Model created in COMSOL Multiphysics 6.4

Condensation Risk in a Wood-Frame Wall

Introduction

This tutorial shows how to model heat and moisture transport in a wood-frame wall to evaluate the risk of condensation inside the wall. Different design and modeling approaches are compared under stationary outdoor conditions. In addition, the effect of the diurnal variation of outdoor humidity on the humidity distribution in the wall is computed.

Model Definition

The model is the 2D representation of a portion of a wood-frame wall placed between different outdoor and indoor conditions. The risk of condensation in the wall is evaluated through the coupled computation of heat and moisture transport. Values of relative humidity close to unity indicate a risk of condensation.

Figure 1 shows the model geometry.

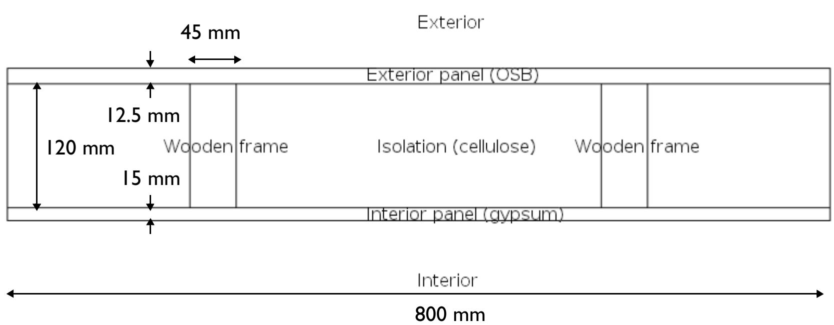


Figure 1: Model geometry.

The wall is made of the following components:

- Two wood studs made in pine
- Three isolation boards made in cellulose
- A bracing made of a wooden panel
- An interior siding made of a gypsum

In addition, a vapor barrier made of plastic coated paper may be placed between the gypsum interior siding and the isolation boards.

Convective heat and moisture flux conditions are applied on the top and bottom boundaries to model the outdoor and indoor air flows surrounding the wall. The outdoor and indoor heat transfer coefficients are set as h_{ext}=25 W/(m·K) and h_{int}=8 W/(m·K). The outdoor and indoor moisture transfer coefficients are set to $\beta_{ext} = 25\cdot10^{-8}$ s/m and $\beta_{int} = 8\cdot10^{-8}$ s/m, according to the heat and mass transfer boundary layers analogy.

The side boundaries are supposed to be totally isolated regarding heat and moisture.

DYNAMIC MODELING OF HEAT AND MOISTURE TRANSPORT

In this approach, both the transport of liquid moisture by capillary forces and the transport of vapor by diffusion are computed, and the latent heat effect due to vapor diffusion is modeled. In addition, heat and moisture storage is considered, and moisture-dependent thermal properties are used. The corresponding equations, defined in the Norm EN 15026, are solved by default by the Moisture Transport in Building Materials and Heat Transfer in Building Materials interfaces:

$$(\rho C_p)_{\mathrm{eff}}\frac{\partial T}{\partial t} - \nabla\cdot(k_{\mathrm{eff}}\nabla T + L_{\mathrm{v}}\delta_{\mathrm{p}}\nabla(\phi p_{\mathrm{sat}})) = Q$$

$$\xi\frac{\partial\phi}{\partial t} - \nabla\cdot(\xi D_{\mathrm{w}}\nabla\phi + \delta_{\mathrm{p}}\nabla(\phi p_{\mathrm{sat}})) = G$$

Here

- $(\rho C_p)_{\mathrm{eff}}$ (SI unit: J/(m^3·K)) is the effective volumetric heat capacity at constant pressure
- T (SI unit: K) is the temperature
- k_{eff} (SI unit: W/(m·K)) is the effective thermal conductivity
- L_{v} (SI unit: J/kg) is the latent heat of evaporation
- δ_{p} (SI unit: s) is the vapor permeability
- ϕ (dimensionless) is the relative humidity
- p_{sat} (SI unit: Pa) is the vapor saturation pressure
- Q (SI unit: W/m^3·s) is the heat source
- ξ (SI unit: kg/m^3) is the moisture storage capacity
- D_{w} (SI unit: m^2/s) is the moisture diffusivity
- G (SI unit: kg/m^3·s) is the moisture source

See Ref. 1 for details about the norm EN 15026.

STATIC MODELING OF HEAT AND MOISTURE TRANSPORT

By ignoring heat and moisture storage, latent heat effect, and capillary transport of liquid moisture, the following equations are obtained for heat and moisture transport:

$$-\nabla \cdot (k_{\mathrm{eff}} \nabla T) = Q$$

$$-\nabla \cdot (\delta_{\mathrm{p}} \nabla(\phi p_{\mathrm{sat}})) = G$$

These equations are known as the Glaser method. They can be solved in the Moisture Transport in Building Materials interface by setting the moisture diffusivity to 0, and in the Heat Transfer in Building Materials interface by setting the vapor permeability to 0.

The advantage of this second approach is that you need to provide less hygroscopic material properties. In particular, the moisture diffusivity used for the expression of the liquid transport flux is not required. However, for high values of relative humidity, the simplifications mentioned above may result in an overestimation of the relative humidity and in consequence of the risk of condensation.

MODELING OF THE VAPOR BARRIER

Upside and downside moisture fluxes defined by $\beta(\phi_{\mathrm{d}} - \phi_{\mathrm{u}})$ and $\beta(\phi_{\mathrm{u}} - \phi_{\mathrm{d}})$ are applied at the interface between the interior siding and the isolation to model the vapor barrier. The moisture transfer coefficient β is defined as

$$\beta = \frac{\delta p_{\mathrm{sat}}}{\mu d_{\mathrm{s}}}$$

where δ is the vapor permeability of still air (SI unit: s), p_{sat} is the saturation pressure of water vapor (SI unit: Pa), μ is the vapor resistance factor (dimensionless), and d_{s} is the vapor barrier thickness (SI unit: m).

DIURNAL VARIATIONS OF OUTDOOR CONDITIONS

The effect of time-dependent outdoor conditions on condensation risk is studied by using typical weather data from ASHRAE database. Average temperature and relative humidity ambient conditions in Dublin from the 15^{th} to the 17^{th} of April are used for the definition of the convective flux conditions on the exterior side of the wall. The simulation is run over two days with the temperature and relative humidity conditions shown in the graph of Figure 2.

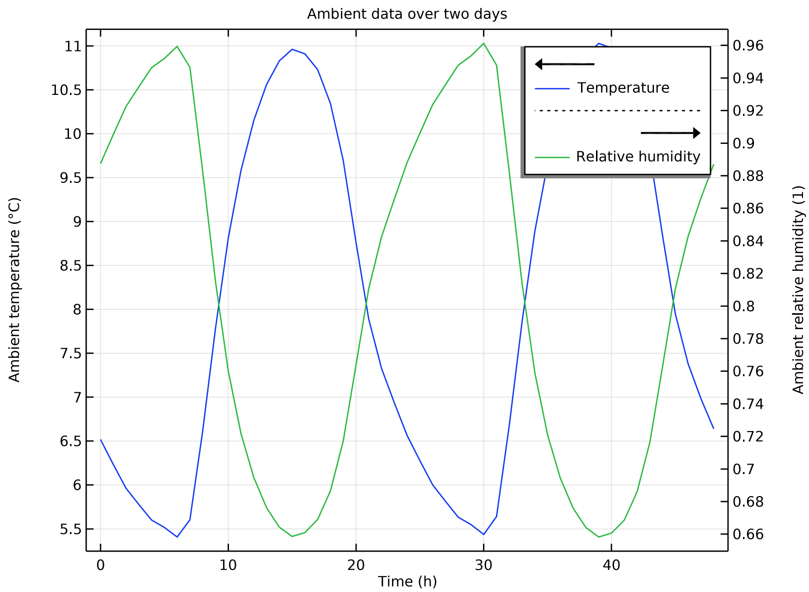


Figure 2: Ambient data for temperature and relative humidity used on the exterior side of the wall.

TEMPERATURE AND MOISTURE DISTRIBUTIONS WITHOUT VAPOR BARRIER

The temperature and moisture distributions due to the different outdoor and indoor conditions are shown in Figure 3 and Figure 4. The highest values of relative humidity are obtained close to the bracing.

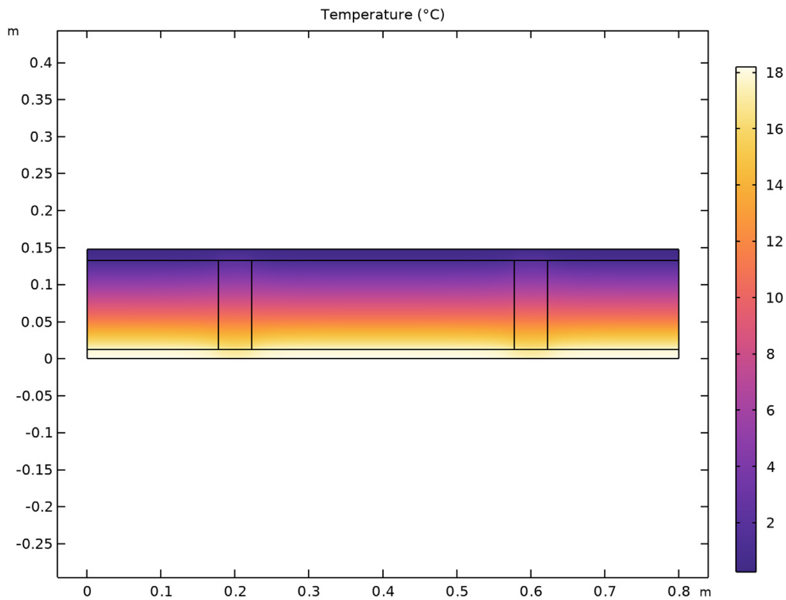


Figure 3: Temperature distribution, stationary study without vapor barrier.

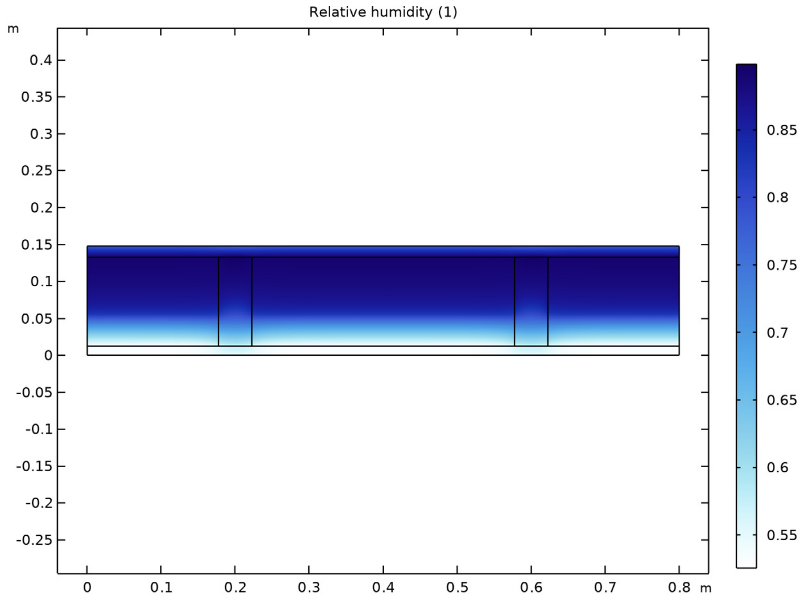


Figure 4: Relative humidity distribution, stationary study without vapor barrier.

EFFECT OF VAPOR BARRIER ON HEAT AND MOISTURE DISTRIBUTION

The graph of Figure 5 shows that the addition of a vapor barrier between the interior siding and the isolation reduces the risk of condensation at the interface between the wooden frame/isolation and the bracing.

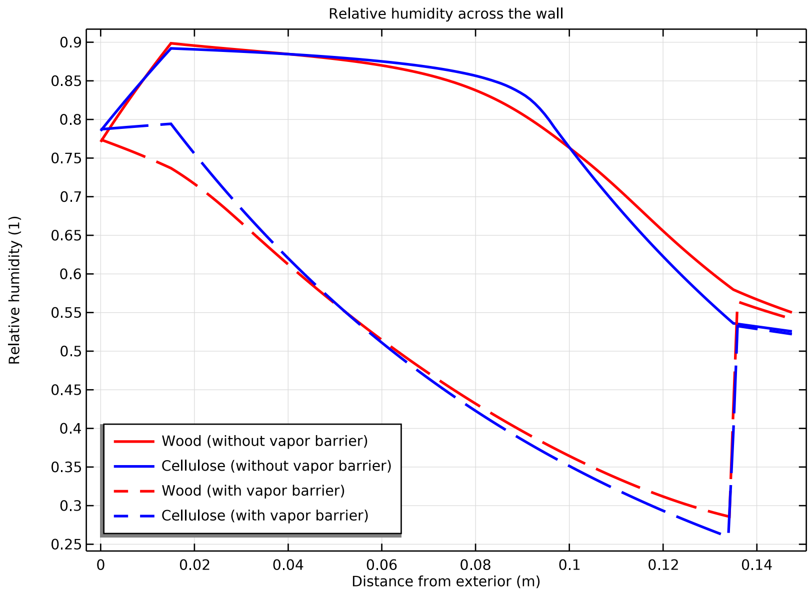


Figure 5: Effect of vapor barrier on relative humidity distribution across the wall, in the wooden frame and in the isolation.

The effect on temperature distribution is shown in Figure 6.

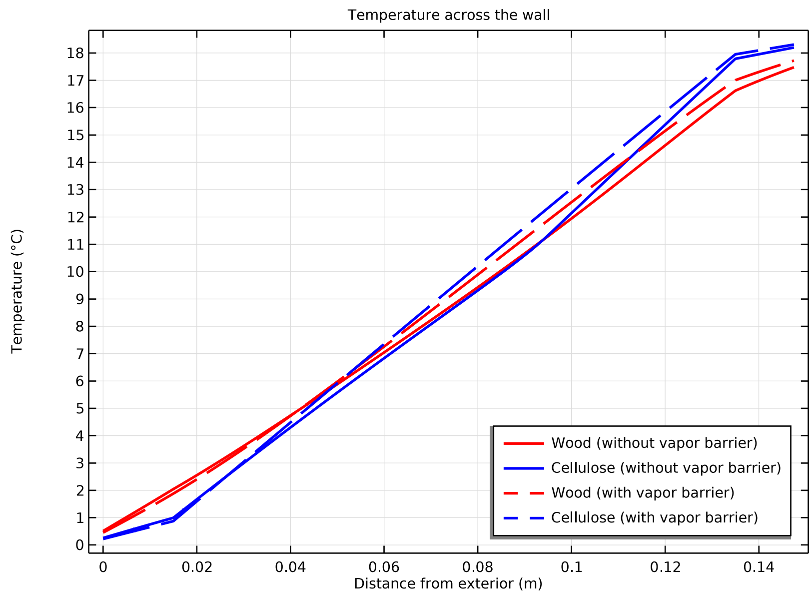


Figure 6: Effect of vapor barrier on temperature distribution across the wall, in the wooden frame and in the isolation.

COMPARISON OF THE MODELING APPROACHES

The Glaser method overestimates the relative humidity and hence the risk of condensation by not taking into account the liquid transport which becomes significant when the relative humidity is high, close to the bracing. The effect on temperature and moisture distribution is shown in Figure 7 and Figure 8.

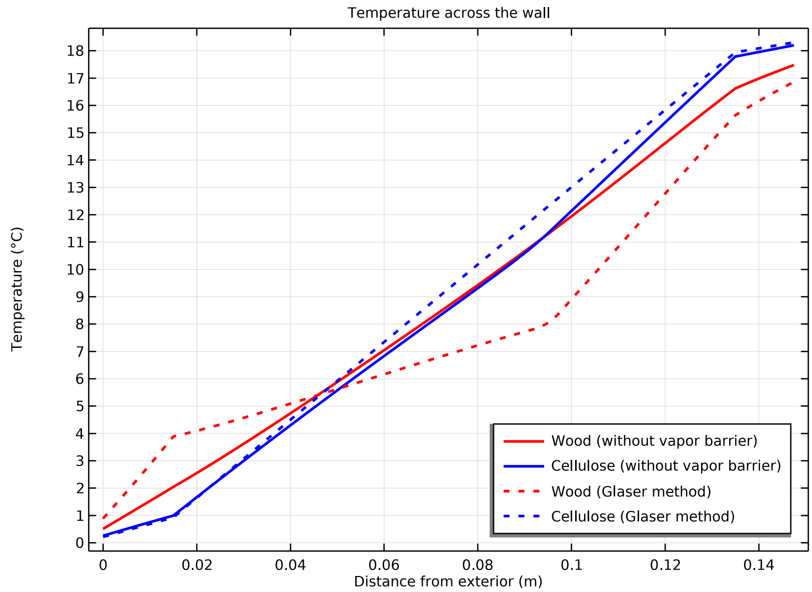


Figure 7: Comparison of the modeling approaches for the temperature distribution across the wall, in the wooden frame and in the isolation.

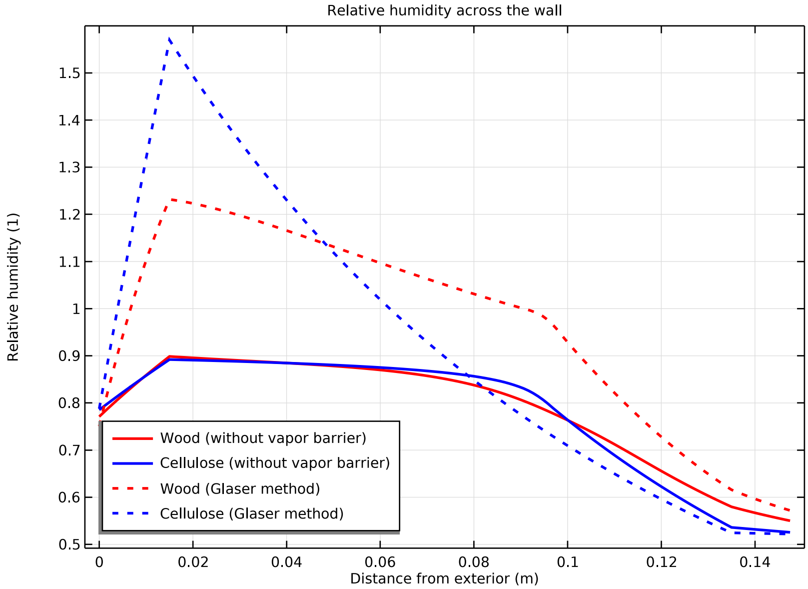


Figure 8: Comparison of the modeling approaches for the relative humidity distribution across the wall, in the wooden frame and in the isolation.

Reference

1. EN 15026, *Hygrothermal performance of building components and building elements - Assessment of moisture transfer by numerical simulation*, CEN, 2007.

Application Library path: `Heat_Transfer_Module/Buildings_and_Constructions/wood_frame_wall`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **2D**.
2 In the **Select Physics** tree, select **Heat Transfer** > **Heat and Moisture Transport** > **Building Materials**.
3 Click **Add**.
4 Click **Study**.
5 In the **Select Study** tree, select **General Studies** > **Stationary**.
6 Click **Done**.

ROOT

First define the geometry of the wall, composed of wood studs and isolation boards, completed at the top and bottom by a bracing and an interior siding.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.
2 In the **Settings** window for **Parameters**, locate the **Parameters** section.
3 Click **Load from File**.
4 Browse to the model's Application Libraries folder and double-click the file `wood_frame_wall_parameters.txt`.

GEOMETRY 1

Rectangle 1 (r1)

1 In the **Geometry** toolbar, click **Rectangle**.
2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
3 In the **Width** text field, type `L`.
4 In the **Height** text field, type `t_il + t_i + t_b`.
5 Click **Build Selected**.
6 Click to expand the **Layers** section. In the table, enter the following settings:

Layer name	Thickness (m)
Layer 1	t_il
Layer 2	t_i

7 Click **Build All Objects**.

Rectangle 2 (r2)

1 In the **Geometry** toolbar, click **Rectangle**.
2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
3 In the **Width** text field, type `d_wf`.
4 In the **Height** text field, type `t_i`.
5 Locate the **Position** section. In the **x** text field, type `L/4-d_wf/2`.
6 In the **y** text field, type `t_il`.
7 Click **Build All Objects**.

Copy 1 (copy1)

1 In the **Geometry** toolbar, click **Transforms** and choose **Copy**.
2 Select the object **r2** only.
3 In the **Settings** window for **Copy**, locate the **Displacement** section.
4 In the **x** text field, type `L/2`.
5 Click **Build All Objects**.

DEFINITIONS

Ambient Properties 1 (ampr1)

1 In the **Physics** toolbar, click **Shared Properties** and choose **Ambient Properties**.
2 In the **Settings** window for **Ambient Properties**, locate the **Ambient Conditions** section.
3 In the T_{amb} text field, type `T_ext`.
4 In the ϕ_{amb} text field, type `phi_ext`.

Now, set up the physics interfaces for the modeling of heat and moisture transport with the method described in Dynamic modeling of Heat and Moisture Transport.

HEAT TRANSFER IN BUILDING MATERIALS (HT)

Building Material 1

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Heat Transfer in Building Materials (ht)** click **Building Material 1**.
2 In the **Settings** window for **Building Material**, locate the **Building Material Properties** section.
3 From the **Specify** list, choose **Vapor resistance factor**.

Heat Flux 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Heat Flux**.

2 Select Boundary 7 only.

3 In the **Settings** window for **Heat Flux**, locate the **Heat Flux** section.

4 From the **Flux type** list, choose **Convective heat flux**.

5 In the h text field, type `h_ext`.

6 From the T_{ext} list, choose **Ambient temperature (ampr1)**.

Heat Flux 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Heat Flux**.

2 Select Boundary 2 only.

3 In the **Settings** window for **Heat Flux**, locate the **Heat Flux** section.

4 From the **Flux type** list, choose **Convective heat flux**.

5 In the h text field, type `h_int`.

6 In the T_{ext} text field, type `T_int`.

Initial Values 1

1 In the **Model Builder** window, click **Initial Values 1**.

2 In the **Settings** window for **Initial Values**, locate the **Initial Values** section.

3 In the T text field, type `T_int`.

MOISTURE TRANSPORT IN BUILDING MATERIALS (MT)

Building Material 1

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Moisture Transport in Building Materials (mt)** click **Building Material 1**.

2 In the **Settings** window for **Building Material**, locate the **Building Material** section.

3 From the **Specify** list, choose **Vapor resistance factor**.

Moisture Flux 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Moisture Flux**.

2 Select Boundary 7 only.

3 In the **Settings** window for **Moisture Flux**, locate the **Moisture Flux** section.

4 From the **Flux type** list, choose **Convective moisture flux, pressures difference**.

5 In the β_p text field, type `beta_ext`.

6 From the T_{ext} list, choose **Ambient temperature (ampr1)**.

7 From the $\phi_{w,ext}$ list, choose **Ambient relative humidity (ampr1)**.

Moisture Flux 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Moisture Flux**.

2 Select Boundary 2 only.

3 In the **Settings** window for **Moisture Flux**, locate the **Moisture Flux** section.

4 From the **Flux type** list, choose **Convective moisture flux, pressures difference**.

5 In the β_p text field, type `beta_int`.

6 In the T_{ext} text field, type `T_int`.

7 In the $\phi_{w,ext}$ text field, type `phi_int`.

Initial Values 1

1 In the **Model Builder** window, click **Initial Values 1**.

2 In the **Settings** window for **Initial Values**, locate the **Initial Values** section.

3 In the $\phi_{w,0}$ text field, type `phi_int`.

Thin Moisture Barrier 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Thin Moisture Barrier**.

2 Select Boundaries 4, 9, 12, 15, and 18 only.

Pick materials from the library for the wood studs (pine), the isolation (cellulose), the interior siding (gypsum), and the vapor barrier (plastic coated paper). In addition, define a new material for the bracing.

ADD MATERIAL

1 In the **Materials** toolbar, click **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **Building** > **Wood (pine)**.

4 Click the **Add to Component** button in the window toolbar.

5 In the tree, select **Building** > **Cellulose board**.

6 Click the **Add to Component** button in the window toolbar.

7 In the tree, select **Building** > **Gypsum board**.

8 Click the **Add to Component** button in the window toolbar.

9 In the tree, select **Building** > **Plastic coated paper**.

10 Click the **Add to Component** button in the window toolbar.

11 In the **Materials** toolbar, click **Add Material** to close the **Add Material** window.

MATERIALS

Wood (pine) (mat1)

Select Domains 4 and 6 only.

Cellulose board (mat2)

1 In the **Model Builder** window, click **Cellulose board (mat2)**.

2 Select Domains 2, 5, and 7 only.

Gypsum board (mat3)

1 In the **Model Builder** window, click **Gypsum board (mat3)**.

2 Select Domain 1 only.

Plastic coated paper (mat4)

1 In the **Model Builder** window, click **Plastic coated paper (mat4)**.

2 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

3 From the **Geometric entity level** list, choose **Boundary**.

4 Select Boundaries 4, 9, 12, 15, and 18 only.

Wooden panel (OSB)

1 In the **Model Builder** window, right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, type `Wooden panel (OSB)` in the **Label** text field.

3 Select Domain 3 only.

k_eff

1 In the **Model Builder** window, expand the **Component 1 (comp1)** > **Materials** > **Wooden panel (OSB) (mat5)** node.

2 Right-click **Component 1 (comp1)** > **Materials** > **Wooden panel (OSB) (mat5)** > **Basic (def)** and choose **Functions** > **Interpolation**.

3 In the **Settings** window for **Interpolation**, type `k_eff` in the **Label** text field.

4 Locate the **Definition** section. In the **Function name** text field, type `k_eff`.

5 In the table, enter the following settings:

t	f(t)
0	0.11
0.97	0.14
1	0.6

6 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Piecewise cubic**.

7 From the **Extrapolation** list, choose **Linear**.

8 Locate the **Units** section. In the **Argument** table, enter the following settings:

Argument	Unit
t	1

9 In the **Function** table, enter the following settings:

Function	Unit
k_eff	W/(m*K)

Interpolation: Dw

1 In the **Home** toolbar, click f(X) **Functions** and choose **Global** > **Interpolation**.

2 In the **Settings** window for **Interpolation**, type `Interpolation: Dw` in the **Label** text field.

3 Locate the **Definition** section. In the **Function name** text field, type `Dw`.

4 In the table, enter the following settings:

t	f(t)
0	2.93e-12
0.97	2.93e-12
1	6.52e-10

5 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Piecewise cubic**.

6 From the **Extrapolation** list, choose **Linear**.

7 Locate the **Units** section. In the **Argument** table, enter the following settings:

Argument	Unit
t	1

8 In the **Function** table, enter the following settings:

Function	Unit
Dw	m^2/s

Analytic: wc

1 In the **Home** toolbar, click f(x) **Functions** and choose **Global** > **Analytic**.

2 In the **Settings** window for **Analytic**, type `Analytic: wc` in the **Label** text field.

3 In the **Function name** text field, type `wc`.

4 Locate the **Definition** section. In the **Expression** text field, type `202.68*x^2 - 24.813*x + 6.1962`.

5 Locate the **Units** section. In the table, enter the following settings:

Argument	Unit
x	1

6 In the **Function** text field, type `kg/m^3`.

Wooden panel (OSB) (mat5)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Materials** click **Wooden panel (OSB) (mat5)**.

2 In the **Settings** window for **Material**, locate the **Material Contents** section.

3 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	`k_eff(mt.phi)`	W/(m·K)	Basic
Density	rho	646	kg/m³	Basic
Heat capacity at constant pressure	Cp	1500	J/(kg·K)	Basic
Diffusion coefficient	D_iso ; Dii = D_iso, Dij = 0	`Dw(mt.phi)`	m²/s	Basic
Water content	w_c	`wc(mt.phi)`	kg/m³	Basic
Vapor resistance factor	mu_vrf_iso ; mu_vrfii = mu_vrf_iso, mu_vrfij = 0	162	1	Basic

4 In the **Model Builder** window, collapse the **Wooden panel (OSB) (mat5)** node.

Refine the mesh to improve the discretization of the bracing and interior siding.

MESH 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.

3 From the **Element size** list, choose **Extremely fine**.

Set the study to ignore the vapor barrier as a first step, and compute.

STUDY 1 (STATIONARY, WITHOUT VAPOR BARRIER)

1 In the **Model Builder** window, click **Study 1**.

2 In the **Settings** window for **Study**, type `Study 1 (Stationary, without vapor barrier)` in the **Label** text field.

Step 1: Stationary

1 In the **Model Builder** window, under **Study 1 (Stationary, without vapor barrier)** click **Step 1: Stationary**.

2 In the **Settings** window for **Stationary**, locate the **Physics and Variables Selection** section.

3 Select the **Modify model configuration for study step** checkbox.

4 In the tree, select **Component 1 (comp1)** > **Moisture Transport in Building Materials (mt)** > **Thin Moisture Barrier 1**.

5 Click **Disable**.

Solution 1 (sol1)

1 In the **Study** toolbar, click **Show Default Solver**.

2 In the **Model Builder** window, expand the **Solution 1 (sol1)** node.

3 In the **Model Builder** window, expand the **Study 1 (Stationary, without vapor barrier)** > **Solver Configurations** > **Solution 1 (sol1)** > **Stationary Solver 1** node, then click **Fully Coupled 1**.

4 In the **Settings** window for **Fully Coupled**, click to expand the **Method and Termination** section.

Due to the high dependency of material properties on relative humidity, the default solver fails to converge. A first solution consists to reduce the damping factor value. Another solution is to use a dynamic damping factor value automatically defined by the solver in each iteration. To do so, use the **Automatic highly nonlinear** method.

5 From the **Nonlinear method** list, choose **Automatic highly nonlinear (Newton)**.

6 In the **Study** toolbar, click **Compute**.

RESULTS

Change the unit of the temperature results to degrees Celsius.

Preferred Units 1

1 In the **Results** toolbar, click **Configurations** and choose **Preferred Units**.

2 In the **Settings** window for **Preferred Units**, locate the **Units** section.

3 Click **Add Physical Quantity**.

4 In the **Physical Quantity** dialog, select **General** > **Temperature (K)** in the tree.

5 Click **OK**.

6 In the **Settings** window for **Preferred Units**, locate the **Units** section.

7 In the table, enter the following settings:

Quantity	Unit	Preferred unit
Temperature	K	°C

8 Click **Apply**.

The default plots show the temperature (Figure 3) and relative humidity (Figure 4) distributions.

Now, define another study and run the computation with the vapor barrier.

ADD STUDY

1 In the **Home** toolbar, click **Add Study** to open the **Add Study** window.

2 Go to the **Add Study** window.

3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies** > **Stationary**.

4 Click the **Add Study** button in the window toolbar.

5 In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY 2 (STATIONARY, WITH VAPOR BARRIER)

1 In the **Settings** window for **Study**, type `Study 2 (Stationary, with vapor barrier)` in the **Label** text field.

2 In the **Study** toolbar, click **Compute**.

RESULTS

Temperature (ht) 1

Plot the temperature and moisture distribution to check the effect of the vapor barrier. First, define cut lines across the wall, through the wood and the cellulose.

Cut Line Wood (Solution 1)

1 In the **Model Builder** window, expand the **Results** > **Datasets** node.

2 Right-click **Results** > **Datasets** and choose **Cut Line 2D**.

3 In the **Settings** window for **Cut Line 2D**, type `Cut Line Wood (Solution 1)` in the **Label** text field.

4 Locate the **Line Data** section. In row **Point 1**, set **X** to `L/4`.

5 In row **Point 2**, set **X** to `L/4`.

6 Click **Plot**.

7 In row **Point 1**, set **Y** to `0.15`.

8 Click **Plot**.

Cut Line Cellulose (Solution 1)

1 Right-click **Cut Line Wood (Solution 1)** and choose **Duplicate**.

2 In the **Settings** window for **Cut Line 2D**, type `Cut Line Cellulose (Solution 1)` in the **Label** text field.

3 Locate the **Line Data** section. In row **Point 1**, set **X** to `L/2`.

4 In row **Point 2**, set **X** to `L/2`.

5 Click **Plot**.

Cut Line Wood (Solution 2)

1 In the **Model Builder** window, right-click **Cut Line Wood (Solution 1)** and choose **Duplicate**.

2 In the **Settings** window for **Cut Line 2D**, type `Cut Line Wood (Solution 2)` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 2 (Stationary, with vapor barrier)/Solution 2 (sol2)**.

4 Click **Plot**.

Cut Line Cellulose (Solution 2)

1 In the **Model Builder** window, right-click **Cut Line Cellulose (Solution 1)** and choose **Duplicate**.

2 In the **Settings** window for **Cut Line 2D**, type `Cut Line Cellulose (Solution 2)` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 2 (Stationary, with vapor barrier)/Solution 2 (sol2)**.

4 Click **Plot**.

Now, follow the instructions below to reproduce the plots of Figure 5 and Figure 6.

Temperature Across the Wall (Comparison)

1 In the **Results** toolbar, click **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Temperature Across the Wall (Comparison)` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **None**.

4 Locate the **Plot Settings** section.

5 Select the **x-axis label** checkbox. In the associated text field, type `Distance from exterior (m)`.

Wood (without vapor barrier)

1 Right-click **Temperature Across the Wall (Comparison)** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 From the **Dataset** list, choose **Cut Line Wood (Solution 1)**.

4 In the **Label** text field, type `Wood (without vapor barrier)`.

5 Click to expand the **Coloring and Style** section. From the **Color** list, choose **Red**.

6 From the **Width** list, choose **2**.

7 Click to expand the **Legends** section. Select the **Show legends** checkbox.

8 Find the **Include** subsection. Select the **Label** checkbox.

9 Clear the **Solution** checkbox.

10 In the **Temperature Across the Wall (Comparison)** toolbar, click **Plot**.

Cellulose (without vapor barrier)

1 Right-click **Wood (without vapor barrier)** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, type `Cellulose (without vapor barrier)` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Cut Line Cellulose (Solution 1)**.

4 Locate the **Coloring and Style** section. From the **Color** list, choose **Blue**.

5 In the **Temperature Across the Wall (Comparison)** toolbar, click **Plot**.

Wood (with vapor barrier)

1 In the **Model Builder** window, right-click **Wood (without vapor barrier)** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, type `Wood (with vapor barrier)` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Cut Line Wood (Solution 2)**.

4 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dashed**.

5 In the **Temperature Across the Wall (Comparison)** toolbar, click **Plot**.

Cellulose (with vapor barrier)

1 In the **Model Builder** window, right-click **Cellulose (without vapor barrier)** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, type `Cellulose (with vapor barrier)` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Cut Line Cellulose (Solution 2)**.

4 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dashed**.

5 In the **Temperature Across the Wall (Comparison)** toolbar, click **Plot**.

Temperature Across the Wall (Comparison)

1 In the **Model Builder** window, click **Temperature Across the Wall (Comparison)**.

2 In the **Settings** window for **1D Plot Group**, locate the **Legend** section.

3 From the **Position** list, choose **Lower right**.

Wood (without vapor barrier)

1 In the **Model Builder** window, click **Wood (without vapor barrier)**.

2 In the **Settings** window for **Line Graph**, click to expand the **Title** section.

3 From the **Title type** list, choose **None**.

Cellulose (without vapor barrier)

1 In the **Model Builder** window, click **Cellulose (without vapor barrier)**.

2 In the **Settings** window for **Line Graph**, locate the **Title** section.

3 From the **Title type** list, choose **None**.

Wood (with vapor barrier)

1 In the **Model Builder** window, click **Wood (with vapor barrier)**.

2 In the **Settings** window for **Line Graph**, locate the **Title** section.

3 From the **Title type** list, choose **None**.

Cellulose (with vapor barrier)

1 In the **Model Builder** window, click **Cellulose (with vapor barrier)**.

2 In the **Settings** window for **Line Graph**, locate the **Title** section.

3 From the **Title type** list, choose **None**.

Temperature Across the Wall (Comparison)

1 In the **Model Builder** window, click **Temperature Across the Wall (Comparison)**.

2 In the **Settings** window for **1D Plot Group**, click to expand the **Title** section.

3 From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Temperature across the wall`.

5 In the **Temperature Across the Wall (Comparison)** toolbar, click **Plot**.

Relative Humidity Across the Wall (Comparison)

1 Right-click **Temperature Across the Wall (Comparison)** and choose **Duplicate**.

2 In the **Model Builder** window, click **Temperature Across the Wall (Comparison) 1**.

3 In the **Settings** window for **1D Plot Group**, type `Relative Humidity Across the Wall (Comparison)` in the **Label** text field.

Wood (without vapor barrier)

1 In the **Model Builder** window, click **Wood (without vapor barrier)**.

2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

3 In the **Expression** text field, type `mt.phi`.

Cellulose (without vapor barrier)

1 In the **Model Builder** window, click **Cellulose (without vapor barrier)**.

2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

3 In the **Expression** text field, type `mt.phi`.

Wood (with vapor barrier)

1 In the **Model Builder** window, click **Wood (with vapor barrier)**.

2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

3 In the **Expression** text field, type `mt.phi`.

4 Click to expand the **Quality** section. From the **Evaluation settings** list, choose **Manual**.

5 From the **Smoothing** list, choose **Everywhere**.

Cellulose (with vapor barrier)

1 In the **Model Builder** window, click **Cellulose (with vapor barrier)**.

2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

3 In the **Expression** text field, type `mt.phi`.

4 Locate the **Quality** section. From the **Evaluation settings** list, choose **Manual**.

5 From the **Smoothing** list, choose **Everywhere**.

6 In the **Relative Humidity Across the Wall (Comparison)** toolbar, click **Plot**.

Relative Humidity Across the Wall (Comparison)

1 In the **Model Builder** window, click **Relative Humidity Across the Wall (Comparison)**.

2 In the **Settings** window for **1D Plot Group**, locate the **Legend** section.

3 From the **Position** list, choose **Lower left**.

4 Locate the **Title** section. In the **Title** text area, type `Relative humidity across the wall`.

5 In the **Relative Humidity Across the Wall (Comparison)** toolbar, click **Plot**.

Next, define new interfaces and a new study for the modeling of heat and moisture transport with the method described in Static modeling of Heat and Moisture Transport.

ADD PHYSICS

1 In the **Home** toolbar, click **Add Physics** to open the **Add Physics** window.

2 Go to the **Add Physics** window.

3 In the tree, select **Heat Transfer** > **Heat and Moisture Transport** > **Building Materials**.

4 Click the **Add to Component 1** button in the window toolbar.

Disable the multiphysics coupling node to be able to set the vapor permeability to 0 in the **Heat Transfer in Building Materials** interface. By doing this the latent heat effect is ignored in the heat transfer equation.

5 In the **Home** toolbar, click **Add Physics** to close the **Add Physics** window.

MULTIPHYSICS

Heat and Moisture 2 (ham2)

In the **Model Builder** window, under **Component 1 (comp1)** > **Multiphysics** right-click **Heat and Moisture 2 (ham2)** and choose **Disable**.

Now, define the physics features.

HEAT TRANSFER IN BUILDING MATERIALS 2 (HT2)

Building Material 1

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Heat Transfer in Building Materials 2 (ht2)** click **Building Material 1**.

2 In the **Settings** window for **Building Material**, locate the **Model Inputs** section.

3 From the ϕ_w list, choose **Relative humidity (mt2/bm1)**.

4 Locate the **Building Material Properties** section. From the δ_p list, choose **User defined**. In the associated text field, type `0`.

Heat Flux 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Heat Flux**.

2 In the **Settings** window for **Heat Flux**, locate the **Heat Flux** section.

3 From the **Flux type** list, choose **Convective heat flux**.

4 In the h text field, type `h_ext`.

5 In the T_{ext} text field, type `T_ext`.

6 Select Boundary 7 only.

Heat Flux 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Heat Flux**.

2 In the **Settings** window for **Heat Flux**, locate the **Heat Flux** section.

3 From the **Flux type** list, choose **Convective heat flux**.

4 In the h text field, type `h_int`.

5 In the T_{ext} text field, type `T_int`.

6 Select Boundary 2 only.

Initial Values 1

1 In the **Model Builder** window, click **Initial Values 1**.

2 In the **Settings** window for **Initial Values**, locate the **Initial Values** section.

3 In the $T2$ text field, type `T_int`.

MOISTURE TRANSPORT IN BUILDING MATERIALS 2 (MT2)

Building Material 1

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Moisture Transport in Building Materials 2 (mt2)** click **Building Material 1**.

2 In the **Settings** window for **Building Material**, locate the **Model Input** section.

3 From the T list, choose **Temperature (ht2)**.

4 In the p_A text field, type `ht2.pA`.

Set the moisture diffusivity to 0 to ignore the capillary transport of liquid moisture.

5 Locate the **Building Material** section. From the D_w list, choose **User defined**. From the **Specify** list, choose **Vapor resistance factor**.

Moisture Flux 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Moisture Flux**.

2 In the **Settings** window for **Moisture Flux**, locate the **Moisture Flux** section.

3 From the **Flux type** list, choose **Convective moisture flux, pressures difference**.

4 In the β_p text field, type `beta_ext`.

5 In the T_{ext} text field, type `T_ext`.

6 In the $\phi_{\mathrm{w,ext}}$ text field, type `phi_ext`.

7 Select Boundary 7 only.

Moisture Flux 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Moisture Flux**.

2 In the **Settings** window for **Moisture Flux**, locate the **Moisture Flux** section.

3 From the **Flux type** list, choose **Convective moisture flux, pressures difference**.

4 In the β_p text field, type `beta_int`.

5 In the T_{ext} text field, type `T_int`.

6 In the $\phi_{\mathrm{w,ext}}$ text field, type `phi_int`.

7 Select Boundary 2 only.

Initial Values 1

1 In the **Model Builder** window, click **Initial Values 1**.

2 In the **Settings** window for **Initial Values**, locate the **Initial Values** section.

3 In the $\phi_{\mathrm{w,0}}$ text field, type `phi_int`.

ADD STUDY

1 In the **Home** toolbar, click **Add Study** to open the **Add Study** window.

2 Go to the **Add Study** window.

3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies** > **Stationary**.

4 Click the **Add Study** button in the window toolbar.

5 In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY 3

Step 1: Stationary

1 In the **Settings** window for **Stationary**, locate the **Physics and Variables Selection** section.

2 In the **Solve for** column of the table, under **Component 1 (comp1)**, clear the checkboxes for **Heat Transfer in Building Materials (ht)** and **Moisture Transport in Building Materials (mt)**.

3 In the **Solve for** column of the table, under **Component 1 (comp1)** > **Multiphysics**, clear the checkbox for **Heat and Moisture 1 (ham1)**.

4 In the **Model Builder** window, click **Study 3**.

5 In the **Settings** window for **Study**, type `Study 3 (Stationary, Glaser method)` in the **Label** text field.

6 In the **Study** toolbar, click **Compute**.

Next, compare the results with those obtained with the first approach (without vapor barrier). Follow the instructions below to reproduce the plots of Figure 7 and Figure 8.

RESULTS

Cut Line Wood (Solution 2) 1

In the **Model Builder** window, right-click **Cut Line Wood (Solution 2)** and choose **Duplicate**.

Cut Line Cellulose (Solution 2) 1

In the **Model Builder** window, right-click **Cut Line Cellulose (Solution 2)** and choose **Duplicate**.

Cut Line Wood (Solution 3)

1 In the **Settings** window for **Cut Line 2D**, locate the **Data** section.

2 From the **Dataset** list, choose **Study 3 (Stationary, Glaser method)/Solution 3 (sol3)**.

3 In the **Label** text field, type `Cut Line Wood (Solution 3)`.

Cut Line Cellulose (Solution 3)

1 In the **Model Builder** window, click **Cut Line Cellulose (Solution 2) 1**.

2 In the **Settings** window for **Cut Line 2D**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 3 (Stationary, Glaser method)/Solution 3 (sol3)**.

4 In the **Label** text field, type `Cut Line Cellulose (Solution 3)`.

Wood (with vapor barrier)

In the **Model Builder** window, under **Results** > **Temperature Across the Wall (Comparison)** right-click **Wood (with vapor barrier)** and choose **Disable**.

Cellulose (with vapor barrier)

In the **Model Builder** window, right-click **Cellulose (with vapor barrier)** and choose **Disable**.

Wood (without vapor barrier) 1

In the **Model Builder** window, right-click **Wood (without vapor barrier)** and choose **Duplicate**.

Cellulose (without vapor barrier) 1

In the **Model Builder** window, right-click **Cellulose (without vapor barrier)** and choose **Duplicate**.

Wood (Glaser method)

1 In the **Settings** window for **Line Graph**, type `Wood (Glaser method)` in the **Label** text field.
2 Locate the **Data** section. From the **Dataset** list, choose **Cut Line Wood (Solution 3)**.
3 Locate the **y-Axis Data** section. In the **Expression** text field, type `T2`.
4 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dotted**.

Cellulose (Glaser method)

1 In the **Model Builder** window, under **Results** > **Temperature Across the Wall (Comparison)** click **Cellulose (without vapor barrier) 1**.
2 In the **Settings** window for **Line Graph**, type `Cellulose (Glaser method)` in the **Label** text field.
3 Locate the **Data** section. From the **Dataset** list, choose **Cut Line Cellulose (Solution 3)**.
4 Locate the **y-Axis Data** section. In the **Expression** text field, type `T2`.
5 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dotted**.
6 In the **Temperature Across the Wall (Comparison)** toolbar, click **Plot**.

Wood (with vapor barrier)

In the **Model Builder** window, under **Results** > **Relative Humidity Across the Wall (Comparison)** right-click **Wood (with vapor barrier)** and choose **Disable**.

Cellulose (with vapor barrier)

In the **Model Builder** window, right-click **Cellulose (with vapor barrier)** and choose **Disable**.

Wood (without vapor barrier) 1

In the **Model Builder** window, right-click **Wood (without vapor barrier)** and choose **Duplicate**.

Cellulose (without vapor barrier) 1

In the **Model Builder** window, right-click **Cellulose (without vapor barrier)** and choose **Duplicate**.

Wood (Glaser method)

1 In the **Settings** window for **Line Graph**, type `Wood (Glaser method)` in the **Label** text field.

2 Locate the **Data** section. From the **Dataset** list, choose **Cut Line Wood (Solution 3)**.

3 Locate the **y-Axis Data** section. In the **Expression** text field, type `mt2.phi`.

4 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dotted**.

Cellulose (Glaser method)

1 In the **Model Builder** window, under **Results** > **Relative Humidity Across the Wall (Comparison)** click **Cellulose (without vapor barrier) 1**.

2 In the **Settings** window for **Line Graph**, type `Cellulose (Glaser method)` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Cut Line Cellulose (Solution 3)**.

4 Locate the **y-Axis Data** section. In the **Expression** text field, type `mt2.phi`.

5 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dotted**.

6 In the **Relative Humidity Across the Wall (Comparison)** toolbar, click **Plot**.

Finally, use weather data from Dublin (GPS coordinates: 53.349, -6.260) for the temperature and relative humidity on exterior side, and set a new time-dependent study to check the evolution of the relative humidity in the bracing and in the isolation over two days. The weather data are available with the Heat Transfer Module license or the Porous Media Module license or the Subsurface Module license.

SHARED PROPERTIES

Ambient Properties 1 (ampr1)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Definitions** > **Shared Properties** click **Ambient Properties 1 (ampr1)**.

2 In the **Settings** window for **Ambient Properties**, locate the **Ambient Settings** section.

3 From the **Ambient data** list, choose **Meteorological data (ASHRAE 2021)**.

4 Locate the **Location** section. From the **Weather station** list, choose **Around location**.

5 In the **Latitude (+ to N), in °** text field, type `53.349`.

6 In the **Longitude (+ to E), in °** text field, type `-6.260`.

7 Click **Set Weather Station**.

8 In the **Weather Station** dialog, select **DUBLIN AP (039690) - 9 km** in the tree.

9 Click **OK**.

10 In the **Settings** window for **Ambient Properties**, locate the **Time** section.

11 Find the **Date** subsection. In the table, enter the following settings:

Day	Month
15	04

12 Find the **Local time** subsection. In the table, enter the following settings:

Hour	Minute	Second
0	00	00

ADD STUDY

1 In the **Home** toolbar, click **Add Study** to open the **Add Study** window.

2 Go to the **Add Study** window.

3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies** > **Time Dependent**.

4 Click the **Add Study** button in the window toolbar.

5 In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY 4 (TIME DEPENDENT, WITH VAPOR BARRIER)

In the **Settings** window for **Study**, type `Study 4 (Time Dependent, with vapor barrier)` in the **Label** text field.

Step 1: Time Dependent

1 In the **Model Builder** window, under **Study 4 (Time Dependent, with vapor barrier)** click **Step 1: Time Dependent**.

2 In the **Settings** window for **Time Dependent**, locate the **Physics and Variables Selection** section.

3 In the **Solve for** column of the table, under **Component 1 (comp1)**, clear the checkboxes for **Heat Transfer in Building Materials 2 (ht2)** and **Moisture Transport in Building Materials 2 (mt2)**.

4 Locate the **Study Settings** section. From the **Time unit** list, choose **h**.

5 In the **Output times** text field, type `range(0,1,48)`.

Solution 4 (sol4)

1 In the **Study** toolbar, click **Show Default Solver**.

Disable the consistent initialization for a better evaluation of mass balance at the beginning of the simulation.

2 In the **Model Builder** window, expand the **Solution 4 (sol4)** node, then click **Time-Dependent Solver 1**.

3 In the **Settings** window for **Time-Dependent Solver**, click to expand the **Time Stepping** section.

4 Find the **Algebraic variable settings** subsection. From the **Consistent initialization** list, choose **Off**.

5 Click **Run**.

Plot the ambient data used as exterior conditions as in Figure 2 by following the instructions below.

RESULTS

Ambient Data

1 In the **Results** toolbar, click **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Ambient Data` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 4 (Time Dependent, with vapor barrier)/Solution 4 (sol4)**.

Point Graph 1

1 Right-click **Ambient Data** and choose **Point Graph**.

2 Select Point 4 only.

3 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.

4 In the **Expression** text field, type `ampr1.T_amb`.

5 Click to expand the **Legends** section. Select the **Show legends** checkbox.

6 From the **Legends** list, choose **Manual**.

7 In the table, enter the following settings:

Legends
`Temperature`

Point Graph 2

1 In the **Model Builder** window, right-click **Ambient Data** and choose **Point Graph**.

2 Select Point 4 only.

3 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.

4 In the **Expression** text field, type `ampr1.phi_amb`.

5 Locate the **Legends** section. Select the **Show legends** checkbox.

6 From the **Legends** list, choose **Manual**.

7 In the table, enter the following settings:

Legends
`Relative humidity`

Ambient Data

1 In the **Model Builder** window, click **Ambient Data**.

2 In the **Settings** window for **1D Plot Group**, locate the **Plot Settings** section.

3 Select the **Two y-axes** checkbox.

4 In the table, select the **Plot on secondary y-axis** checkbox for **Point Graph 2**.

5 Locate the **Title** section. From the **Title type** list, choose **Manual**.

6 In the **Title** text area, type `Ambient data over two days`.

7 Click the **Zoom Extents** button in the **Graphics** toolbar.

8 In the **Ambient Data** toolbar, click **Plot**.

Define probes to plot the relative humidity in the bracing and in the isolation over time.

DEFINITIONS

Domain Point Probe: Relative humidity (bracing)

1 In the **Definitions** toolbar, click **Probes** and choose **Domain Point Probe**.

2 In the **Settings** window for **Domain Point Probe**, type `Domain Point Probe: Relative humidity (bracing)` in the **Label** text field.

3 Locate the **Point Selection** section. In row **Coordinates**, set **x** to `L/2`.

4 In row **Coordinates**, set **y** to `t_il+t_i+t_b*0.95`.

Point Probe Expression 1 (ppb1)

1 In the **Model Builder** window, expand the **Domain Point Probe: Relative humidity (bracing)** node, then click **Point Probe Expression 1 (ppb1)**.

2 In the **Settings** window for **Point Probe Expression**, locate the **Expression** section.

3 In the **Expression** text field, type `mt.phi`.

4 Click **Update Results**.

Domain Point Probe: Relative humidity (isolation)

1 In the **Model Builder** window, right-click **Domain Point Probe: Relative humidity (bracing)** and choose **Duplicate**.

2 In the **Model Builder** window, click **Domain Point Probe: Relative humidity (bracing) 1**.

3 In the **Settings** window for **Domain Point Probe**, type `Domain Point Probe: Relative humidity (isolation)` in the **Label** text field.

4 Locate the **Point Selection** section. In row **Coordinates**, set **y** to `t_il+t_i*0.95`.

Point Probe Expression 1 (ppb2)

1 In the **Model Builder** window, click **Point Probe Expression 1 (ppb2)**.

2 In the **Settings** window for **Point Probe Expression**, click to expand the **Table and Window Settings** section.

3 From the **Output table** list, choose **New table**.

4 Click **Update Results**.

RESULTS

Relative Humidity Over Two Days

1 In the **Model Builder** window, under **Results** click **Probe Plot Group 12**.

2 In the **Settings** window for **1D Plot Group**, type `Relative Humidity Over Two Days` in the **Label** text field.

3 Locate the **Title** section. From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Relative humidity over two days`.

5 Locate the **Plot Settings** section.

6 Select the **y-axis label** checkbox. In the associated text field, type `Relative humidity (1)`.

Probe Table Graph 1

1 In the **Model Builder** window, expand the **Relative Humidity Over Two Days** node, then click **Probe Table Graph 1**.

2 In the **Settings** window for **Table Graph**, click to expand the **Legends** section.

3 From the **Legends** list, choose **Manual**.

4 In the table, enter the following settings:

Legends
`Point: (0.4, 0.14675)`

Probe Table Graph 2

1 In the **Model Builder** window, click **Probe Table Graph 2**.

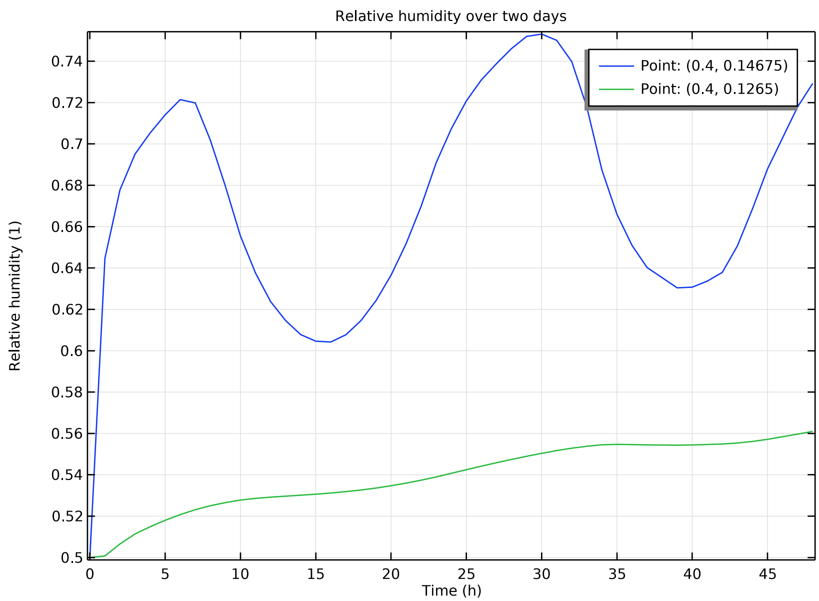
2 In the **Settings** window for **Table Graph**, locate the **Legends** section.

3 From the **Legends** list, choose **Manual**.

4 In the table, enter the following settings:

Legends
`Point: (0.4, 0.1265)`

5 In the **Relative Humidity Over Two Days** toolbar, click **Plot**.



Mass Balance

Follow the instructions below to check the overall mass balance over time.

1 In the **Results** toolbar, click **Global Evaluation**.

2 In the **Settings** window for **Global Evaluation**, type `Mass Balance` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 4 (Time Dependent, with vapor barrier)/Solution 4 (sol4)**.

4 Click **Replace Expression** in the upper-right corner of the **Expressions** section. From the menu, choose **Component 1 (comp1)** > **Moisture Transport in Building Materials** > **Mass balance** > **mt.massBalance - Mass balance - kg/s**.

5 Click **Add Expression** in the upper-right corner of the **Expressions** section. From the menu, choose **Component 1 (comp1)** > **Moisture Transport in Building Materials** > **Mass balance** > **mt.dwcInt - Total accumulated moisture rate - kg/s**.

6 Click **Add Expression** in the upper-right corner of the **Expressions** section. From the menu, choose **Component 1 (comp1)** > **Moisture Transport in Building Materials** > **Mass balance** > **mt.ntfluxInt - Total net moisture rate - kg/s**.

7 Click **Add Expression** in the upper-right corner of the **Expressions** section. From the menu, choose **Component 1 (comp1)** > **Moisture Transport in Building Materials** > **Mass balance** > **mt.GInt - Total mass source - kg/s**.

8 Click **=** **Evaluate**.

TABLE 3

1 Go to the **Table 3** window.

2 Click the **Table Graph** button in the window toolbar.

RESULTS

Mass Balance

1 In the **Model Builder** window, under **Results** click **1D Plot Group 13**.

2 In the **Settings** window for **1D Plot Group**, type `Mass Balance` in the **Label** text field.

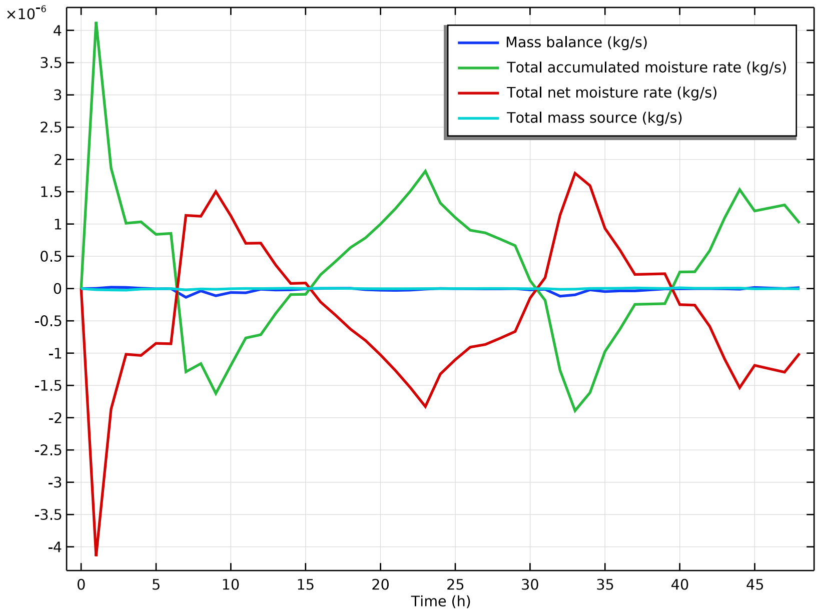
Table Graph 1

1 In the **Model Builder** window, click **Table Graph 1**.

2 In the **Settings** window for **Table Graph**, locate the **Legends** section.

3 Select the **Show legends** checkbox.

4 Locate the **Coloring and Style** section. From the **Width** list, choose **2**.



Finally, to create a 3D plot of the relative humidity, follow the instructions below.

Extrusion 2D 1

1 In the **Results** toolbar, click **More Datasets** and choose **Extrusion 2D**.

2 In the **Settings** window for **Extrusion 2D**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 2 (Stationary, with vapor barrier)/Solution 2 (sol2)**.

4 Locate the **Extrusion** section. In the **z maximum** text field, type `0.2`.

Relative Humidity 3D

1 In the **Results** toolbar, click **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Relative Humidity 3D` in the **Label** text field.

Relative Humidity

1 Right-click **Relative Humidity 3D** and choose **Surface**.

2 In the **Settings** window for **Surface**, type `Relative Humidity` in the **Label** text field.

3 Locate the **Expression** section. In the **Expression** text field, type `mt.phi`.

4 Locate the **Coloring and Style** section. From the **Color table** list, choose **JupiterAuroraBorealis**.

5 From the **Color table transformation** list, choose **Reverse**.

6 In the **Relative Humidity 3D** toolbar, click **Plot**.

7 Click the **Zoom Extents** button in the **Graphics** toolbar.