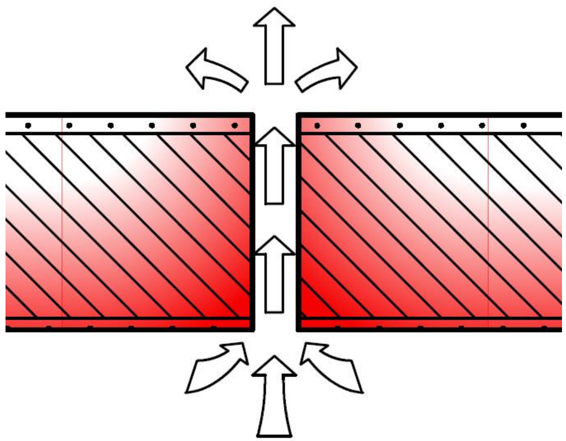


Problem: Moisture entry by air infiltration > Drying by vapor diffusion

Damage caused by Air Infiltration

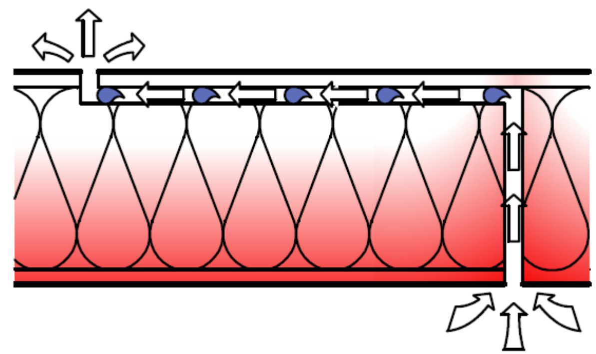
What kind of leakages are responsible for moisture damages?

„Energy“ leak



Warming of the flow path in case of strong air flux
→ no or only little condensation

„Moisture“ leak



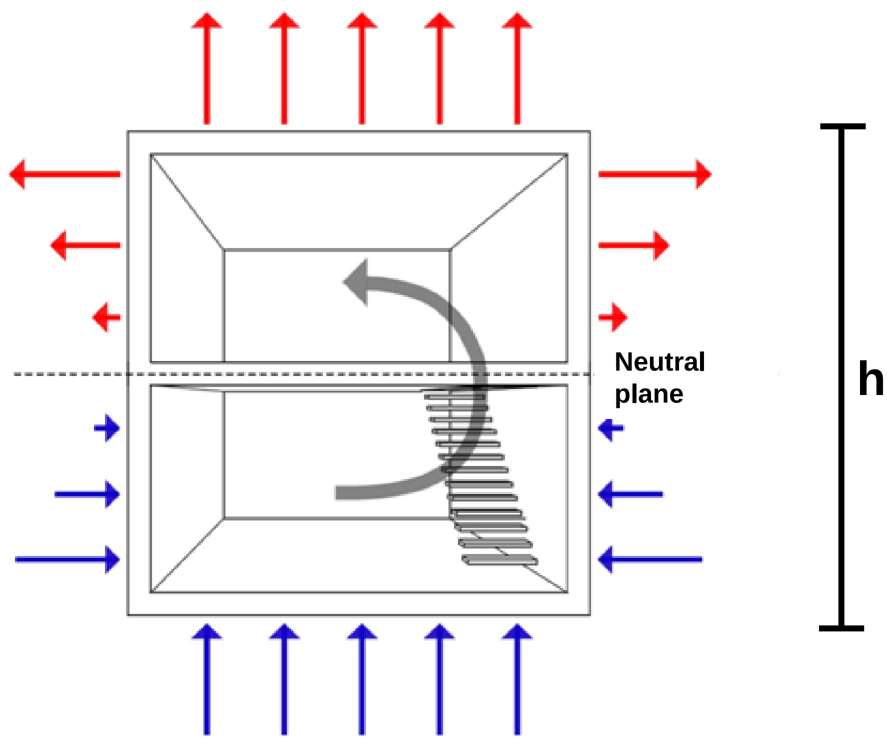
Cooling of the air in case of slow and tortuous air flux
→ potential of serious condensation

Dew water due to vapor convection only for “moisture” leakages,
if $P_i > P_e$ and $\theta_{source\ position}$ < temperature of dew point of the indoor air.

Damage caused by Air Infiltration

Overpressure depends on:

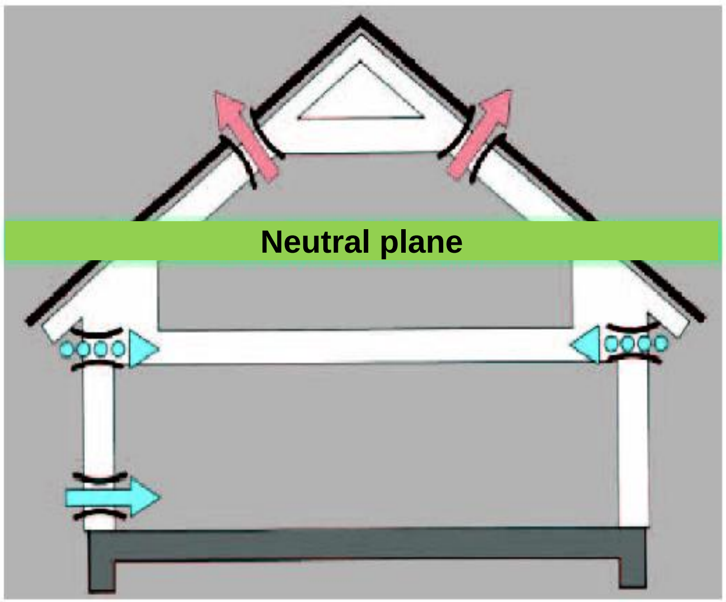
- temperature difference between indoors and outdoors
- height of connected indoor air volume

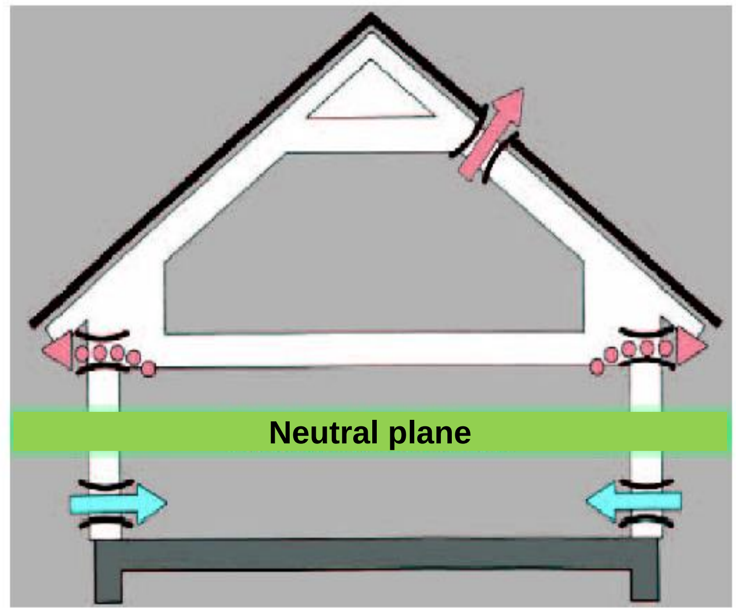


Overpressure due to buoyancy (stack effect) permanently present in winter

Damage caused by Air Infiltration

- Air flow in the overpressure range from inside to outside (moisture entry)
- Air flow in the vacuum range from outside to inside (drying)





→ No moisture problems due to convection in the bottom part of the building

German Standard DIN 68800-2

Since 2012, German Standard DIN 68800 requires to consider air infiltration as standard case for the moisture design of wooden light weight constructions

5.2.4 Tauwasser

Eine unzuträgliche Veränderung des Feuchtegehaltes durch Tauwasser aus Wasserdampfdiffusion oder Wasserdampfkonvektion ist zu verhindern.

Es ist sicherzustellen, dass an Kaltwasser führenden Leitungen innerhalb von Bauteilen kein Tauwasser ausfällt.

Die Bauteile der Gebäudehülle sind gegen Wasserdampfkonvektion luftdicht auszubilden.

Der Tauwasserschutz für die raumseitige Oberfläche und für den Querschnitt der Bauteile ist nach DIN 4108-3 oder DIN EN 15026 nachzuweisen. Ein solcher Nachweis ist für die Konstruktionen nach Anhang A nicht erforderlich, mit Ausnahme der in Bild A.23 dargestellten Balkone/Terassen.

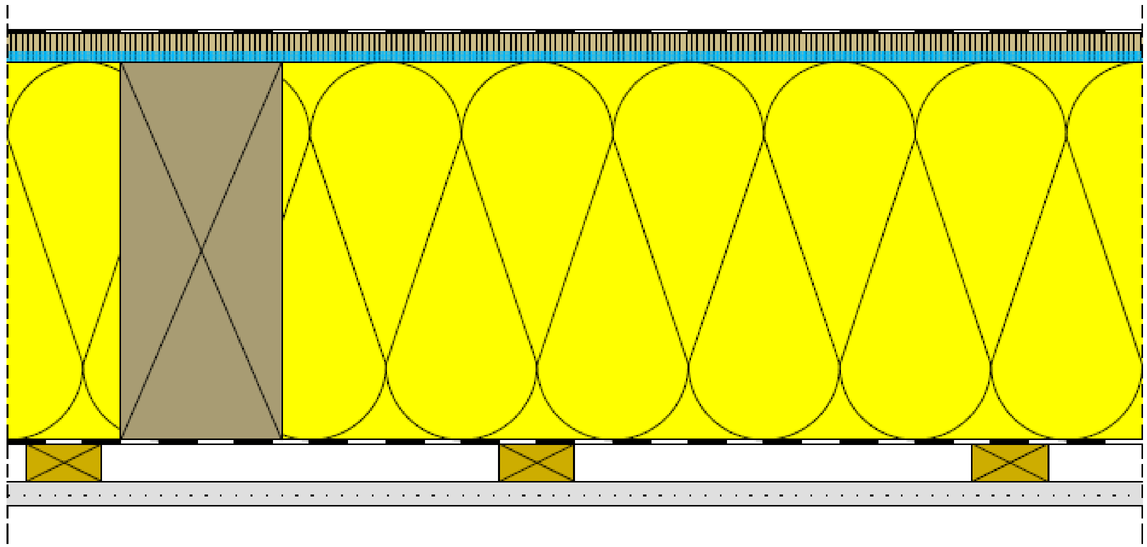
Für beidseitig geschlossene Bauteile der Gebäudehülle ist bei der Berechnung mit den Verfahren nach DIN 4108-3 (Glaser-Verfahren) zur Berücksichtigung eines konvektiven Feuchteeintrages und von Anfangsfeuchten eine zusätzliche rechnerische Trocknungsreserve ≥ 250 g/(m²a) bei Dächern und ≥ 100 g/(m²a) bei Wänden und Decken nachzuweisen. Beim Nachweis mit numerischen Simulationsverfahren nach DIN EN 15026 ist der konvektive Feuchteeintrag entsprechend der geplanten Luftdurchlässigkeit mit dem q_{50}-Wert nach DIN 4108-7 in Rechnung zu stellen. Die rechnerische Berücksichtigung eines konvektiven Feuchteeintrages und von Anfangsfeuchten ist nicht erforderlich für Konstruktionen nach Anhang A und für Bauteile mit wasserdampfdiffusionsäquivalenten Luftschichtdicken nach Tabelle 1.

ANMERKUNG Bauteile der Gebäudehülle sind alle Bauteile, die an kältere Bereiche grenzen, wie z. B. Bauteile der Außenwände, der Dächer, der Wände oder Decken zum Erdreich, zu unbeheizten Kellern oder Dachräumen.

Proceeding

All necessary input data for the simulation of a light-weight flat roof are described below with special focus on the air infiltration source.

Also the evaluation of the construction will be explained.



Proceeding: Input - Component

Component – Assembly/Monitor Positions

Roofing membrane

Usually the roofing membrane is not simulated as a material layer, but it is taken into account as s_d-value in the surface transfer parameters.

Roof assembly

The other layers beneath the roofing membrane (in the cavity section) are all included in the simulation model.

Note: For the evaluation of the moisture conditions, mostly the cavity section is considered. Here normally occur the most critical conditions due to the highest insulation level combined with the lowest vapor diffusion resistance: This leads to the highest vapor pressure gradients, while in the rafter section the vapor diffusion resistance is higher and the thermal conductivity lower.

Proceeding: Input - Moisture Source

Component – Assembly/Monitor Positions

Moisture source

According to the German standard DIN 68800 [1] the convective moisture entry in wooden constructions has always to be taken into account. For hygrothermal simulations a transient model is proposed. For that the IBP air infiltration model is used.

The moisture source has to be deposited at that position within the assembly, where the dew water formation is expected. Usually that's inside the second air-tightness layer or membrane.

The moisture source should be spread over several grid elements to ensure that the accumulated dew water can be absorbed by that area (a thickness of 5 to 10 mm can be recommended).

It is useful to place the moisture source in tha material which cam absorb the dew water (for example at the interface between mineral wool insulation and wooden sheathing the sheathing would be chosen).

Component – Assembly/Monitor Positions

Moisture source

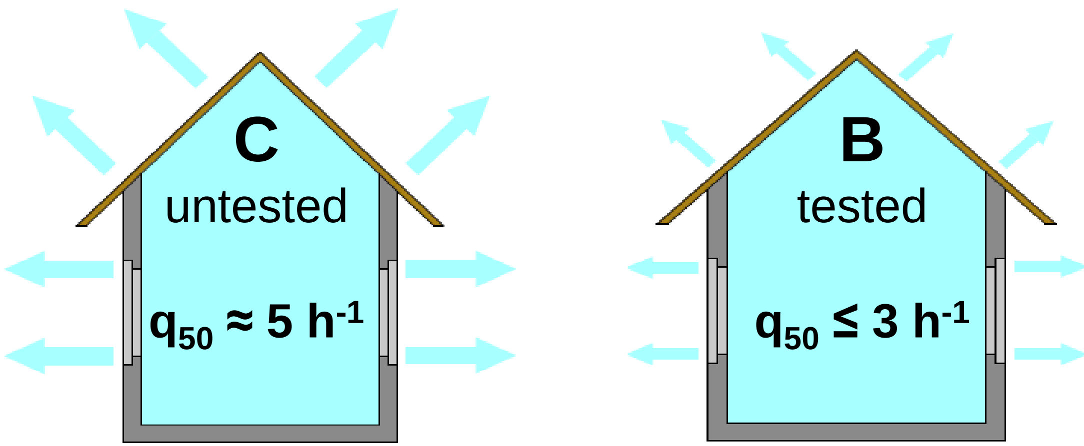
The amount of condensation water is determined for every hour automatically from the overpressure due to thermal buoyancy in the building (temperature difference between outside and inside and stack height), the interior relative humidity, the temperature at the source position and the specified air-tightness of the building envelope [2].

The single parameters are described in detail on the following slides.

Air Infiltration Model IBP:

Envelope Infiltration q_{50} [m³/m²h]

For single-family houses, the numerical value of q_{50} corresponds approx. to the n_{50}-value (with different units), especially for bigger houses a conversion is necessary.



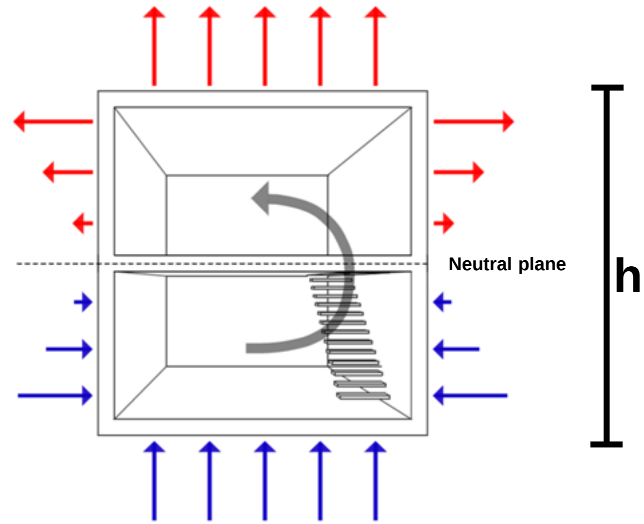
According to DIN 4108-3, air tightness class C is to be used for untested buildings. With a measured q_{50}-value ≤ 3 m³/(m²h), air tightness class B can be applied.

Proceeding: Input - Moisture Source

Air Infiltraion Model IBP:

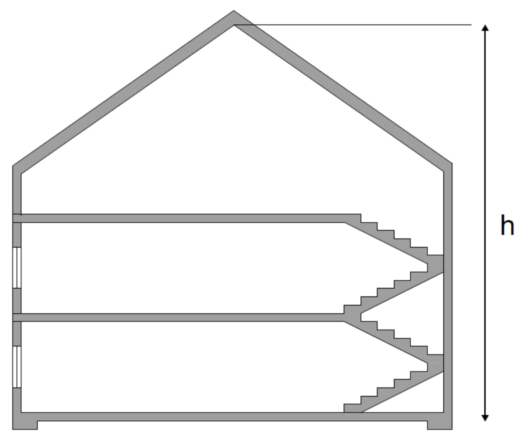
Stack Height [m]:

Corresponds to the height of the connected and heated indoor air space.



Example: Single-family houses with open stairwell

→ here the total building height (h) (possibly including heated cellar) should be applied.

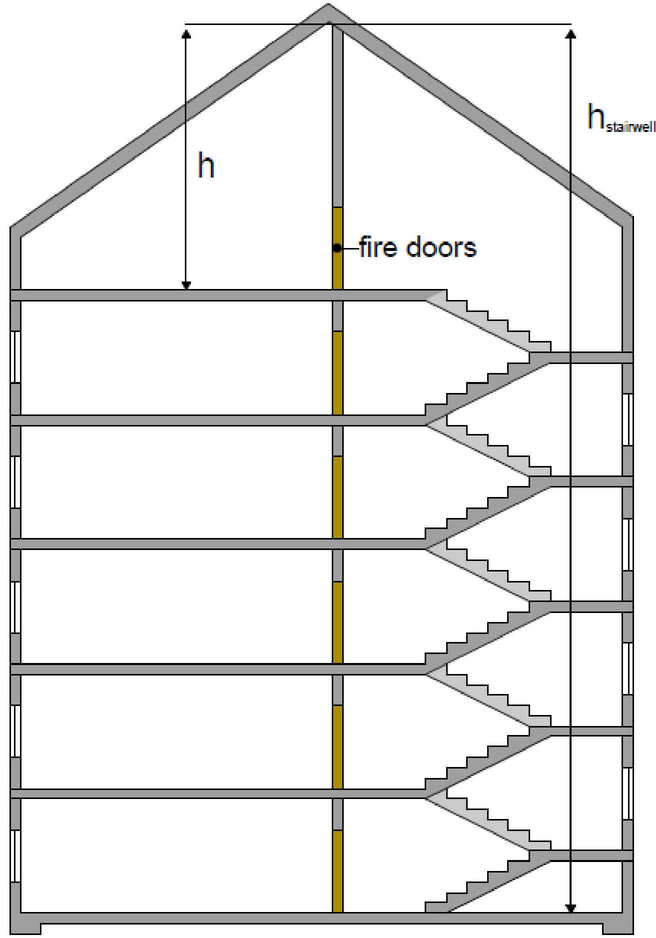


Air Infiltraion Model IBP:

Example: apartment buildings with „separate“ stairwell

→ In case of pressure-sealed fire doors a meaningful reduction of the stack height is justified. For example for the roof only the height of the upper floor (h) can be used (or two story heights to be more on the safe side)

In the stairwell, the height of the contiguous air space would be significantly larger ($h_{stairwell}$), but in most cases the stairwell is unheated with lower pressure difference between inside and outside. Furthermore, the moisture load in the stairwell is usually lower (this should be taken into account by suitable climate conditions).



Proceeding: Input - Moisture Source

Air Infiltraion Model IBP:

Mechanical Ventilation Overpressure [Pa]:

Here, it is possible to take into account overpressures or negative pressures generated by existing air-conditioning systems.

The declared value is constantly set to the pressure difference between inside and outside.

Proceeding: Input - Moisture Source

Air Infiltraion Model IBP:

Summary:

Modeling of vapor convection due to leakages for the evaluation of the moisture protection with the help of hygrothermal simulations.

The moisture entry due to vapor convection is determined for every time step situation-specific depending on:

- the transient boundary conditions (interior and exterior climate)
- the temperature at the expected position of the dew water formation
- the air tightness of the building envelope
- the stack height

Proceeding: Input - Orientation / Inclination

Component - Orientation

Orientation

Usually the relevant orientation is North, because here the radiation gains are the lowest. Alternatively, for specific projects, the most unfavorable real orientation can be used.

Inclination

The inclination of the flat roof should be specified according to the planned roof inclination.

Component – Surface Transfer Coefficient

Heat transfer coefficient on the exterior surface

The heat transfer coefficient for flat roofs is usually 19 W/m²K.

s_d-value on the exterior surface

Here the s_d-value of the roofing membrane has to be indicate, if it is not taken into account as a single component layer.

Note: If the roof membrane is taken into account as a single component layer, no s_d-value is to be specified here.

Adhering Fraction of Rain

If the roof membrane is taken into account as a s_d-value in the surface transfer parameters, the rain absorption must be switched off. The setting for the s_d-value only affects the diffusion behavior and not the liquid transport.

Component – Surface Transfer Coefficient

Short-Wave Radiation Absorptivity

The short-wave radiation absorptivity is chosen according the color of the roofing membrane.

Long-Wave Radiation Emissivity

The long-wave radiation emissivity for roofing membranes is usually 0.9.

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 undercooling as a result of long-wave radiation.

Component – Initial Conditions

Initial Temperature and Moisture in Component:

A constant relative initial moisture of 80 % and an initial temperature of 20°C should be used as default setting.

Proceeding: Input - Control

Control

Calculation Period / Profiles:

A calculation start on 1 October is recommended because the component absorbs moisture in the following winter months before a possible drying occurs in spring. This start date is usually the most critical case.

The calculation period depends on when the construction reaches its dynamic equilibrium. Usually a period of 5 years is sufficient. The period must be extended, if the dynamic equilibrium is not yet recognizable after the calculation.

Numerics:

The default setting can be used for numerics.

Proceeding: Input - Climate

Climate

Outdoor:

It should be used a suitable climate data set for the building location.

For this purpose the hygrothermal test reference years (HRY), which were produced in a research project [3] for 11 locations in Germany, are suitable. These locations are typical for the respective climate region.
More information on this in the WUFI®-Help (F1) → Topic: Hygrothermal reference years.

The outdoor climate of Holzkirchen is regarded as critically representative for Germany in many applications. However, especially in the assessment of roofs, locations with less radiation can be more unfavorable.

Proceeding: Input - Climate

Climate

Indoor:

For the design aspect we recommend the indoor climate with medium moisture load + 5 % according to the WTA Guideline 6-2 [5].

Alternatively, depending on the use of the building, the indoor climate according EN 15026 [4] with medium or high moisture load can be used.

Proceeding: Evaluation - General

General:

Check the numerical quality of the result using convergence failures and balances!
→ Guideline for the Result Evaluation

No long-term moisture accumulation in the construction!

Evaluation of the total water content:

→ Usually only qualitative assessment of the moisture balance

→ Decreases: Component dries

→ No change over annual cycle :
dynamic equilibrium is reached

→ Long-term increase:
permanent moisture accumulation in the construction

Proceeding: Evaluation - General

General:

Evaluation of the water content in individual material layers:

→ Qualitative assessment of the moisture balance

→ Quantitative assessment of the moisture values

→ Initial increase: can be caused by a redistribution of the initial moisture in the construction

→ Long-term increase: moisture accumulation in the material layer

→ Moisture-sensitive materials (for example wood and wooden based materials…) must not exceed the respective limit values.

Proceeding: Evaluation - General

General:

Identification of critical positions within the construction:

→ Possible with WUFI® Animation1D (movie)

→ Extreme values in the relative humidity and in the water content often represent critical positions (for example at layer boundaries…)

Proceeding: Evaluation - Wood Decay

Wood decay – Evaluation according to DIN 68800 [1]

Critical conditions concerning the damage of wood can occur by long-term exceeding of the limit values of 20 % by mass for wood and 18 % by mass for wooden based materials according to DIN 68800 [1].

However, these limit values contain high safety margins and there is no specification of the evaluation range.

If the water content in the framework remains below these limit values, no further evaluation is necessary.

Proceeding: Evaluation - Wood Decay

Wood decay – Evaluation according to WTA Guideline 6-8 [6]

If the limit values according to DIN 68800 [1] are exceeded, an further evaluation can be done according to the new WTA Guideline 6-8 [6].

Here the evaluation of wooden constructions occurs on the basis of temperature-dependent limit values. The daily mean of the relative pore air moisture content over the most critical 10 mm of the wood must not exceed 95 % at 0 °C and 86 % at 30 °C.

This allows a more accurate and realistic evaluation.

Proceeding: Evaluation - Wood Decay

Extract from the WTA Guideline 6-8 [6]:

6.4 Bewertung von Simulationsergebnissen

Die Auswertung erfolgt nach zwei Kriterien:

a) Die Bewertung bezüglich holzzerstörender Pilze erfolgt bei Holz über die mittlere Porenluftfeuchte der maßgebenden (kritischen) 10 mm Schicht.

b) Für die Beurteilung der konstruktiven Aspekte (siehe Abschnitt 6.5) wird die mittlere Holzfeuchte der gesamten Materialschicht herangezogen (Holz und Holzwerkstoffe). Bei vielen Holzwerkstoffen ist dies das maßgebende Beurteilungskriterium.

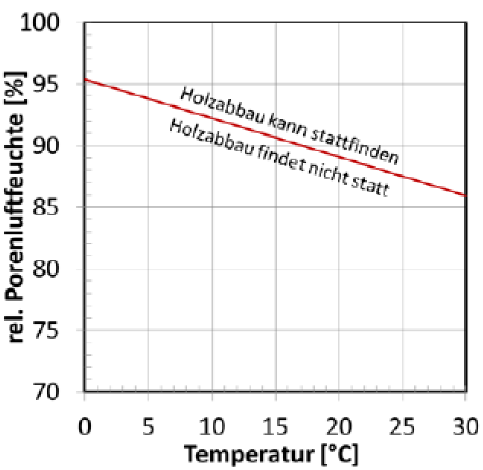


Abbildung 1: Grenzkurve der rel. Porenluftfeuchte bezogen auf die Temperatur einer 10 mm dicken Holzschicht, die im Tagesmittel nicht überschritten werden darf.

Literature

[1] DIN 68800-2: Wood preservation – Part 2: Preventive constructional measures in buildings. Beuth Verlag, February 2022.

[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] Forschungsbericht: Energieoptimiertes Bauen: Klima- und Oberflächenübergangsbedingungen für die hygrothermische Bauteilsimulation. IBP-Bericht HTB-021/2016. Durchgeführt im Auftrag vom Projektträger Jülich (PTJ UMW). Juli 2016.

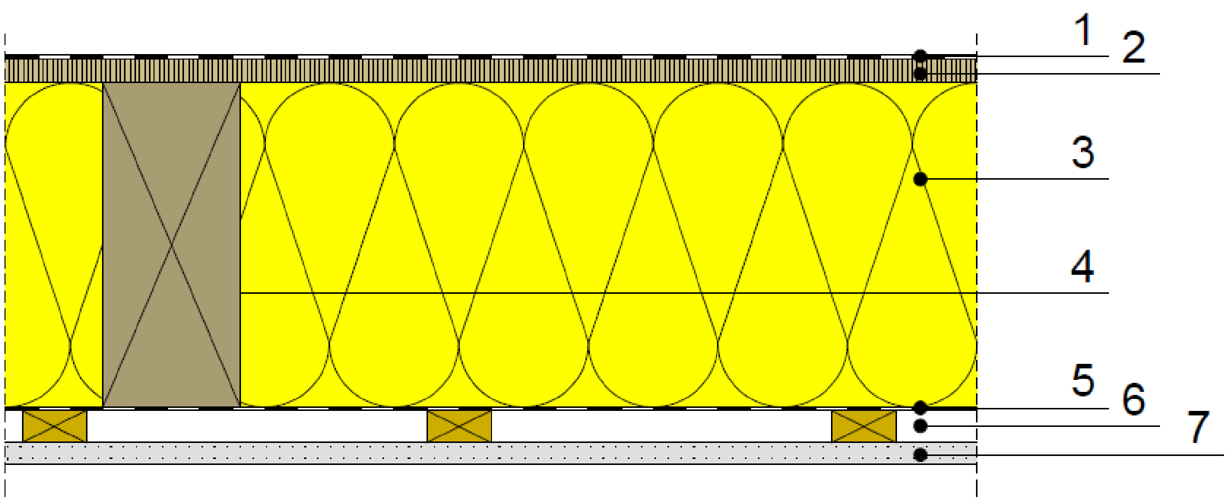
[4] EN 15026: Hygrothermal performance of building components and building elements - Assessment of moisture transfer by numerical simulation. Beuth Verlag, December 2023.

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

[6] WTA Guideline 6-8: Assessment of humidity in timber constructions - Simplified verifications and simulation. August 2016.

Example: Wooden Flat Roof Construction

Hygrothermal assessment of a wooden flat roof construction.



1 Roofing Membrane
2 Wooden Sheathing
3 Insulation
4 Rafter
5 Vapor Retarder
6 Installation Level
7 Gypsum Board

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Example: Wooden Flat Roof Construction

Assembly (from outside to inside):

• Vapor retarder (s_d = 300m)		
• Oriented Strand Board (density 615 kg/m³)	0.022	m
• Mineral Wool (heat cond.: 0.04 W/mK)	0.24	m
• PA-Membrane	0.001	m
• Air Layer (25 mm)	0.025	m
• Gypsum Board	0.0125	m

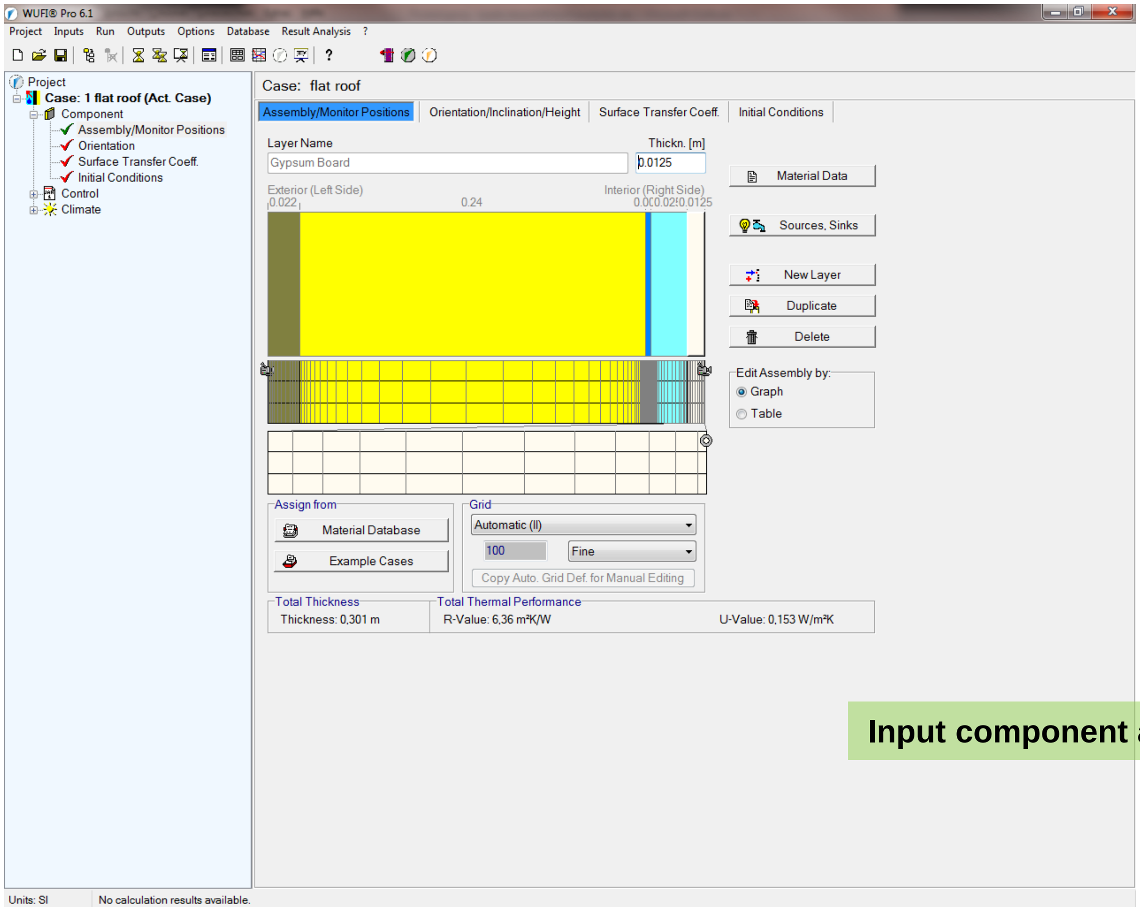
Example: Wooden Flat Roof Construction

Boundary Conditions:

- Flat roof (3° to the North)
- Dark roofing membrane:
  short-wave radiation absorptivity: 0.8
  long-wave radiation emissivity: 0.9
- Outdoor climate: Holzkirchen
- Indoor climate: EN 15026 with medium moisture load
- Envelope infiltration: q_{50} = 3 m³/m³h
- Stack height: 5 m

Example: Wooden Flat Roof Construction

Input: Component – Assembly / Monitor Positions

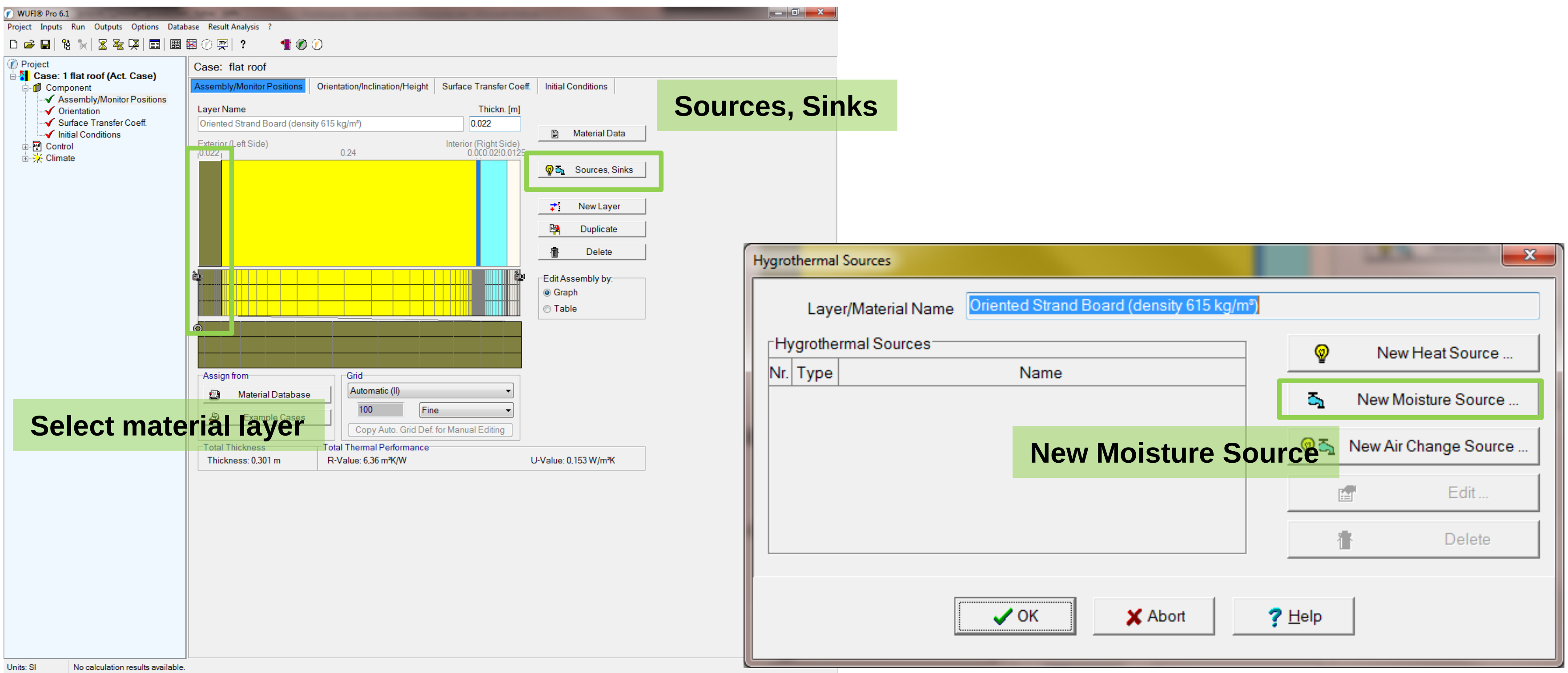


Input component assembly

Example: Wooden Flat Roof Construction

<u>Input:</u> Component – Assembly / Monitor Positions

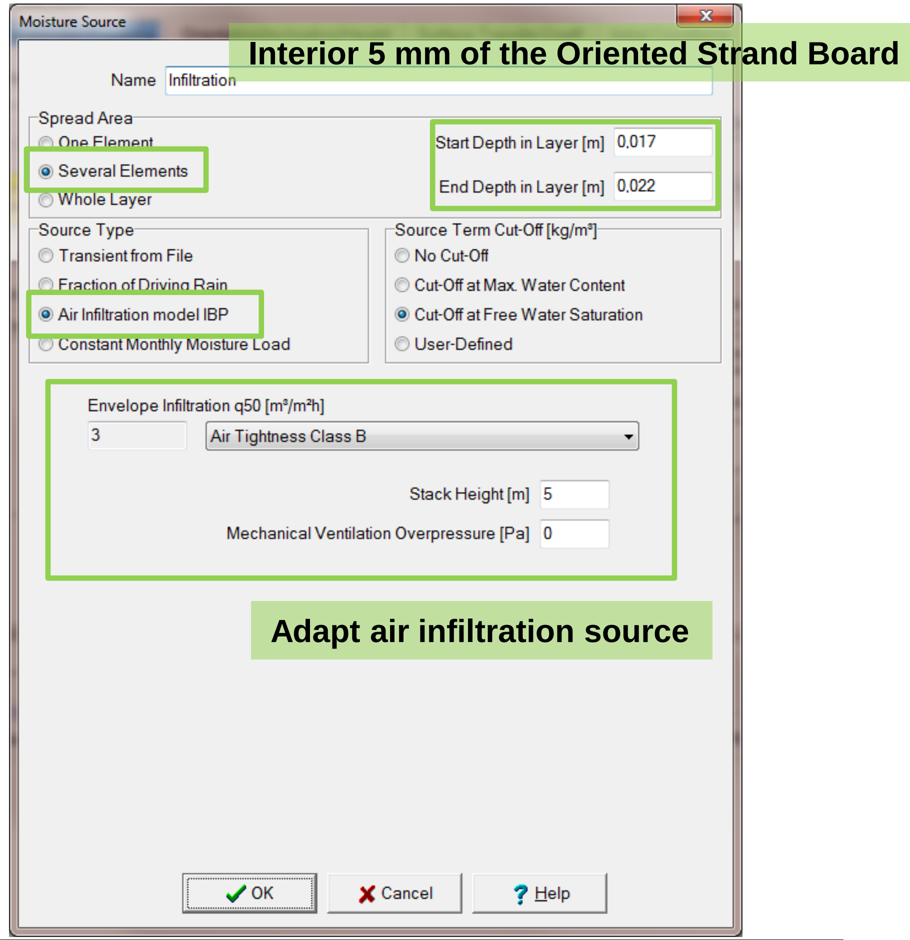
Moisture source in the interior 5 mm of the Oriented Strand Board.



Example: Wooden Flat Roof Construction

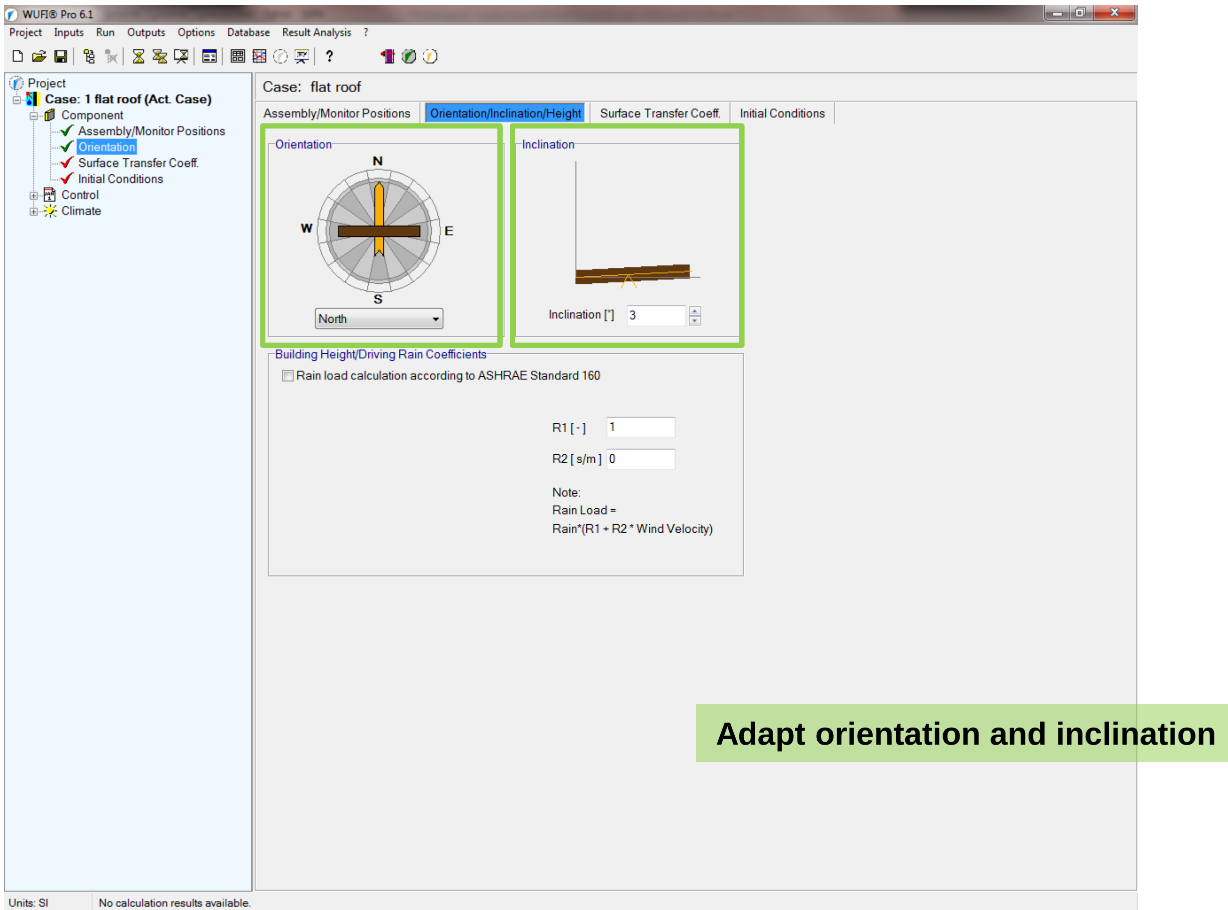
Input: Component – Assembly / Monitor Positions

Moisture source in the interior
5 mm of the Oriented Strand Board.



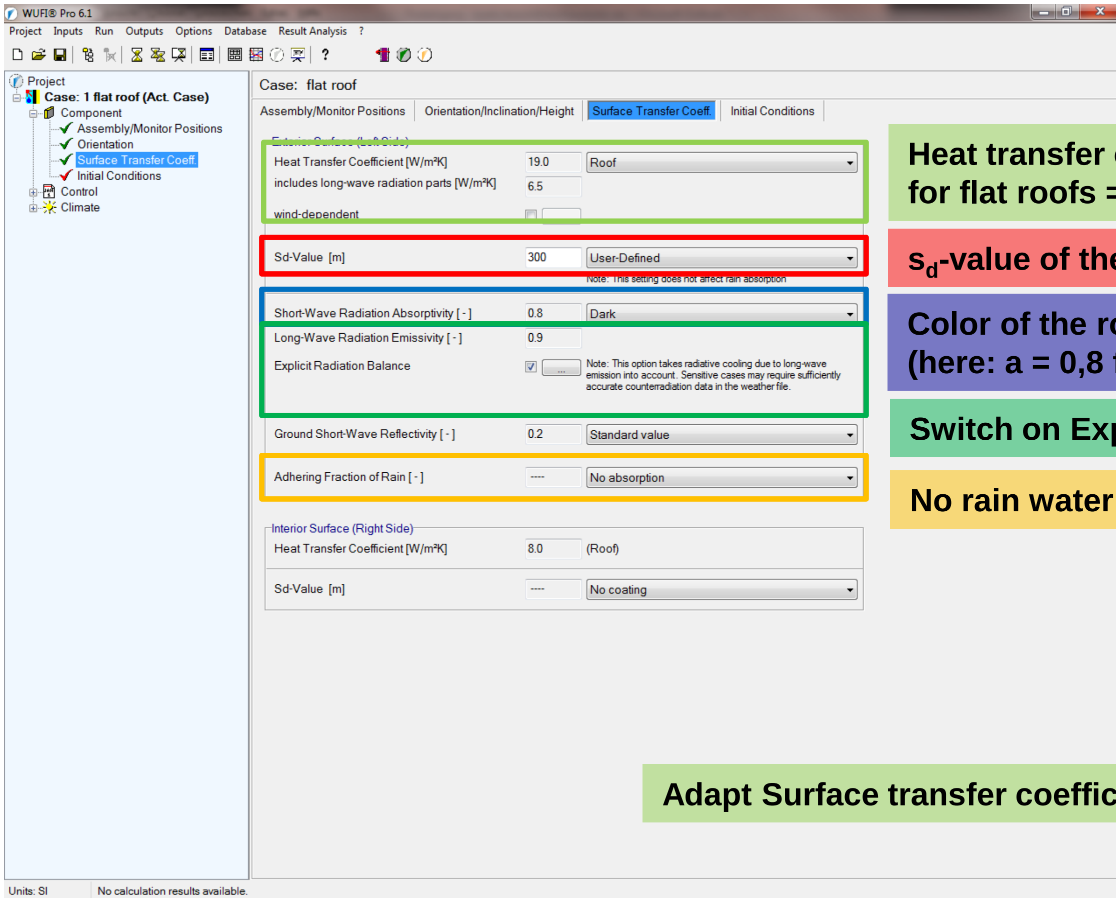
Example: Wooden Flat Roof Construction

Input: Component - Orientation



Example: Wooden Flat Roof Construction

Input: Component – Surface Transfer Coeff.



Heat transfer coefficient for flat roofs = 19 W/m²K

s_d-value of the roofing membrane = 300 m

Color of the roofing membrane (here: a = 0,8 for dark roofing membranes)

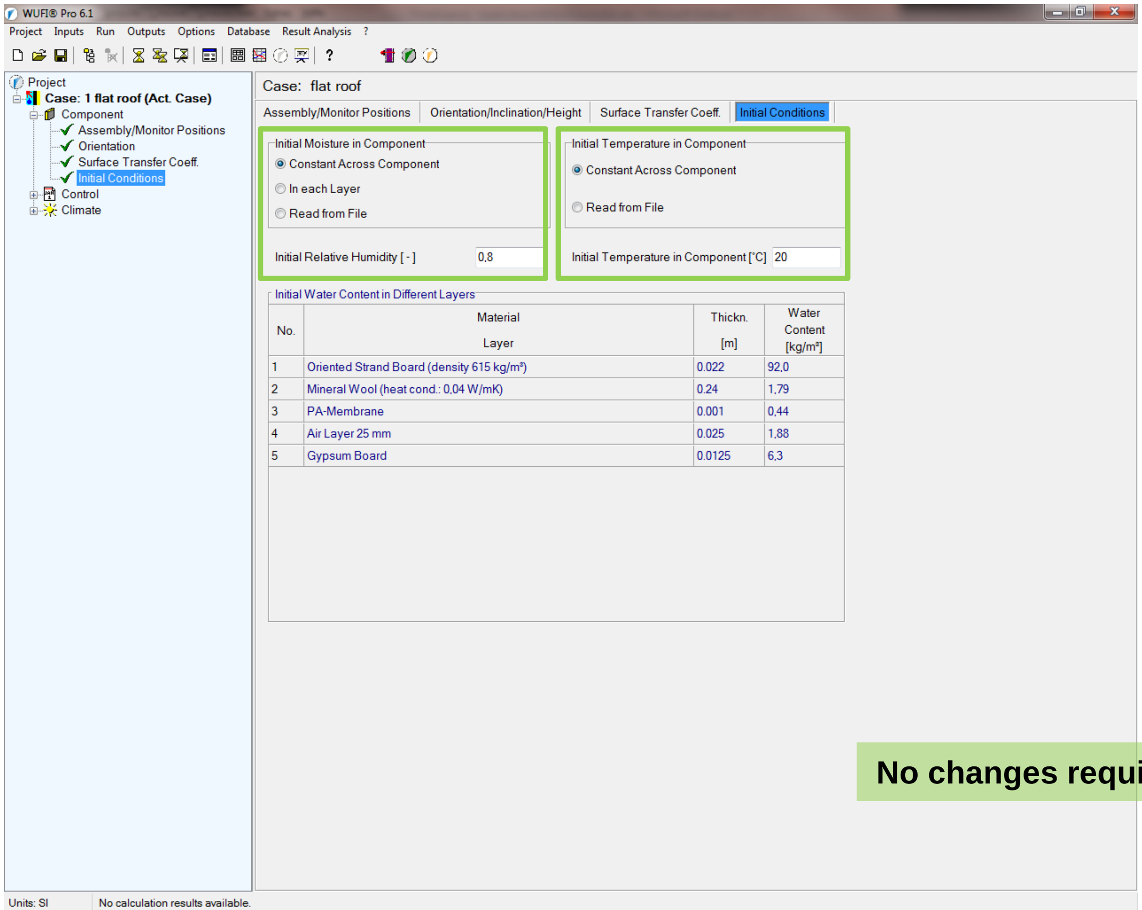
Switch on Explicit Radiation Balance!

No rain water absorption!

Adapt Surface transfer coefficients!

Example: Wooden Flat Roof Construction

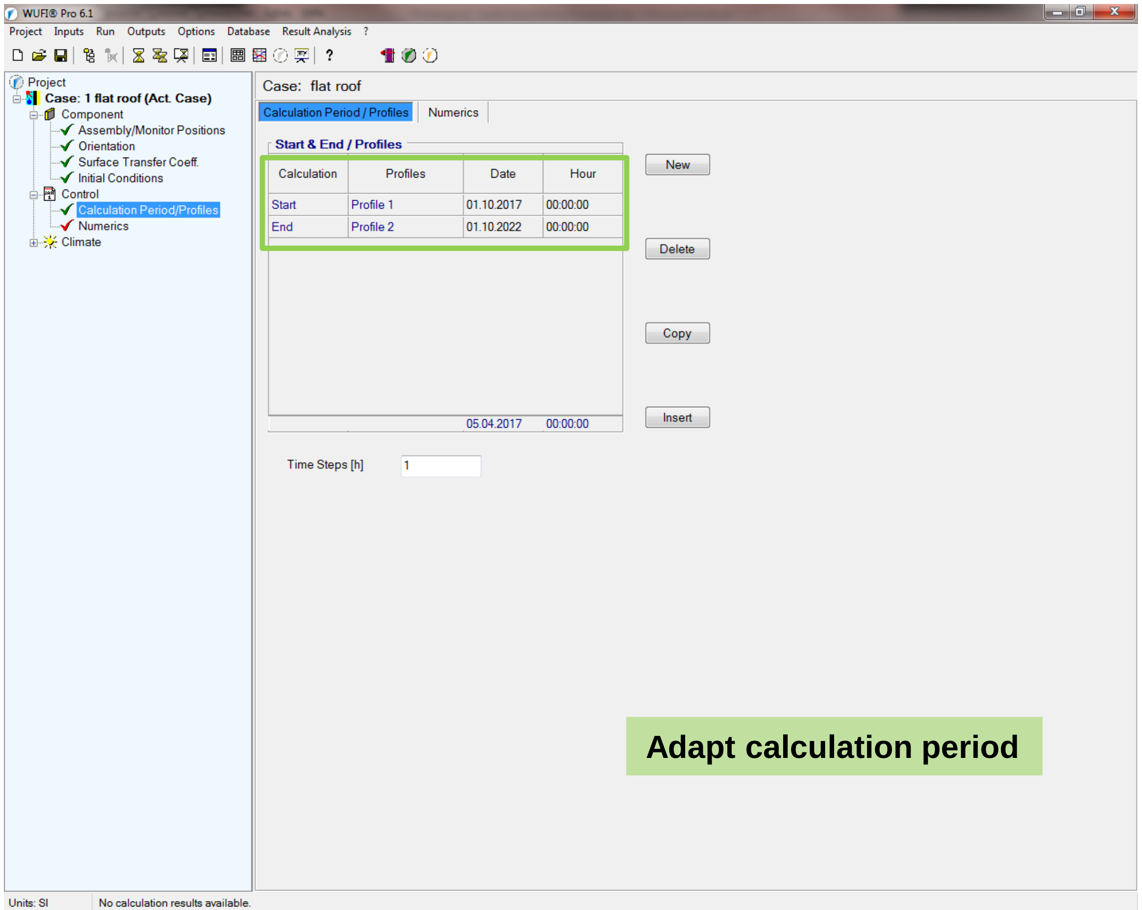
__Input:__ Component – Initial Conditions



No changes required

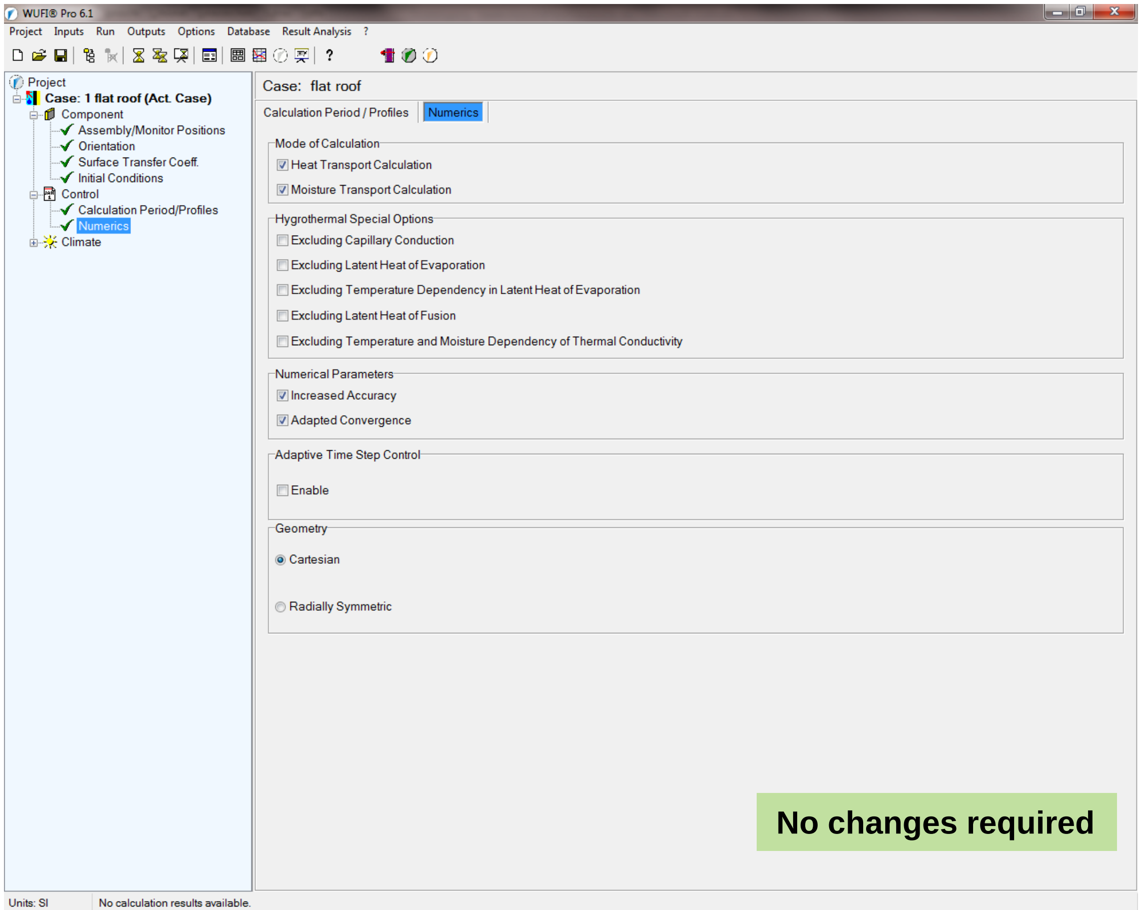
Example: Wooden Flat Roof Construction

Input: Control – Calculation Period / Profiles



Example: Wooden Flat Roof Construction

Input: Control – Numerics



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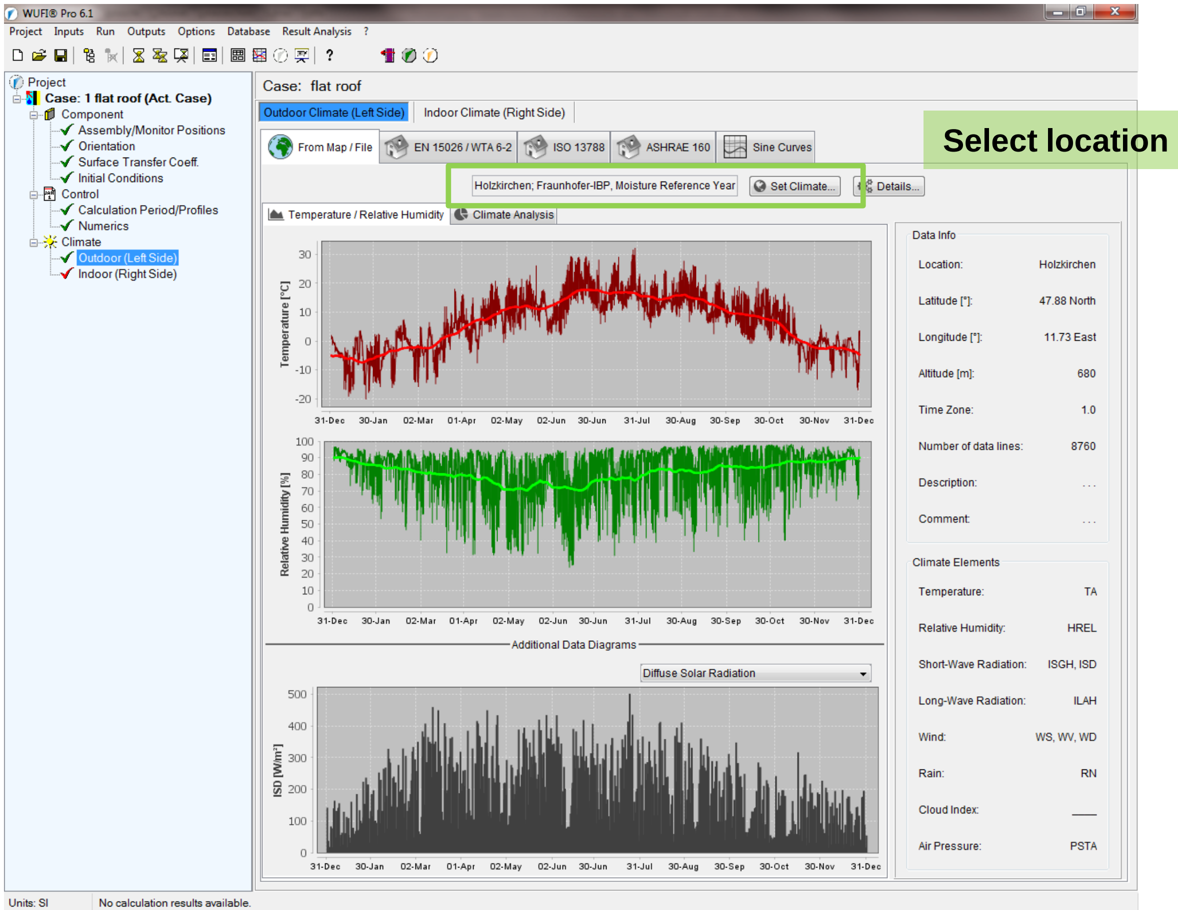
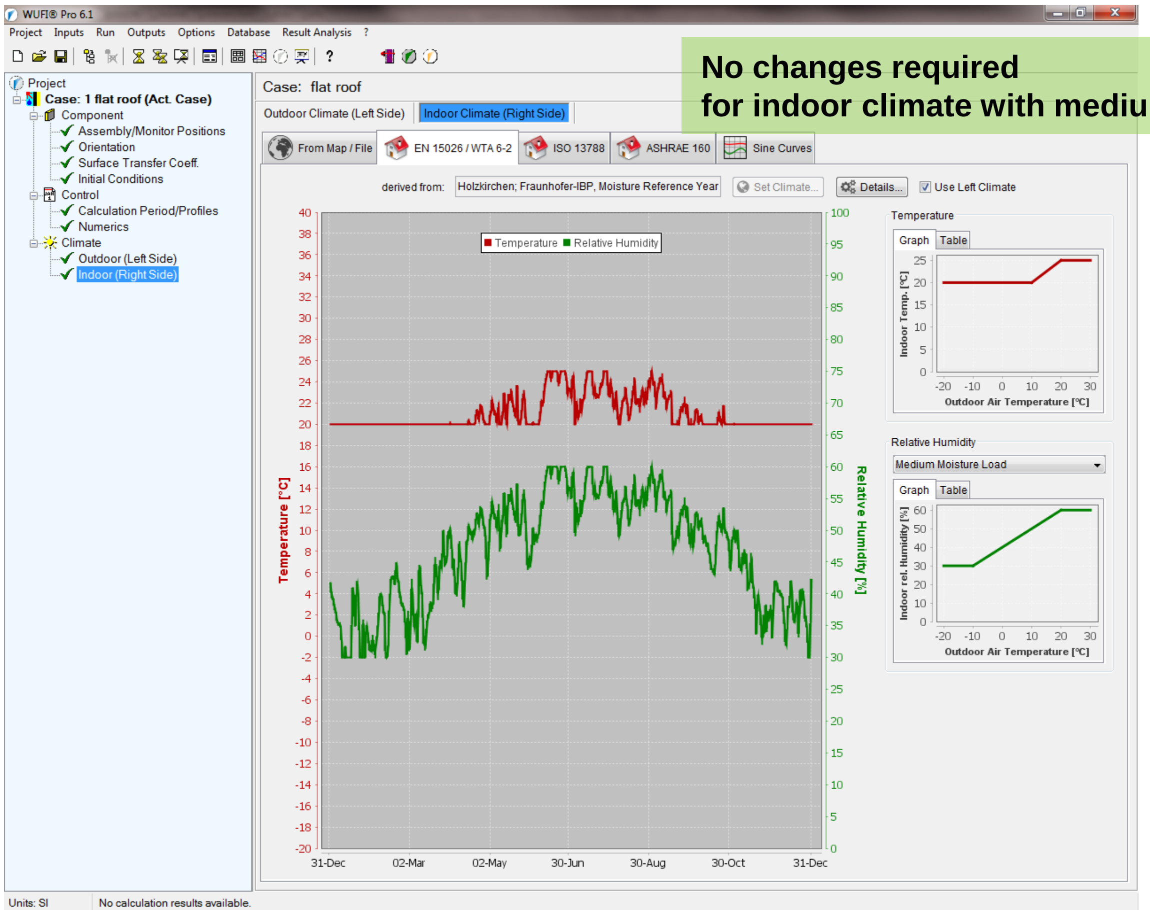
Example: Wooden Flat Roof Construction

<u>Input:</u> Climate – Outdoor (left side)



Example: Wooden Flat Roof Construction

<u>Input:</u> Climate – Indoor (right side)



No changes required for indoor climate with medium moisture load

Example: Wooden Flat Roof Construction

<u>Evaluation:</u>

Numerics

Status of Last Calculation

Status of Calculation

Calculation: Time and Date	16.07.2024 11:13:44
Computing Time	1 min,9 sec.
Begin / End of calculation	01.10.2017 / 01.10.2022
No. of Convergence Failures	0

Check for numerical quality

Integral of fluxes, left side (kl,dl)	[kg/m²]	-0,02 0,02
Integral of fluxes, right side (kr,dr)	[kg/m²]	1,4E-7 1,38
Balance 1	[kg/m²]	-0,89
Balance 2	[kg/m²]	-0,89

Water Content [kg/m²]

	Start	End	Min.	Max.
Total Water Content	2,58	1,66	1,6	2,66

Water Content [kg/m³]

Layer/Material	Start	End	Min.	Max.

Close Help

No convergence failures and no balance differences

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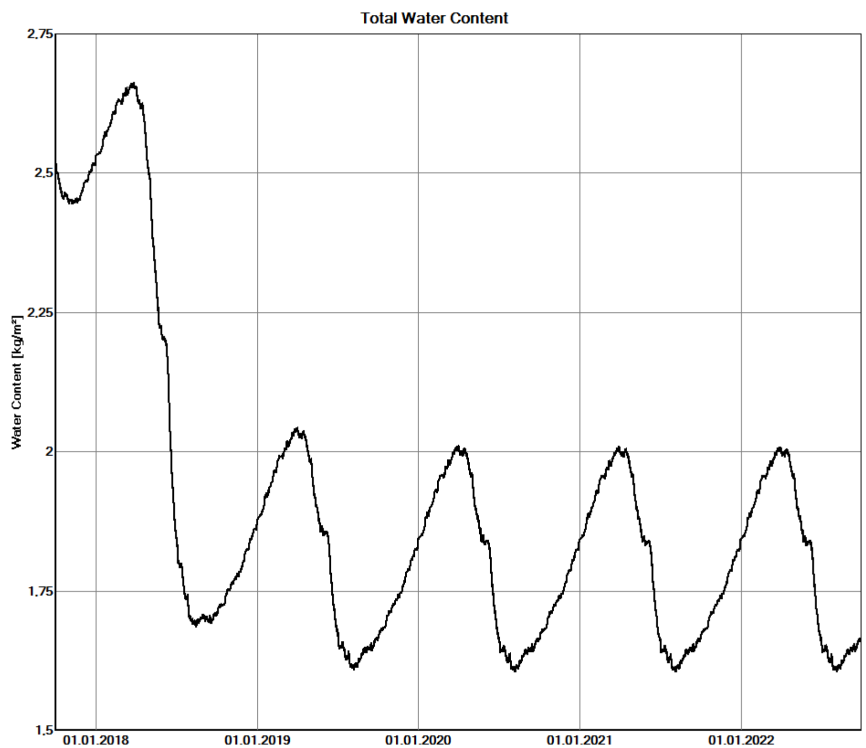
Example: Wooden Flat Roof Construction

Evaluation with the Quick Graphs:

Total Water Content



Evaluation:

Total water content decreases and reaches the dynamic equilibrium after 3 years

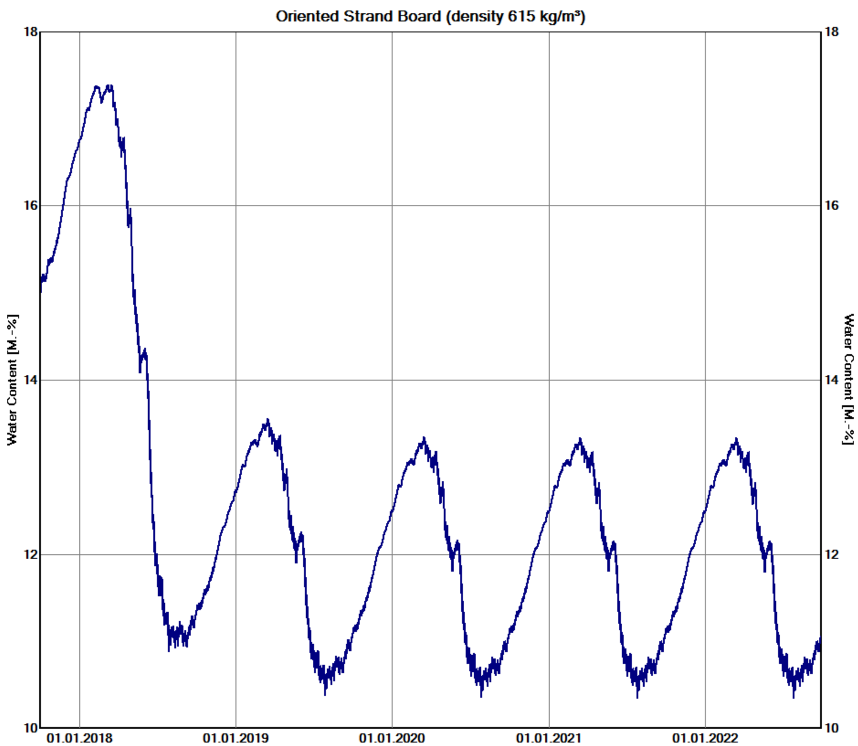
→ OK

→ Detailed evaluation of the individual layers

Example: Wooden Flat Roof Construction

Evaluation with the Quick Graphs:

Water Content in the Oriented Strand Board



Evaluation:

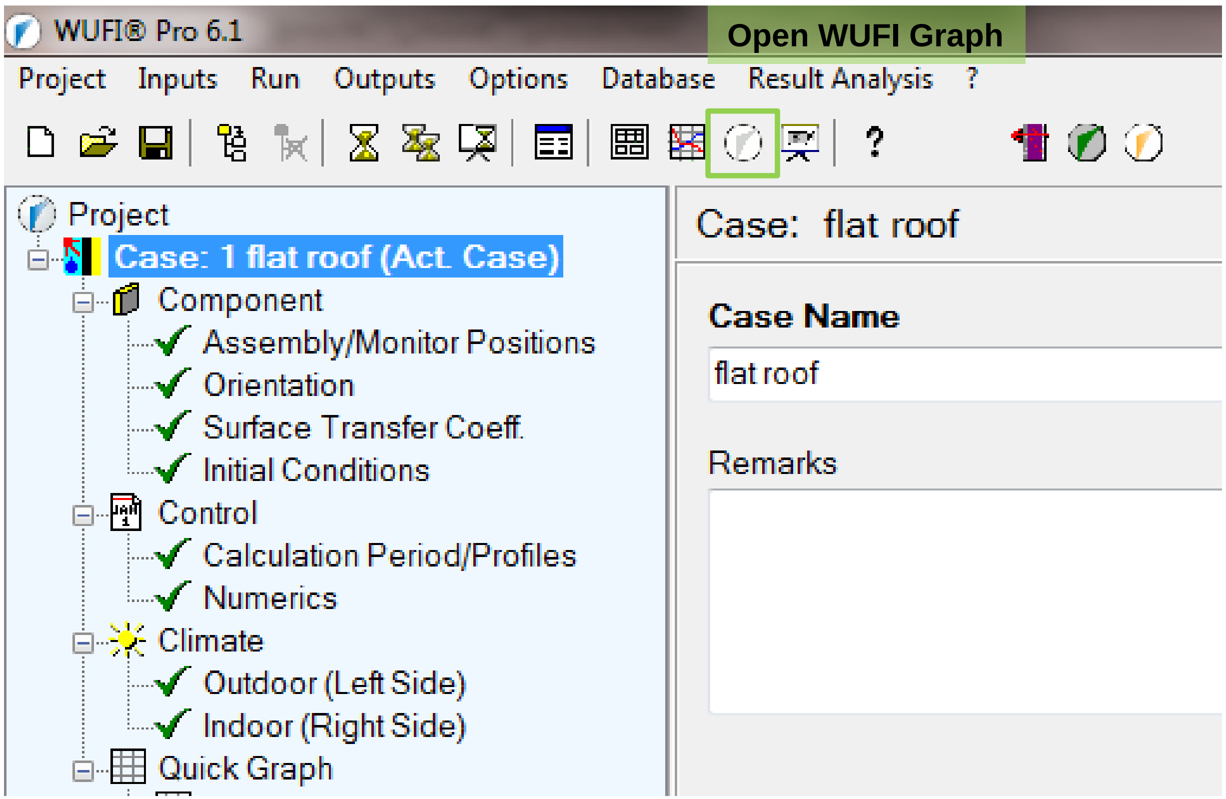
Water content in the Oriented Strand Board decreases and reaches the dynamic equilibrium also after 3 years.

The water content remains below the limit value of 18 % by mass according to DIN 68800 → uncritical!

→ However, the evaluation of the wood moisture according to WTA is shown

Example: Wooden Flat Roof Construction

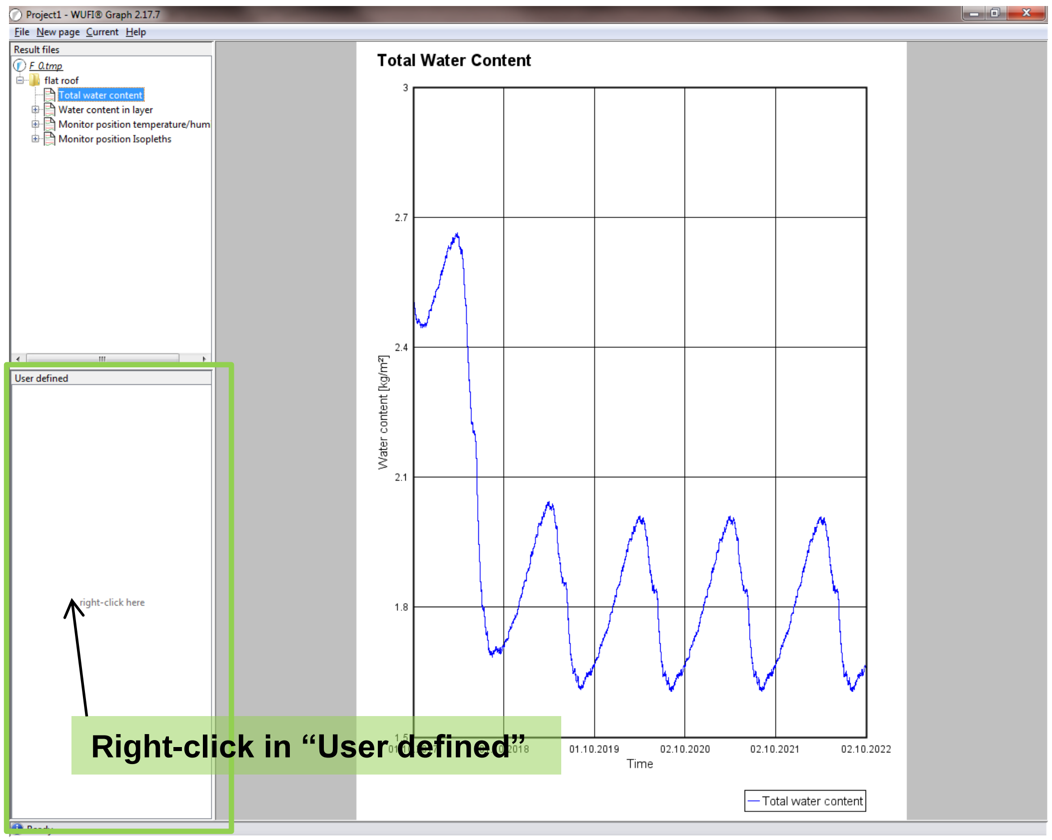
Evaluation with WUFI Gaph:
wood pore air moisture in the Oriented Strand Board according WTA 6-8



Example: Wooden Flat Roof Construction

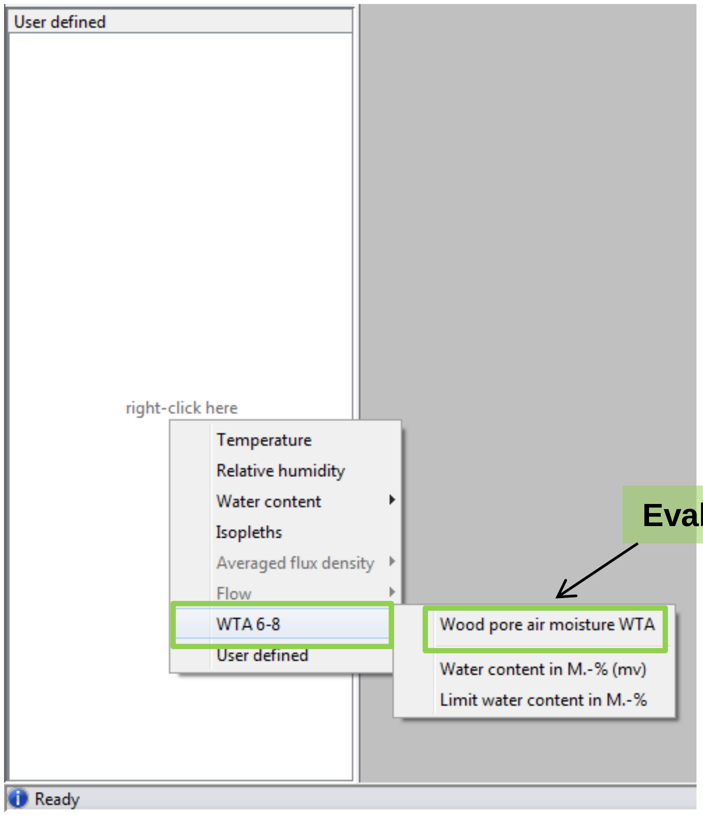
<u>Evaluation with WUFI Gaph:</u>

wood pore air moisture in the Oriented Strand Board according WTA 6-8



Example: Wooden Flat Roof Construction

Evaluation with WUFI Gaph:
wood pore air moisture in the Oriented Strand Board according WTA 6-8



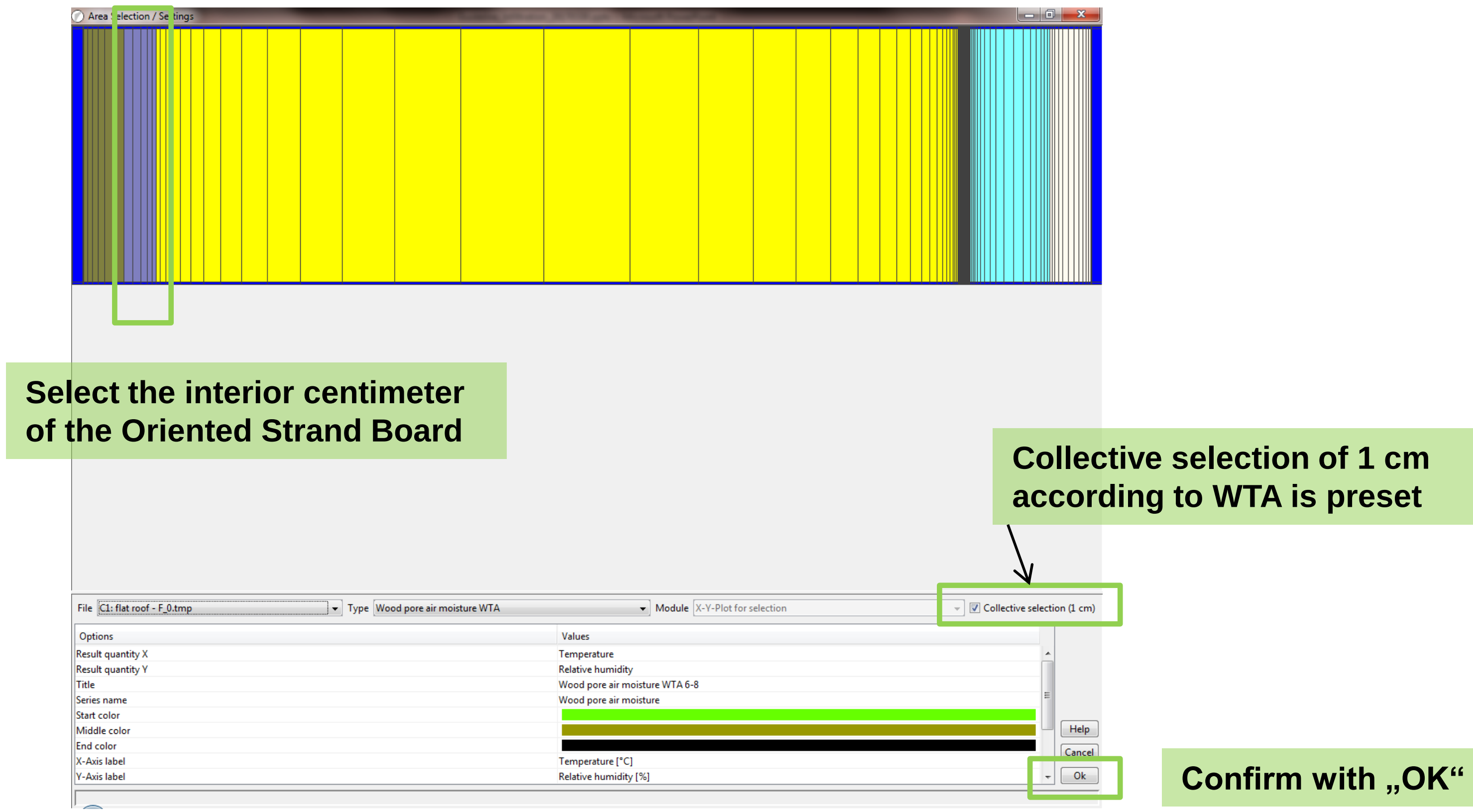
Evaluation of the wood pore air moisture according to WTA

Fraunhofer IBP

Example: Wooden Flat Roof Construction

Evaluation with WUFI Gaph:

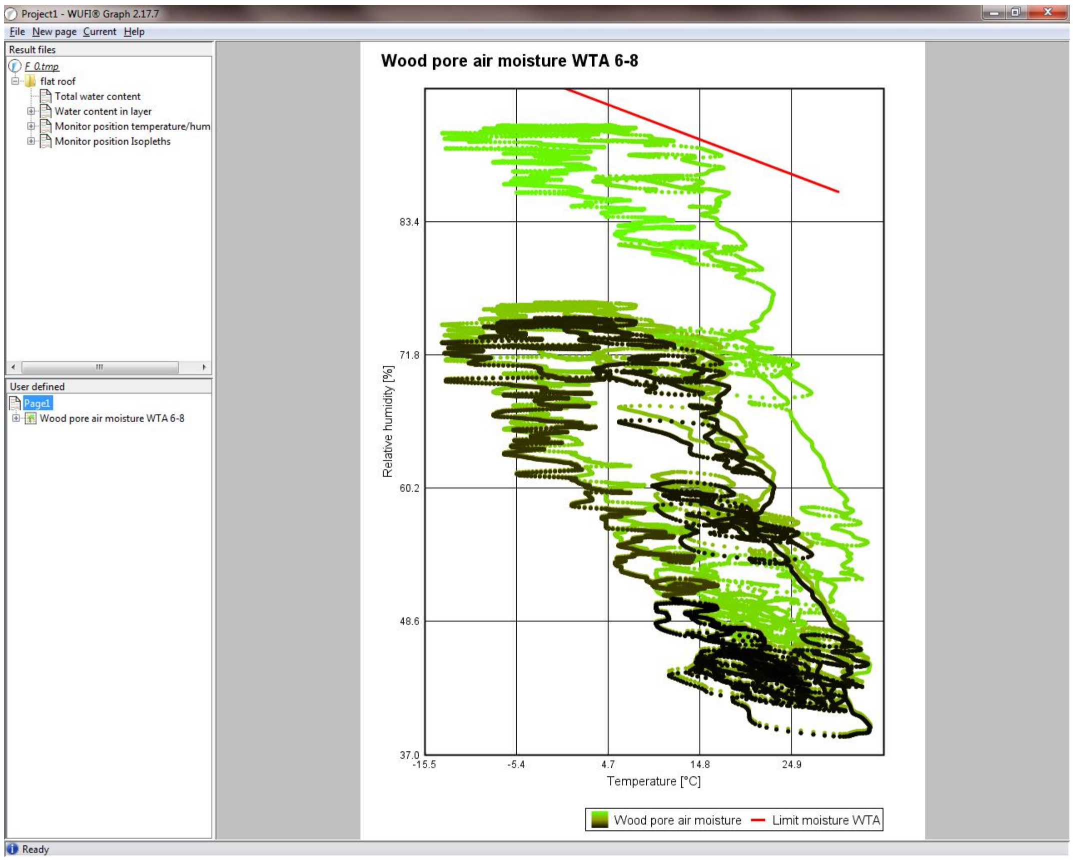
wood pore air moisture in the Oriented Strand Board according WTA 6-8



Example: Wooden Flat Roof Construction

Evaluation with WUFI Gaph:

wood pore air moisture in the Oriented Strand Board according WTA 6-8



Evaluation:

The relative pore air moisture in the interior centimeter of the Oriented Strand Board doesn't exceed the limit value according to WTA.

→ uncritical

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