Hygrothermal simulation of a lightweight timber wall

Heiko Fechner

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1. Overview

This tutorial shows a lightweight timber construction wall with a rear-ventilated facing layer, which is to be simulated and evaluated with DELPHIN. It deals with the geometry creation, simplifications, mapping of rear ventilation using field conditions and much more.

The following graphics show the basic structure of the lightweight timber wall as a corner and as a 1D simplification.

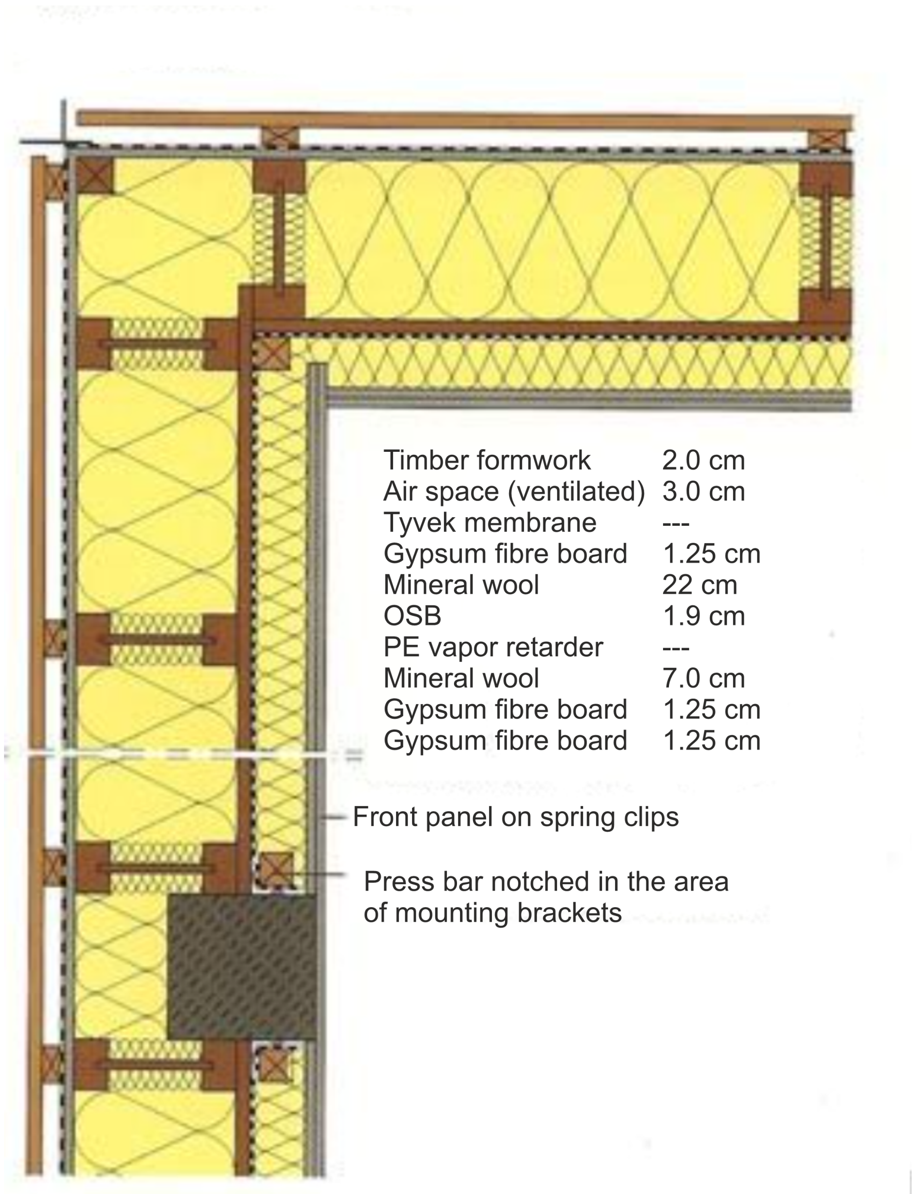


Figure 1. Sketch of the construction with corner area

To begin with, only the wall should be calculated. The next picture shows the section with the dimensions.

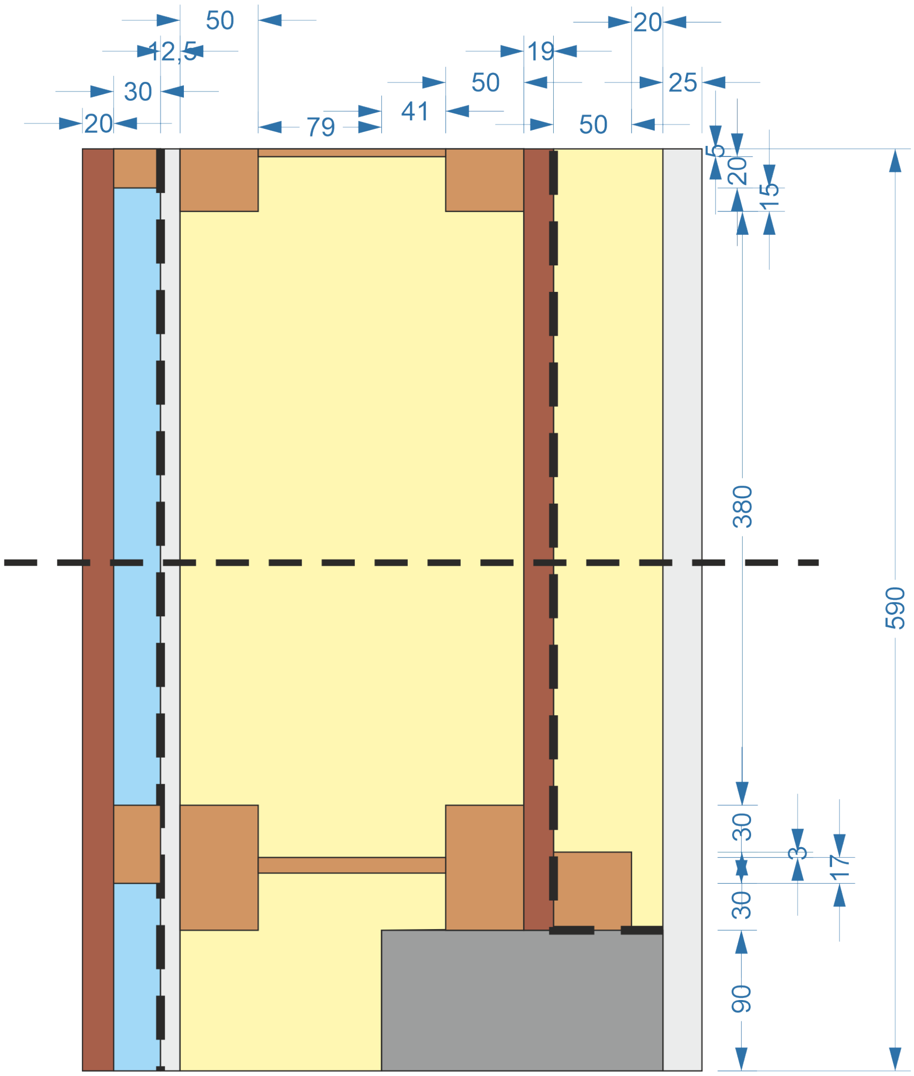


Figure 2. Sketch of the wall construction

2. Structure and evaluation of the construction 1D

For an initial pre-simulation, only the wall cross-section should be calculated as 1D. Later, the detail will be extended to 2D. The dashed line in the sketch above shows the sectional plane. This results in a construction as shown in the picture below.

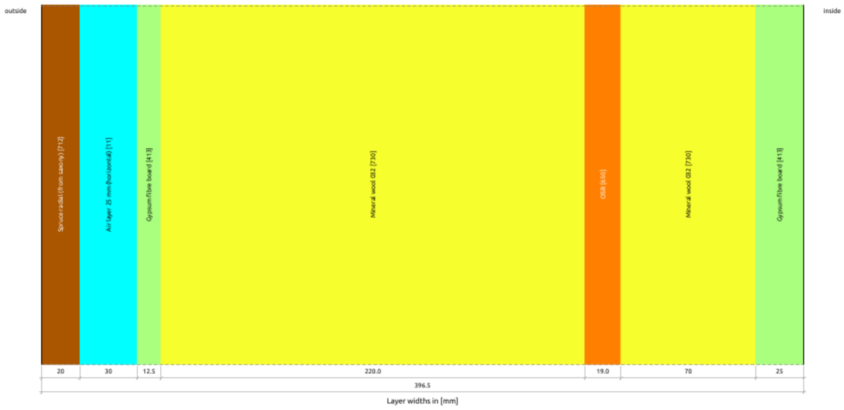


Figure 3. Wall construction in 1D

This construction can be created using the project wizard as described in Tutorial 1. The two vapor retarders should be modeled as contact conditions and are therefore not provided as layers. The construction therefore has 7 layers. Further adjustments must be made to complete the simulation:

- Adding and assigning the vapor retarders as contact conditions
- Ventilation of the outer air space with a source
- Insertion of a leakage source in accordance with DIN 4108-3 D.6.2
- Adding further outputs for verifications

The use of a source for mapping the rain pentration of the facing layer in accordance with DIN 4108-3 D.6.3 is not necessary here because the surface of the base structure can be assumed to be water-repellent due to the Tyvek film.

2.1. Vapor retarders as contact conditions

To simplify the simulation, vapor retarders can be represented as additional resistances between the material layers (see also ISO 15026 2023 6.2). In DELPHIN, these resistances are also called contact conditions. They allow the mapping of all vapor retarders including those with a variable moisture effect. In this construction there are two vapor retarders, a PE foil on the inside and a Tyvek foil on the outer air space. First, the two contact conditions are created. To do this, click on the green plus in the appropriate dialog (usually at the bottom right).

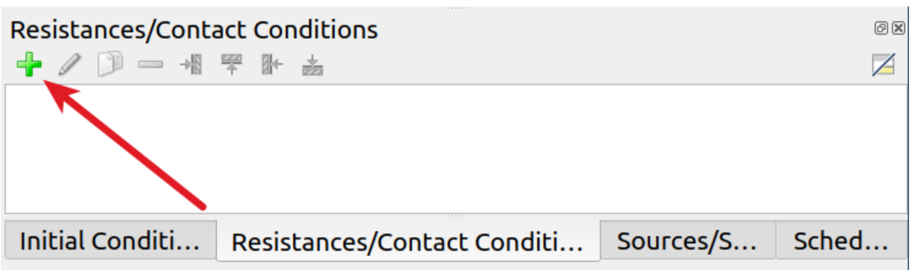


Figure 4. Adding contact conditions

In the following dialog, you must first select the type. In addition to other types, there are two variants for vapor retarders:

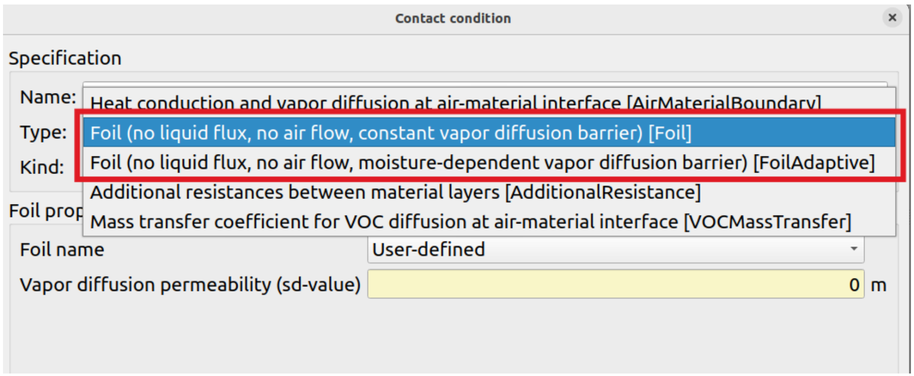


Figure 5. Type selection in the contact condition dialog

- Foil …, constant vapor diffusion barrier
- Foil …, moisture-variable vapor diffusion barrier

In this construction, both vapor barriers have a constant vapor diffusion resistance. You can now select one from the list of existing vapor retarders in the database or define your own by clicking on *'User-defined'*. The Tyvek foil is included in the database, but the PE foil is not. So we select *'User defined'* for this and enter an estimated sd value of 1000m. Finally, we give the whole thing a meaningful name.

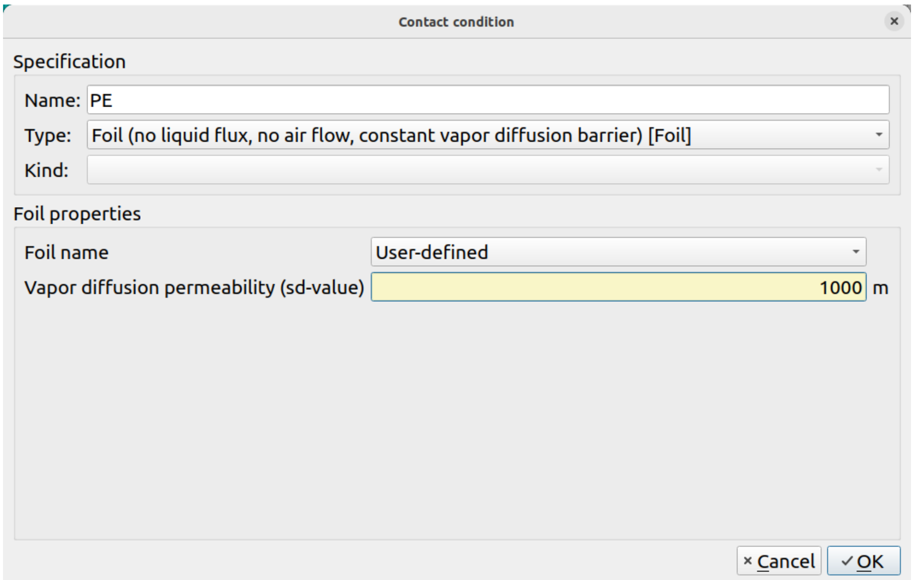


Figure 6. PE film as user-defined contact condition

There is an entry in the database for the Tyvek foil, so it simply needs to be selected. Now the contact conditions only need to be assigned to the construction. To do this, proceed as follows:

1. Select an element at the material boundary (it does not matter which side)
2. Select the contact condition in the list

3. Click on the correct assignment button to select the correct side

When assigning, please note that you are not selecting an element but a side. For example, if you have selected the element to the left of the material boundary, the right-hand side must be assigned. The process is shown in the image below.

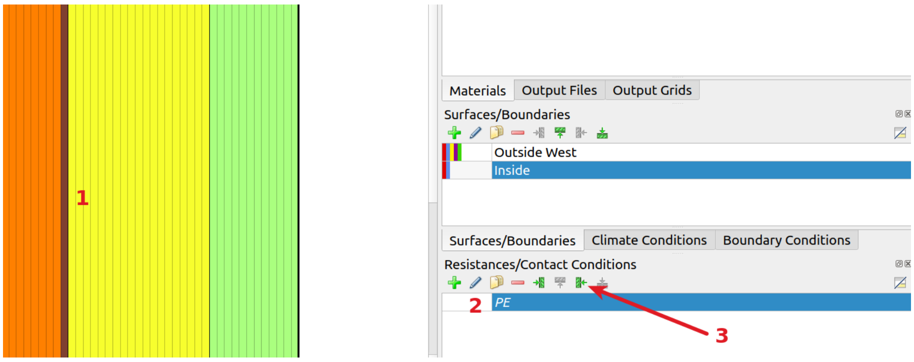


Figure 7. Assignment of the PE foil as contact condition

After assignment, the contact conditions are displayed in the construction as a thick dashed lines.

Figure 8. Construction with two assigned contact conditions

2.2. Ventilation of the air space

The air space behind the outer battens is ventilated. This can be mapped using a source (field condition) (see WTA 6.2 2014 5.1). To do this, first create a source of the type *'Air exchange with ambient air …'* and then assign it to the air space.

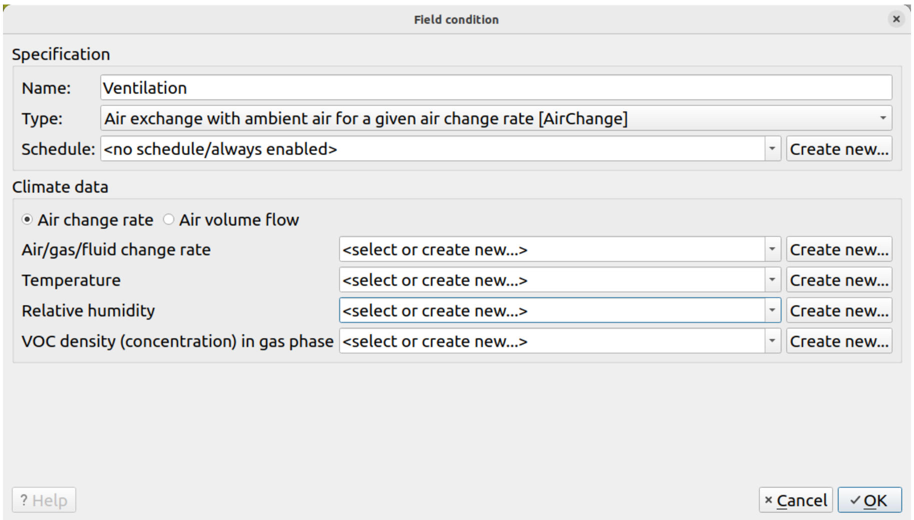


Figure 9. Dialog for creating a source for air exchange

After selecting the type, the following parameters must be defined

- Type of climate for ventilation (air exchange rate or air volume flow)
- Climate for ventilation
- Climate with temperature and humidity of the incoming air

In this example, the air exchange rate is to be used. You can specify a time-dependent value here by creating a suitable climate data set. For this tutorial, however, a constant air exchange rate is to be specified. If the selection box says <*Select or create new*>, the button to the right must show *'Create new'*. Clicking on it opens the dialog for a new climate condition. The default setting here is a constant value for *'Type'*. The input field below is initially colored red because no valid value has yet been entered. You then only need to enter the desired number here.

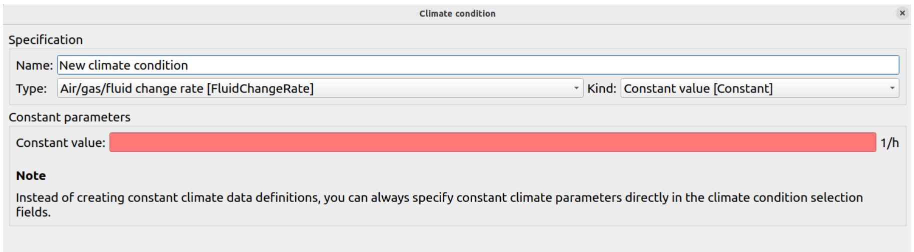


Figure 10. Dialog for climate condition - Start

You must now enter a name and enter the air change rate in 1/h as the value. The WTA leaflet 6.2 recommends a value of 20 h^{-1} in chapter 5.1 for ventilated and small-scale facades. More data can be found in the literature. For example, the following table can be found in *'Mayer, E,; Künzel, H.: Untersuchung über die Belüftung des Luftraums hinter vorgesetzten Fassadenbekleidungen aus kleinformatigen Elementen, Forschungsbericht Nr. B Ho 22/80, Holzkirchen 1980'*.

Table 1. Table with air exchange rates for rear ventilation

Type of rear ventilation	**Air change rates in h^{-1}**					
	No shielding		Medium shielding		Strong shielding	
	Air layer thickness in mm					
	30	50	30	50	30	50
Ventilated façade	50	30	32	20	17	11
Ventilated air layer with joints	20	12	13	7	7	3

For our example we choose a value of $20h^{-1}$.

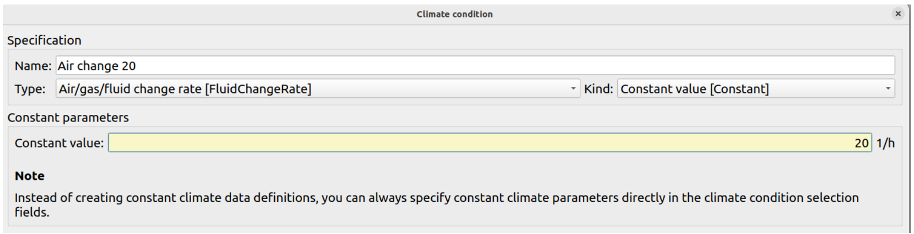


Figure 11. Dialog for climate condition - filled in

After closing this dialog by clicking on 'Ok', we return to the source dialog. Here we only need to select the temperature and humidity of the incoming air from the existing entries. The VOC density can be neglected.

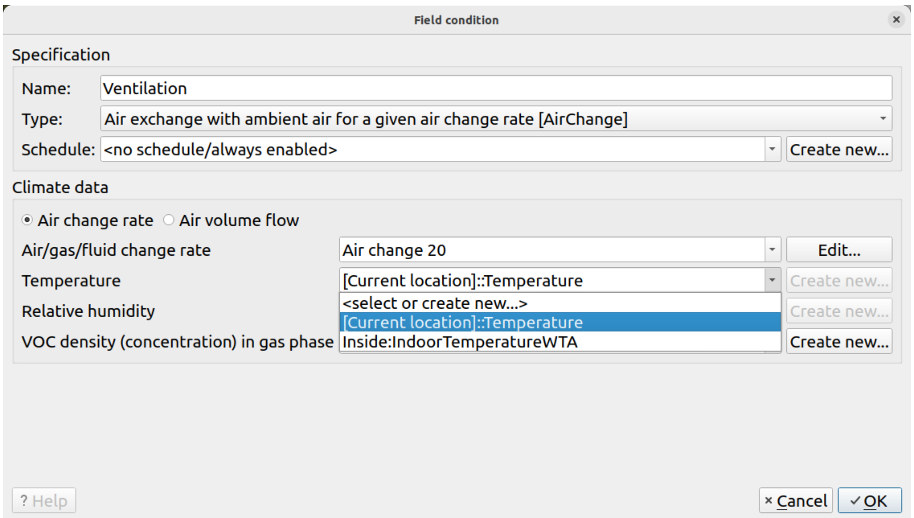


Figure 12. Source dialog with climate selection list

If you click on the triangle in the selection list, all currently available climate conditions of this type appear. In the current example, there is only one value for the outdoor climate ('[Current location]::...') and one value for the indoor climate. Select the outdoor climate for temperature and relative humidity. The dialog is now completed and can be assigned to the air layer.

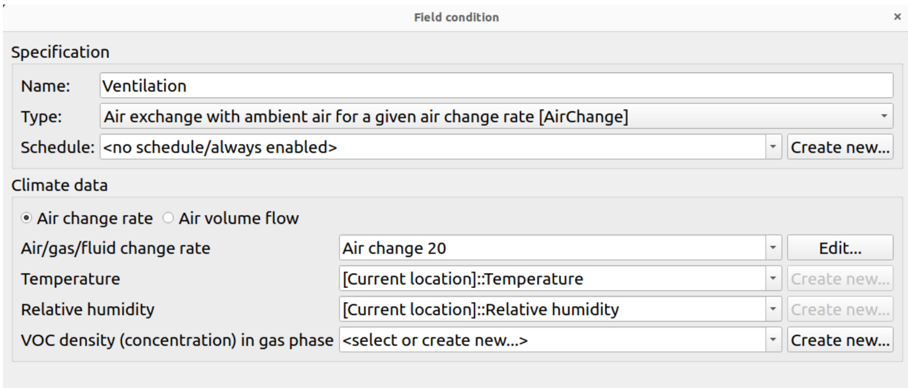


Figure 13. Source dialog - finished

2.3. Leakage source

According to DIN 4108-3 D6.2, a moisture source must be provided for lightweight constructions that takes convective moisture intake into account. This goes back to DIN 68800-2. It is argued there that lightweight constructions cannot be practically airtight and that possible moisture intake due to air flow from the inside to the outside should therefore be provided for. How this works in practice is explained in Tutorial Moisture source leakages .... However, the question is also whether such a source is necessary here. The following table can be found in DIN 68800-2.

Table 2. Table for determining the necessity of a drying reserve (leakage source)

sd value outside	sd value inside
≤ 0.1 m	≥ 1.0 m
≤ 0.3 m	≥ 2.0 m
0.3 m≤ sd ≤ 4.0 m	6 * sd outside

In the case of this construction, the sd value is around 1000m on the inside (PE foil) and around 0.3m on the outside (Tyvek plus gypsum fiberboard). This would fulfill the condition in the table and a source would not be necessary.

2.4. Outputs for assessment

As a result of creating the construction using the project wizard, there are already outputs for the total moisture content, profiles for temperature, moisture content and relative humidity as well as values on the surfaces.

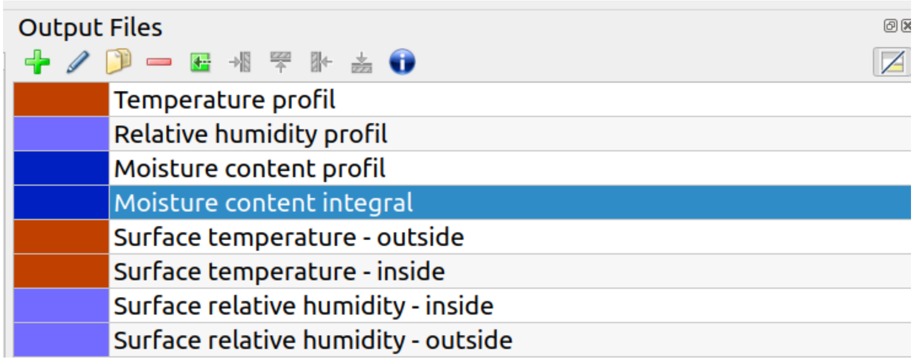


Figure 14. Predefined standard outputs

Furthermore, the automatic assessments should be activated, which already test for moisture accumulation, frost damage and mold on the interior surface and provide outputs. The latter two evaluations are not actually required for this construction, as neither frost nor mold are likely. In addition, an evaluation of wood damage would be possible. For this purpose, outputs on mass-related moisture content, temperature and relative humidity would have to be generated as mean values of the affected wood layer. But here, too, the meaningfulness must be questioned. It makes no sense to evaluate the outer cladding and the inner layer of wood is sandwiched between two layers of insulation, which makes damage unlikely. Another possible evaluation would be the moisture content on the outermost mineral wool layer. If a lot of condensation occurs here, there is a risk of run-off. This should be tested. For this purpose, an output for the water mass density in kg/m^3 is added and assigned to the outermost 10 mm of the mineral wool. This value should be less than 100g (based on $1m^2$ wall area). The following picture shows the settings.

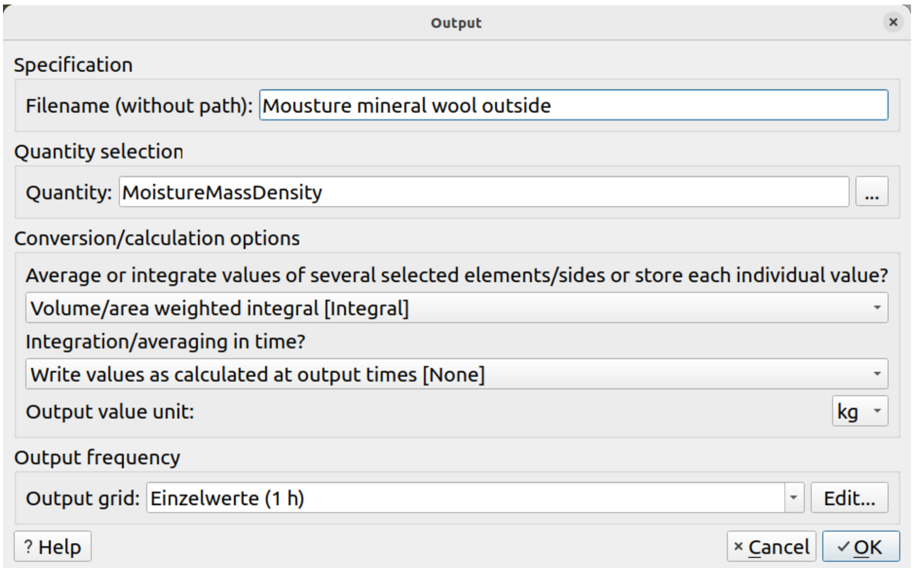


Figure 15. Output settings for the moisture of the outer mineral wool layer

The following image shows the selection of an area for the assignment of this output.

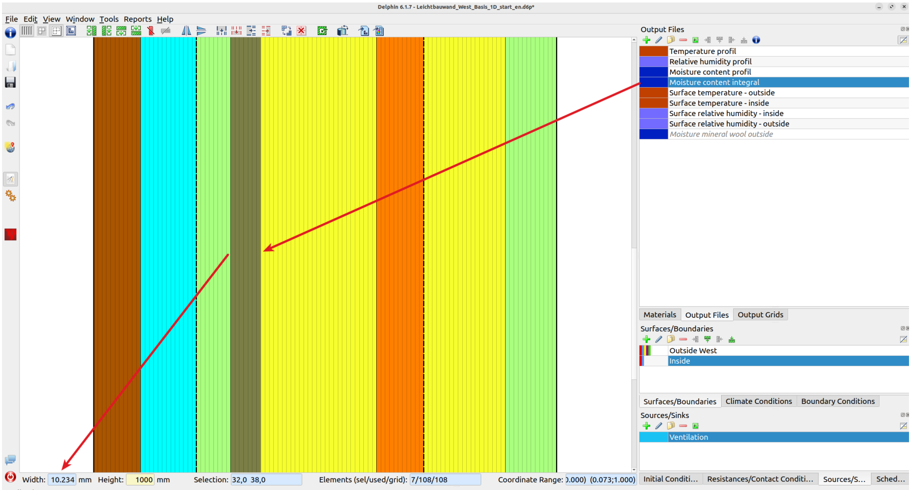


Figure 16. Output for the moisture of the outer mineral wool layer

The area is now not exactly 10mm wide. This is due to the current discretization. If you want a layer exactly 10mm wide, you have to define this beforehand by modeling the mineral wool as two layers. You could delete the discretization, split the mineral wool so that the layer consists of two partial layers (10mm + 210mm) and then discretize it again. The following image shows the result.

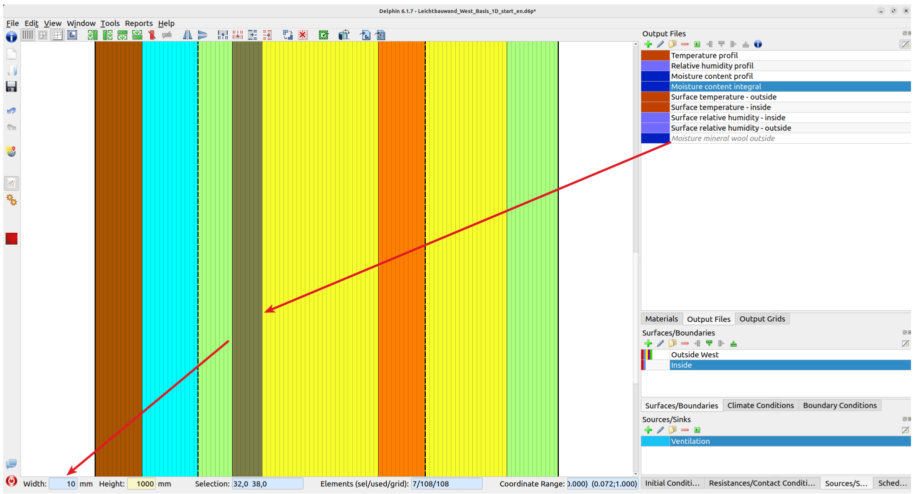
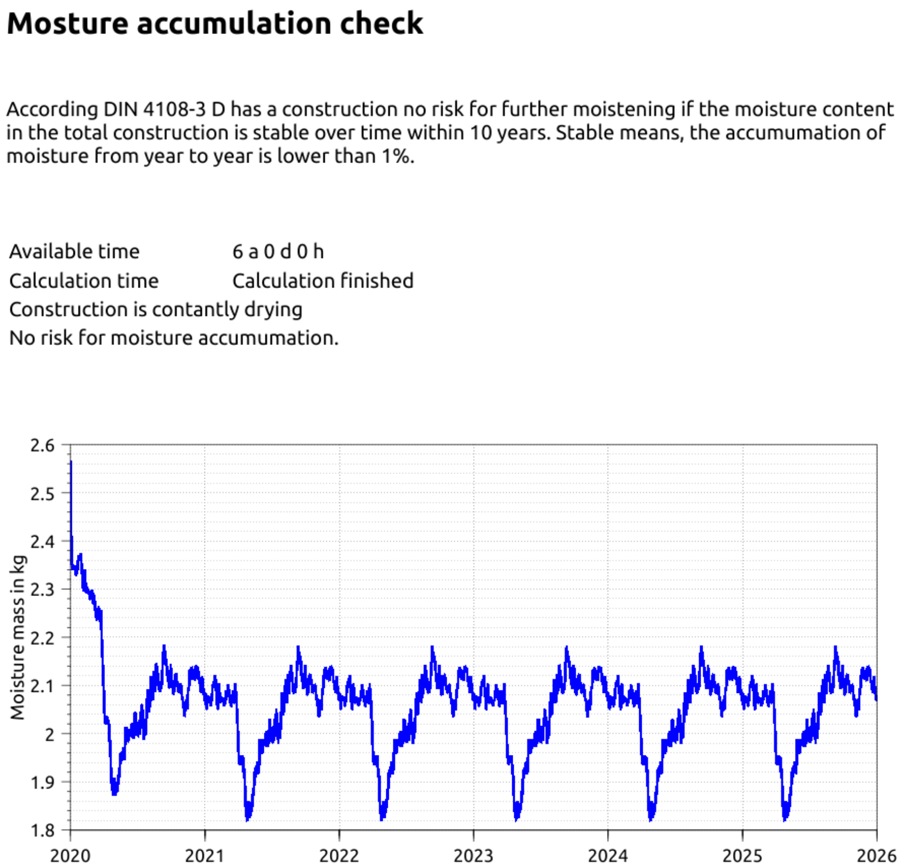


Figure 17. Output for the moisture of the outer mineral wool layer with thickness adjustment

2.5. Evaluation of the results

As this is a 1D calculation, you can first look at the report for the evaluations. This report automatically tests for moisture accumulation, frost damage and mold.


Mosture accumulation check

According DIN 4108-3 D has a construction no risk for further moistening if the moisture content in the total construction is stable over time within 10 years. Stable means, the accumumation of moisture from year to year is lower than 1%.

Available time	6 a 0 d 0 h
Calculation time	Calculation finished

Construction is contantly drying
No risk for moisture accumumation.

Figure 18. Output report with test for moisture accumulation

The test for moisture accumulation shows that a stable condition is reached after approx. 2 years. There is therefore no risk. According to DIN 4108-3 D.7.2, highly water-bearing layers, such as facing formwork, should be excluded from this test. This can be set in the report options as shown in the next image.

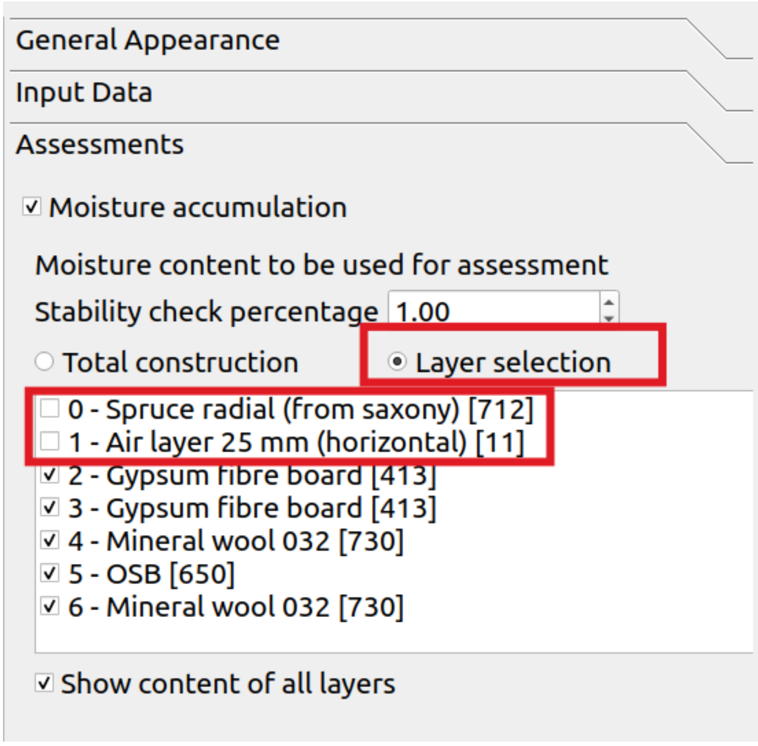


Figure 19. Output report - options for layer selection

The tests for frost risk and mold were also negative. The following image shows an example of the mold test.

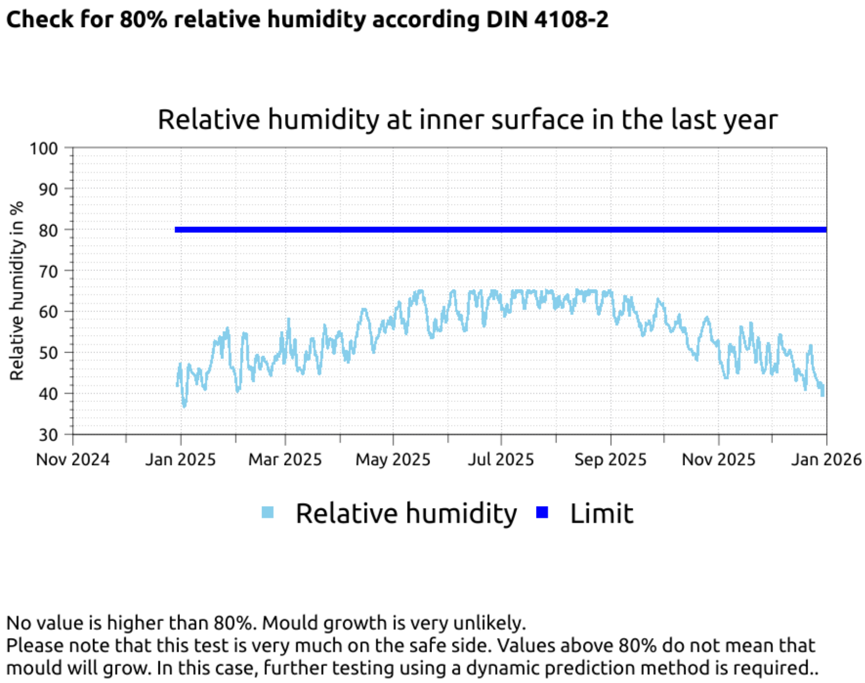


Figure 20. Output report with test for mold on the interior surface

You can find out more about outputs and evaluations in tutorials 4 and 5 on our website www.bauklimatik-dresden.de/delphin/documentation.php.

The calculation and evaluation of the 1D case is now complete. In order to be able to evaluate any thermal bridge effects, a section of the construction should now be calculated in 2D.

3. Structure and evaluation of the 2D construction

3.1. Procedure for creating the model

The construction as shown in Figure 2 should be used as the basis for this calculation. To prepare the input, the construction is first divided into sections in the x and y directions. The number of rows (y) and columns (x) resulting from all existing material boundaries and edges should be determined. It is advisable to use a simple vector drawing program for this task.

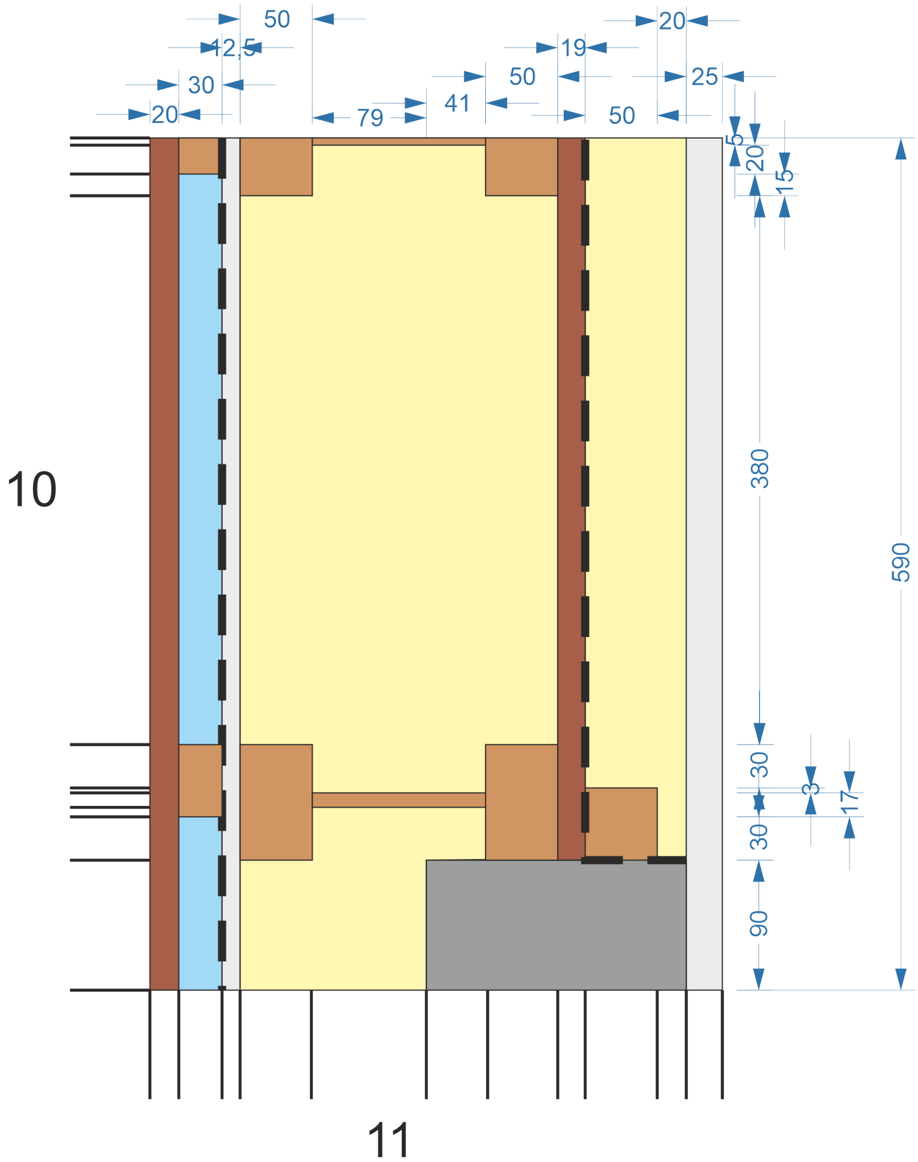


Figure 21. Division of the construction into x and y sections

There are 11 columns and 10 rows. The thicknesses of the sections result from the dimensions in the drawing and are as follows:

- Columns (from left to right) in mm
    - 20; 30; 12.5; 50; 79; 41; 50; 19; 50; 20; 25
- Rows (from bottom to top) in mm
    - 90; 30; 7; 10; 3; 30; 380; 15; 20; 5

If a 1D variant already exists, there are several ways to set up a 2D project:

- completely new using the project wizard
- based on the 1D construction
    - Extend the existing geometry
    - Delete the old geometry and create a new one in the geometry view

For complex 2D geometries, it is often better to start from scratch. Then you just have to make sure that the materials and boundary conditions match the original 1D design. Extending an existing 1D project is only recommended for simple geometries such as a wall edge or an internal wall connection. In this case, you should work on the basis of the 1D project but create the geometry from scratch. Proceed as follows:

- Delete all layers (columns or rows) except for the last one (because not possible)
- Remove the last material assignment
- Add columns and rows with specification of heights and widths
- Add missing materials (concrete)
- Assigning the materials
- Assigning the contact conditions
- Assigning the sources for ventilation of air space
- Checking and correcting the boundary conditions
- Discretization
- Checking and reassigning outputs

3.2. Deleting the existing geometry

First remove the discretization by clicking the corresponding button.

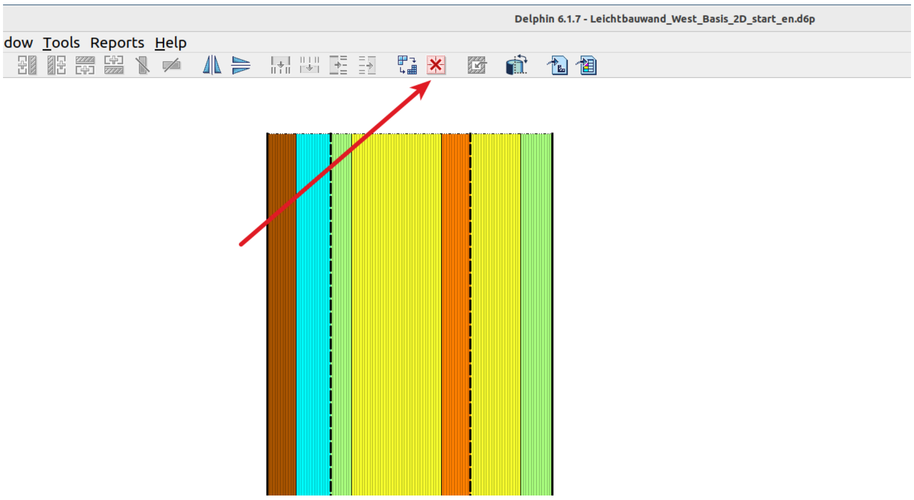


Figure 22. Remove the discretization

All existing columns should then be deleted. To do this, select a column and press the button for deleting columns. You can also delete several columns at once, but not all of them.

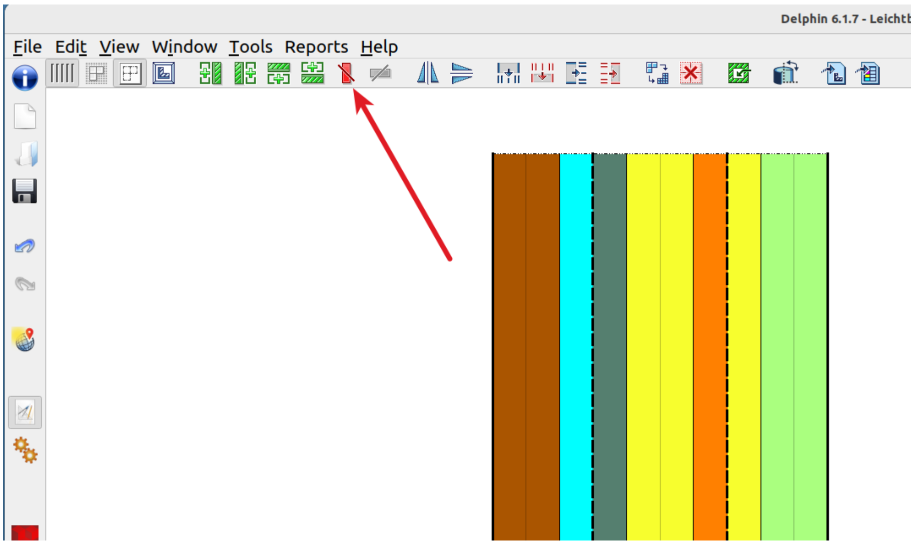


Figure 23. Deleting a column from the geometry

After there is only one column left, you have to remove the material assignment. To do this, open the assignment window for the materials (1), select the remaining assignment (2) and delete it by clicking on the minus button (3) or pressing *Del*.

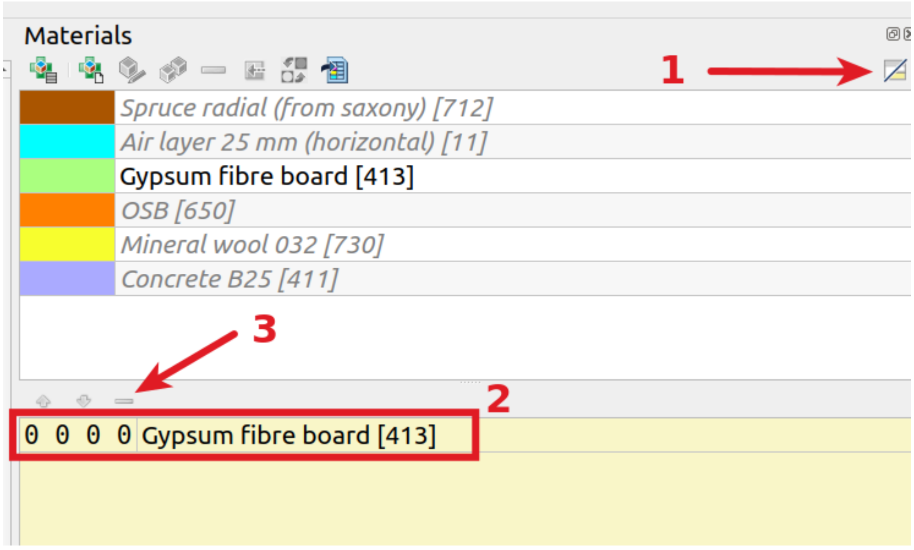


Figure 24. Remove the last material assignment

Then you have an empty geometry without assignment and can create the new 2D geometry.

3.3. Geometry and material assignment

Rows and columns are added using the 4 green buttons at the top of the geometry toolbar.

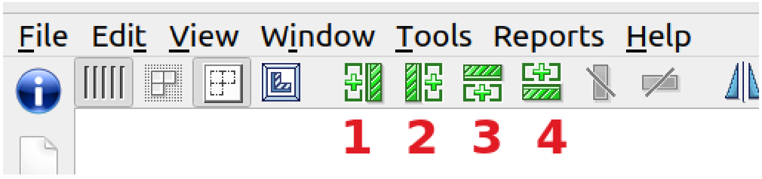


Figure 25. Buttons for adding columns and rows

1. Add column to the left of the selected
2. Add column to the right of the selected
3. Add row below the selected
4. Add row above the selected item

Select one or more elements and then click on the appropriate button. A dialog then appears in which you can specify the height or width of the layer.

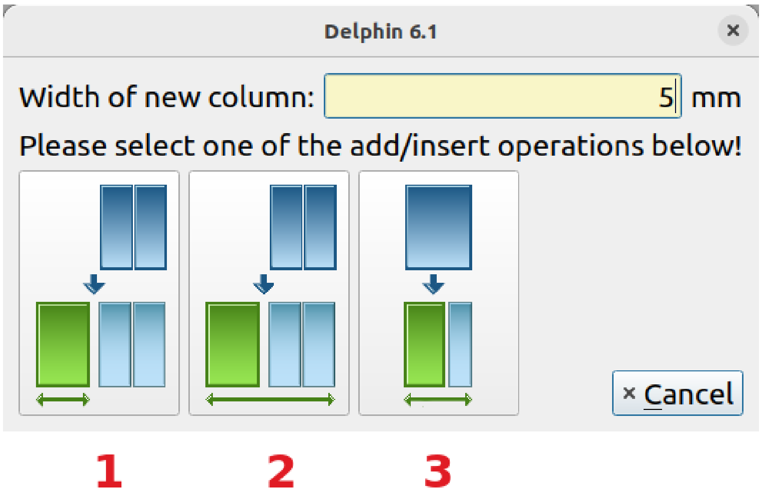


Figure 26. Dialog for adding columns or rows

First enter the width or height at the top right. Then click on one of the three large buttons at the bottom left. These have the following meaning:

1. Width or height only applies to newly added column or row
2. Width or height only applies to the selected area plus the newly added column or row
   - new is the difference between the specified value minus the selected area
3. as for 2. but only the neighboring element is counted

For this structure, you only need button 1. Once all rows and columns have been added, you can assign the materials.

When assigning materials, it is a good idea to switch on the non-equidistant display mode. This is much clearer. The following two images demonstrate the finished geometry view without materials in both views.

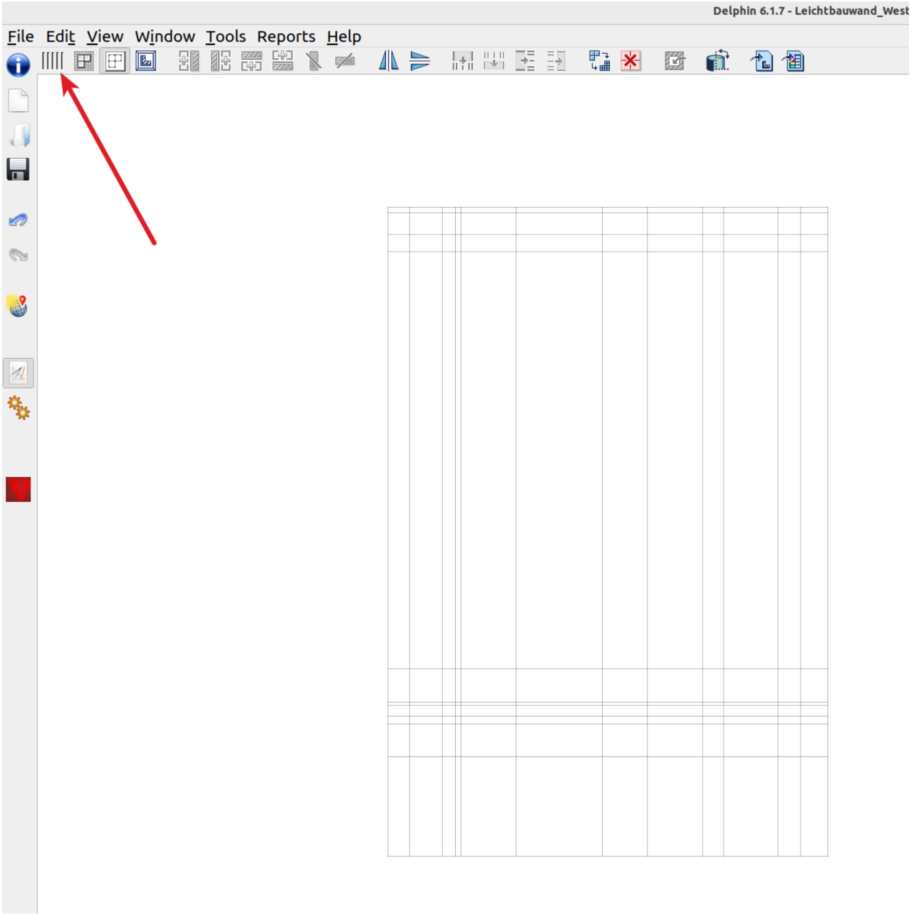


Figure 27. Geometry view in non-equidistant mode

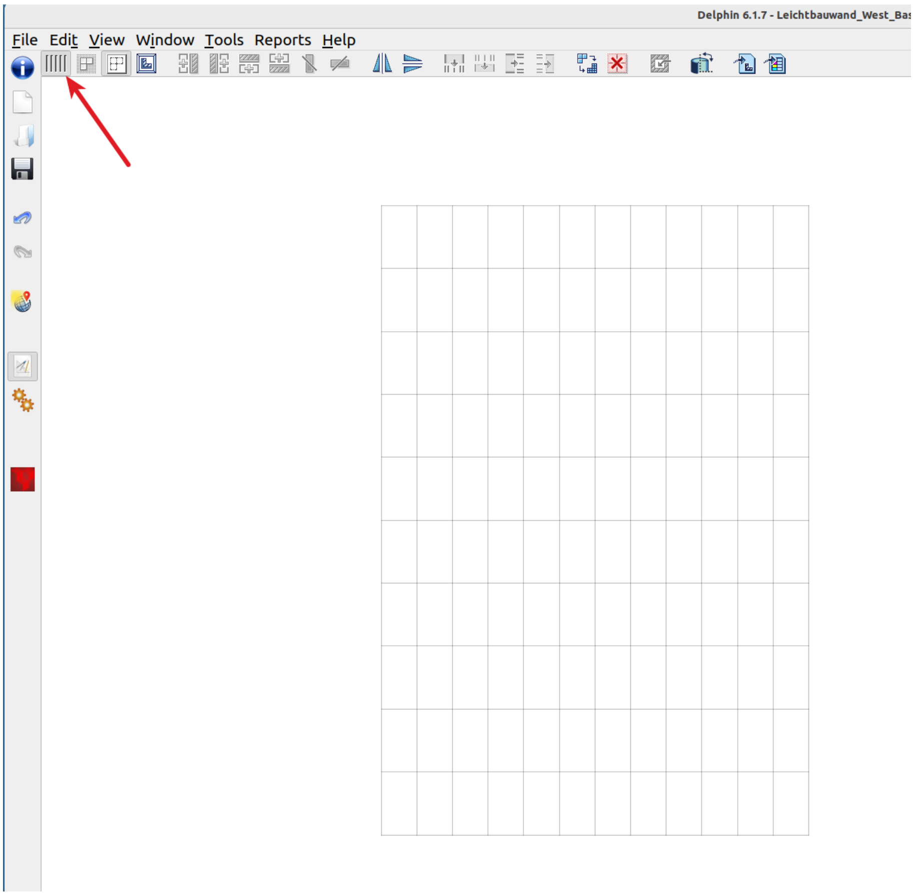


Figure 28. Geometry view in equidistant mode

DELPHIN allows areas to overlap when assigning materials. However, this makes it difficult to maintain an overview during checks and subsequent changes and can easily lead to errors. It should therefore be avoided. The following image shows the geometry with finished assignments.

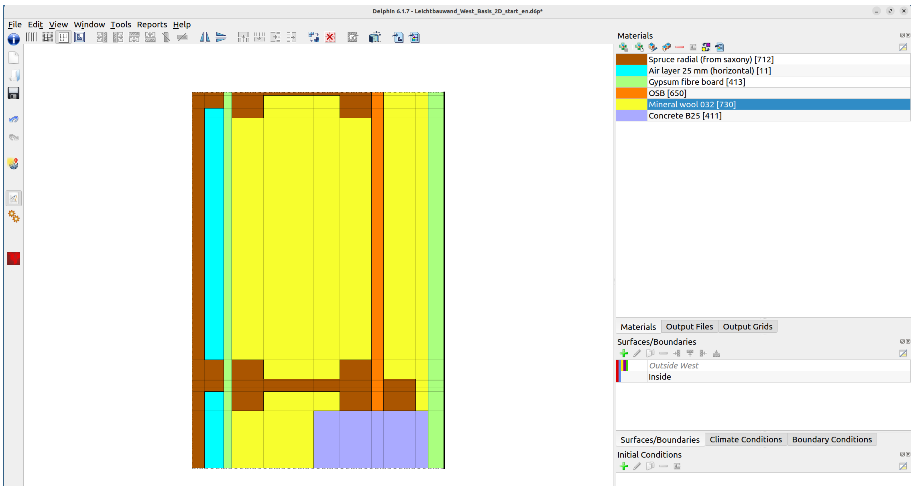


Figure 29. Geometry view with materials

The next point is the assignment of the vapor retarders as contact conditions. The Tyvek foil on the outside is located on the outside of the gypsum fiberboard, as in the 1D construction. The inner vapor barrier (airtight layer) runs along the inside of the OSB board and is then routed around the bottom of the concrete support. The finished assignment can be seen in the next picture.

3.4. Surface, contact conditions and sources

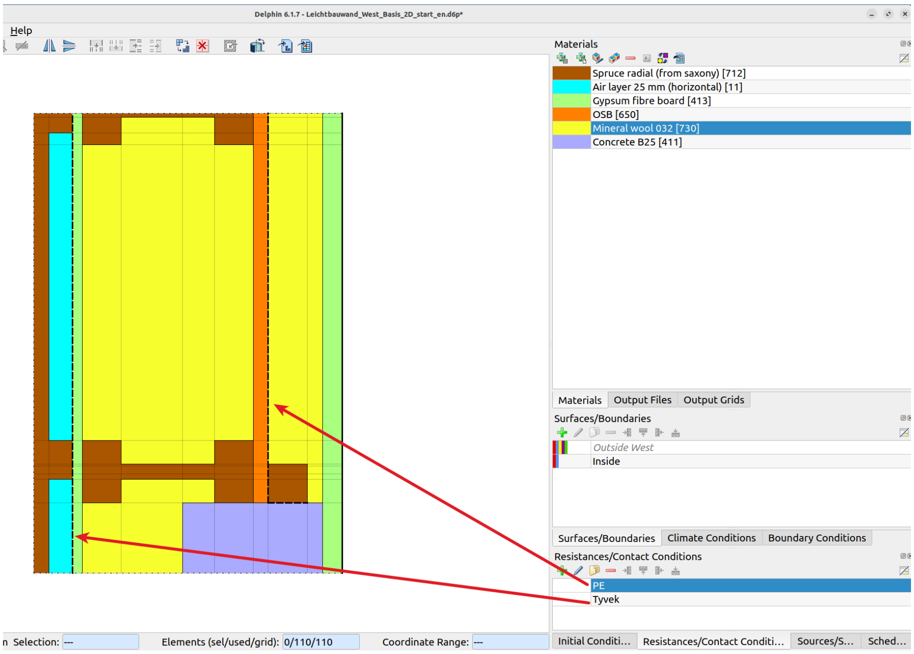


Figure 30. Geometry view with vapor retarders

The source for the ventilation is then assigned to the two air spaces on the outside. There is nothing else to consider.

The boundary conditions are still present. Whether they are still assigned depends on the type and sequence in which the layers are deleted. To check this, first look at the list of surfaces. In the image below, you can see that the outer surface is shown in gray and in italics. This indicates a missing assignment. To see the position of the assignment, simply click on (select) a surface in the list. The assignment positions are then displayed in the geometry view.

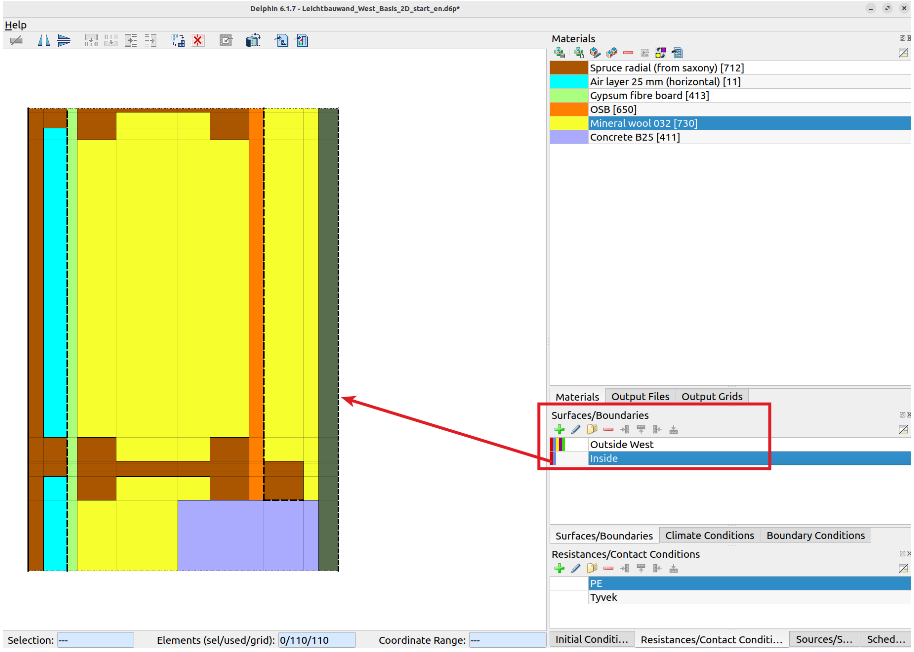


Figure 31. Geometry view with assignment of surfaces

The inner surface is correctly assigned. The outer surface must now be assigned to the entire left side of the construction. If everything is correct, two thick lines should be visible on the left and right edges. The top and bottom boundaries are marked by semicolon lines, which represents an adiabatic boundary. This means that no fluxes flow across these boundaries. This is possible with this construction because the boundaries represent symmetry axes.

3.5. Discretization

The next step is discretization. The discretization wizard is called up for this purpose. The grid to be created can be adjusted in the dialog that then appears.

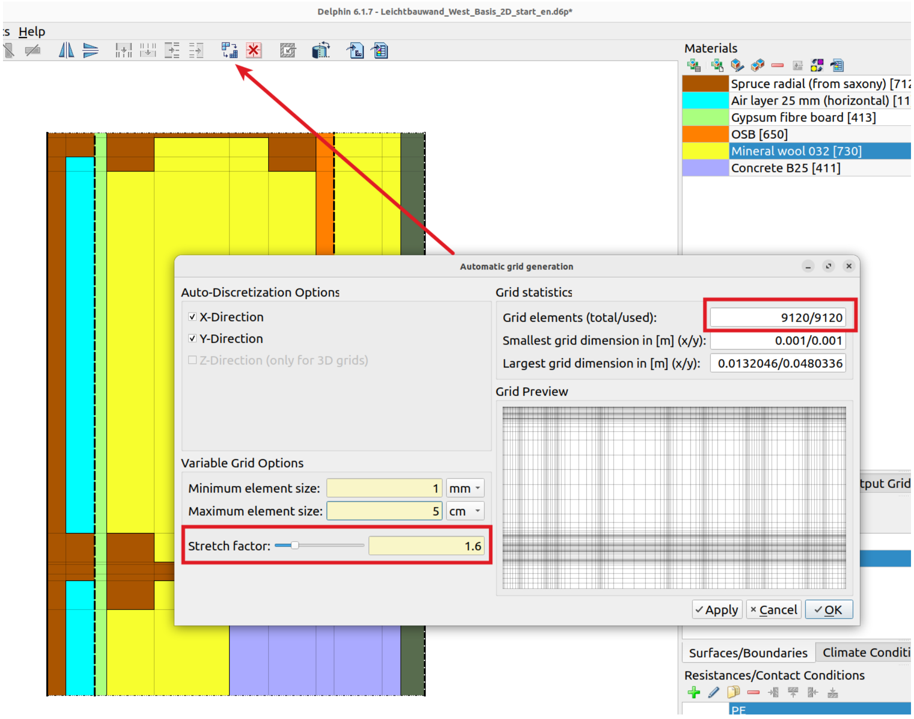


Figure 32. Dialog for the discretization of the construction

The settings can be seen in the image above. For this construction, the stretch factor was set to 1.6. The minimum and maximum element sizes remain at the default values of 1mm and 5cm. This results in a number of elements of around 9400 in this case, which is quite a lot and can lead to long calculation times on a normal computer or laptop. You could further increase the stretch factor and the maximum element size. As an example, the next image shows the setting for 1.9 and 15cm. This reduces the number of elements to 6800.

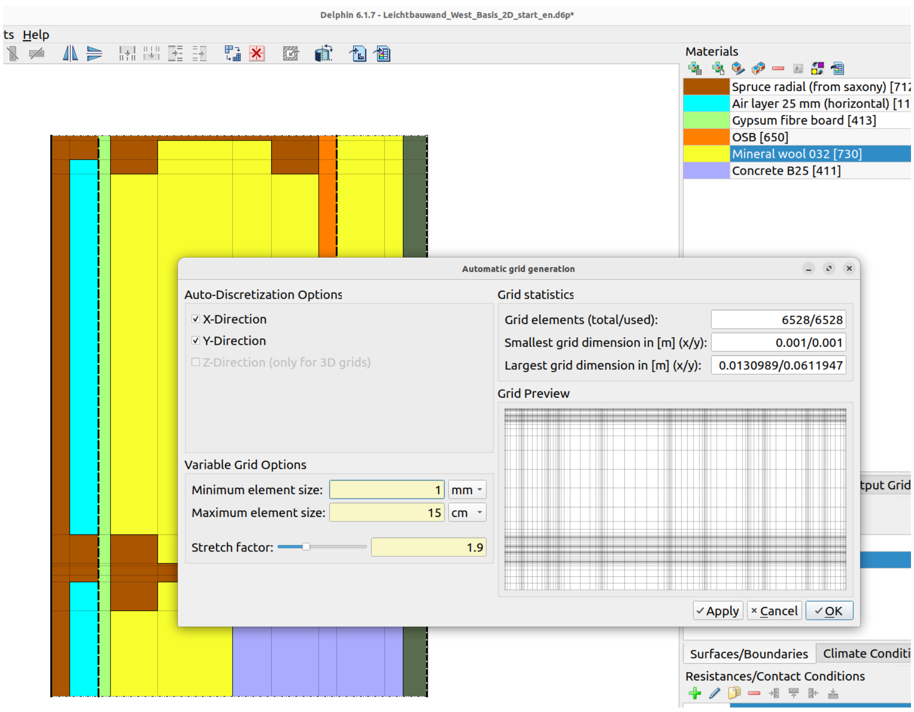


Figure 33. Dialog for the discretization of the construction with changed settings

You can now make further adjustments. A stretch factor of more than 2.6 is not recommended.

3.6. Output and evaluation

Since the geometry is completely new, only the outputs that affect the entire construction should still be assigned. Outputs for the evaluation of the construction must still be added. Up to and including DELPHIN 6.1.7 there is no automatic evaluation of 2D simulations. The most important evaluations for this construction concern wood damage and run-off moisture in the mineral wool. The wood damage assessment requires wood moisture in M%, temperature and relative humidity of partial areas of the timber construction. Areas measuring 1x1cm are usually selected. In order to select the correct areas before the calculation, you can first carry out a simulation with constant climatic boundary conditions for a limited period of time. Such simulations are quite fast. From the humidity profile at the end, you can identify areas in which a damage assessment seems sensible. The following figure shows such an relative humidity profile after 100 days of calculation.

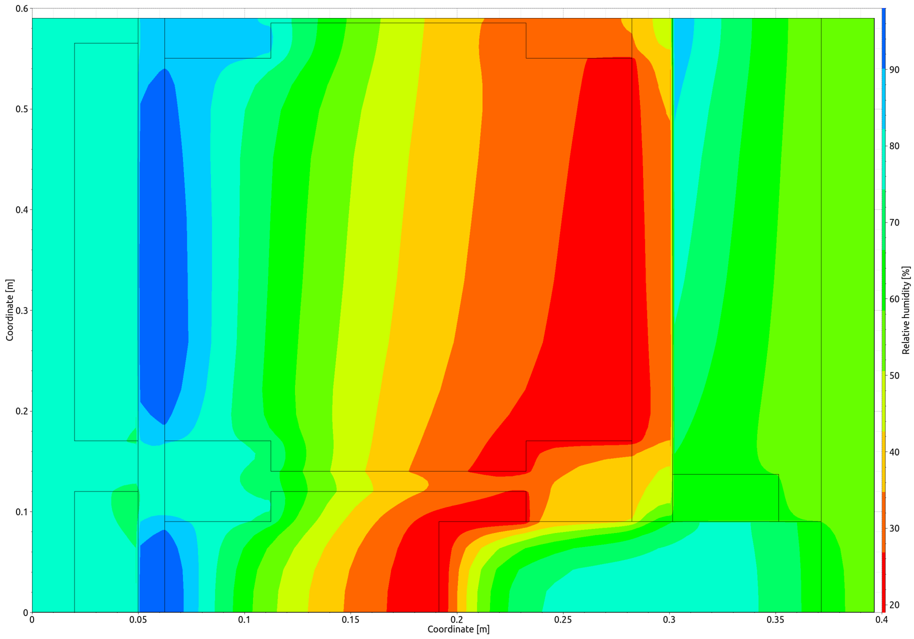


Figure 34. Relative humidity distribution after 100 days of constant climatic boundary conditions

You can clearly see the increased moisture in the outer board. In the area of the timber studs, the moisture is lower due to the thermal bridge effect. The highest moisture content in a timber component can be seen in the area of the upper timber stud. This is also where the outputs for a wood damage assessment should be located. The calculation can now be carried out with the normal climate. For comparison, two different discretizations were also calculated for this example.

The following diagram shows the moisture content in the upper timber stud for both discretizations.

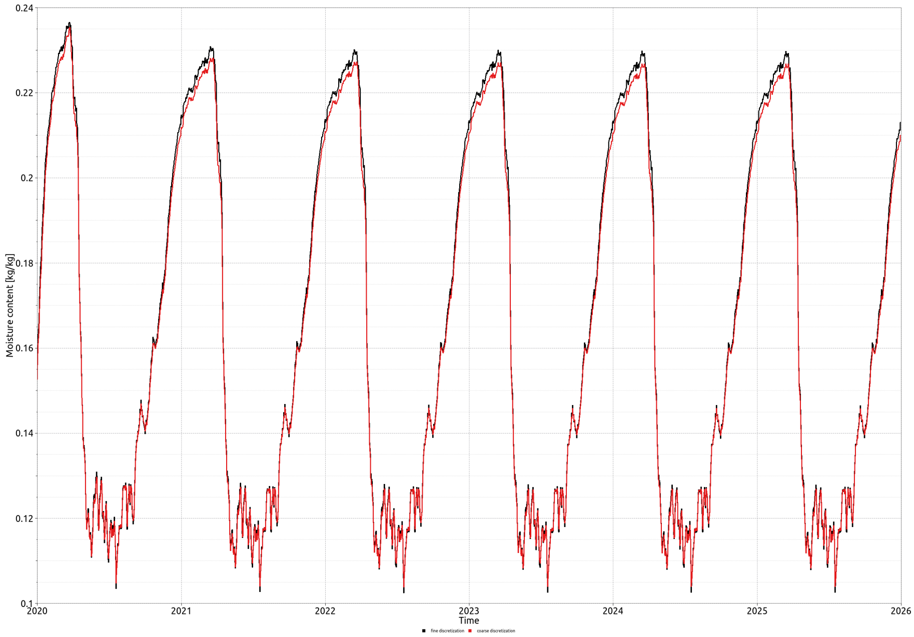


Figure 35. Moisture content in the upper timber stud

You can see small differences, especially in the peak values. The finer discretization shows slightly higher values. Although the values are stable, they are often above the limit value of 20M% (DIN 68800-2). This design is therefore to be considered critical. The coarser discretization was here more than twice as fast as the finer one, with a ratio of the number of elements of 9000 to 5000. Finally, an evaluation of the moisture content of the outer mineral wool layer follows with a comparison of the 1D calculation with both 2D calculations (coarse and fine).

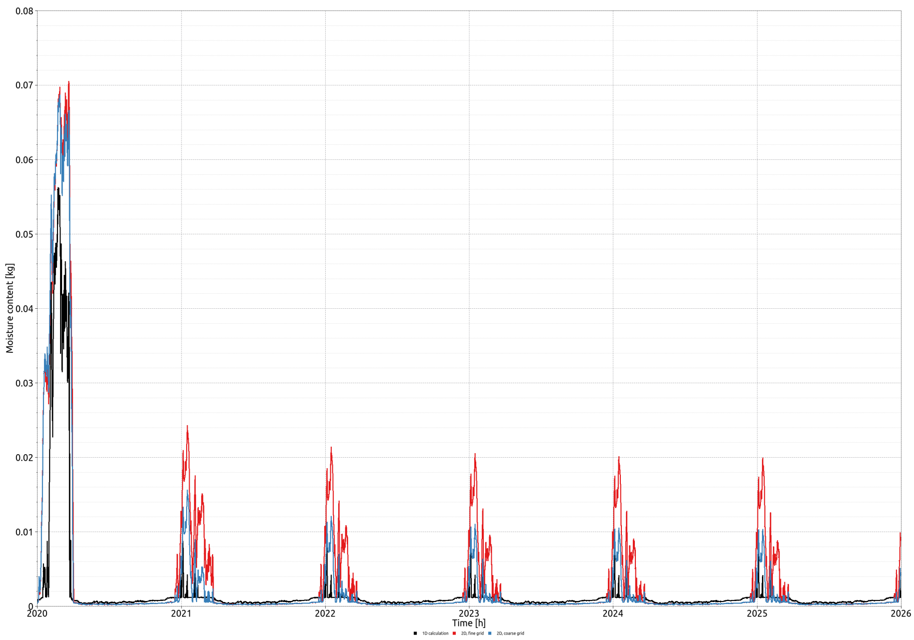


Figure 36. Moisture content in the outer mineral wool layer in comparison of all variants

Here you can clearly see that the 2D calculation with the fine discretization has the highest moisture content. However, as the limit value of 100g is never exceeded, condensation is not expected to run off.