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 $h_{\text{ext}} = 25 \, \text{W/(m·K)}$ and $h_{\text{int}} = 8 \, \text{W/(m·K)}$. The outdoor and indoor moisture transfer coefficients are set to $\beta_{\text{ext}} = 25 \cdot 10^{-8} \, \text{s/m}$ and $\beta_{\text{int}} = 8 \cdot 10^{-8} \, \text{s/m}$, 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:

$$
(\rho C_p)_{\text{eff}} \frac{\partial T}{\partial t} \cdot \nabla \cdot \left( k_{\text{eff}} \nabla T + L_v \delta_p \nabla (\phi p_{\text{sat}}) \right) = Q
$$

$$
\xi \frac{\partial \phi}{\partial t} \cdot \nabla \cdot \left( \xi D_w \nabla \phi + \delta_p \nabla (\phi p_{\text{sat}}) \right) = G
$$

Here

- $(\rho C_p)_{\text{eff}}$ (SI unit: J/(m$^3$·K)) is the effective volumetric heat capacity at constant pressure
- $T$ (SI unit: K) is the temperature
- $k_{\text{eff}}$ (SI unit: W/(m·K)) is the effective thermal conductivity
- $L_v$ (SI unit: J/kg) is the latent heat of evaporation
- $\delta_p$ (SI unit: s) is the vapor permeability
- $\phi$ (dimensionless) is the relative humidity
- $p_{\text{sat}}$ (SI unit: Pa) is the vapor saturation pressure
- $Q$ (SI unit: W/m$^3$·s) is the heat source
- $\xi$ (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:

\[-\nabla \cdot (k_{\text{eff}} \nabla T) = Q\]

\[-\nabla \cdot (\delta_p \nabla (\phi p_{\text{sat}})) = G\]

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 \(\beta_d (\phi_d - \phi_u)\) and \(\beta_d (\phi_u - \phi_d)\) are applied at the interface between the interior siding and the isolation to model the vapor barrier. The moisture transfer coefficient \(\beta\) is defined as

\[\beta = \frac{\delta p_{\text{sat}}}{\mu d_s}\]

where \(\delta\) is the vapor permeability of still air (SI unit: s), \(p_{\text{sat}}\) is the saturation pressure of water vapor (SI unit: Pa), \(\mu\) 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 15th to the 17th 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.
Results and Discussion

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


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:

<table>
<thead>
<tr>
<th>Layer name</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>( t_{il} )</td>
</tr>
<tr>
<td>Layer 2</td>
<td>( t_i )</td>
</tr>
</tbody>
</table>
7 Click Build All Objects.
**Rectangle 2 (r2)**

1. In the **Geometry** toolbar, click \( \text{Rectangle} \).
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 \( \text{Build All Objects} \).

**Copy 1 (copy1)**

1. In the **Geometry** toolbar, click \( \text{Transforms} \) 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 \( \text{Build All Objects} \).

**Definitions**

**Ambient Properties 1 (ampr1)**

1. In the **Physics** toolbar, click \( \text{Shared Properties} \) and choose **Ambient Properties**.
2. In the **Settings** window for **Ambient Properties**, locate the **Ambient Conditions** section.
3. In the **T**\( \_\text{amb} \) text field, type \( T_{\text{ext}} \).
4. In the **\( \phi \)_\text{amb}** text field, type \( \phi_{\text{ext}} \).

Now, set 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 (compl)> 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 \( \beta_p \) text field, type \( beta_{ext} \).
6 From the \( T_{ext} \) list, choose Ambient temperature (ampr1).
7 From the $\phi_{w,\text{ext}}$ 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 $\beta_p$ text field, type `beta_int`.
6 In the $T_{\text{ext}}$ text field, type `T_int`.
7 In the $\phi_{w,\text{ext}}$ 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 **Home** 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 **Add to Component** in the window toolbar.
5 In the tree, select **Building>Cellulose board**.
6 Click **Add to Component** in the window toolbar.
7 In the tree, select **Building>Gypsum board**.
8 Click **Add to Component** in the window toolbar.
9 In the tree, select **Building>Plastic coated paper**.
10 Click **Add to Component** in the window toolbar.
11 In the **Home** toolbar, click **Add Material** to close the **Add Material** window.
MATERIALS

Wood (pine) (mat1)
1 In the Model Builder window, under Component 1 (comp1)>Materials click Wood (pine) (mat1).
2 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:

<table>
<thead>
<tr>
<th>t</th>
<th>f(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.11</td>
</tr>
</tbody>
</table>
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:

<table>
<thead>
<tr>
<th>Argument</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Function</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>k_eff</td>
<td>W/(m*K)</td>
</tr>
</tbody>
</table>

**Interpolation: Dw**

1 In the **Home** toolbar, click **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:

<table>
<thead>
<tr>
<th>t</th>
<th>f(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.93e-12</td>
</tr>
<tr>
<td>0.97</td>
<td>2.93e-12</td>
</tr>
<tr>
<td>1</td>
<td>6.52e-10</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Argument</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>1</td>
</tr>
</tbody>
</table>
In the **Function** table, enter the following settings:

<table>
<thead>
<tr>
<th>Function</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_w$</td>
<td>m$^2$/s</td>
</tr>
</tbody>
</table>

*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 $202.68 \times x^2 - 24.813 \times x + 6.1962$.
5. Locate the **Units** section. In the table, enter the following settings:

<table>
<thead>
<tr>
<th>Argument</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>1</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Property</th>
<th>Variable</th>
<th>Value</th>
<th>Unit</th>
<th>Property group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity</td>
<td>$k_{iso}$ ; $k_{ii} = k_{iso}$, $k_{ij} = 0$</td>
<td>$k_{eff}(mt.phi)$</td>
<td>W/(m·K)</td>
<td>Basic</td>
</tr>
<tr>
<td>Density</td>
<td>rho</td>
<td>646</td>
<td>kg/m$^3$</td>
<td>Basic</td>
</tr>
<tr>
<td>Heat capacity at constant pressure</td>
<td>Cp</td>
<td>1500</td>
<td>J/(kg·K)</td>
<td>Basic</td>
</tr>
<tr>
<td>Diffusion coefficient</td>
<td>$D_{iso}$ ; $D_{ii} = D_{iso}$, $D_{ij} = 0$</td>
<td>$D_{w}(mt.phi)$</td>
<td>m$^2$/s</td>
<td>Basic</td>
</tr>
<tr>
<td>Water content</td>
<td>$w_c$</td>
<td>$w_{c}(mt.phi)$</td>
<td>kg/m$^3$</td>
<td>Basic</td>
</tr>
<tr>
<td>Vapor resistance factor</td>
<td>$\mu_{vrf}$</td>
<td>162</td>
<td>l</td>
<td>Basic</td>
</tr>
</tbody>
</table>

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** check box.
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

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

1 In the Model Builder window, expand the Results>Temperature (ht) node, then click Surface.
2 In the Settings window for Surface, locate the Expression section.
3 From the Unit list, choose degC.

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

ADD STUDY
1 In the Study 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 Add Study in the window toolbar.
5 In the Study toolbar, click Add Study to close the Add Study window.

STUDY 2 (STATIONARY, WITH VAPOR BARRIER)
1 In the Model Builder window, click Study 2.
2 In the Settings window for Study, type Study 2 (Stationary, with vapor barrier) in the Label text field.
3 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 \( \text{Plot} \).
7 In row Point 1, set Y to 0.15.
8 Click \( \text{Plot} \).

**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 \( \text{Plot} \).

**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 \( \text{Plot} \).

**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 \( \text{Plot} \).

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 \( \text{1D Plot Group} \).
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** check box. 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 Locate the **y-Axis Data** section. From the **Unit** list, choose **degC**.

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** check box.

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

9 In the table, enter the following settings:

<table>
<thead>
<tr>
<th><strong>Legends</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood (without vapor barrier)</td>
</tr>
</tbody>
</table>

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

11 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 Locate the **Legends** section. In the table, enter the following settings:

<table>
<thead>
<tr>
<th><strong>Legends</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose (without vapor barrier)</td>
</tr>
</tbody>
</table>

```
6 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 Locate the Legends section. In the table, enter the following settings:

<table>
<thead>
<tr>
<th>Legends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood (with vapor barrier)</td>
</tr>
</tbody>
</table>

6 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 Locate the Legends section. In the table, enter the following settings:

<table>
<thead>
<tr>
<th>Legends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose (with vapor barrier)</td>
</tr>
</tbody>
</table>

6 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.
In the **Expression** text field, type \( \text{mt}. \phi_i \).

**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 \( \text{mt}. \phi_i \).

**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 \( \text{mt}. \phi_i \).
4. 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 **Add to Component 1** 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 $\phi_w$ list, choose Relative humidity (mt2/bm1).
4. Locate the Building Material Properties section. From the $\delta_p$ 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 $ht2.p_A$.
   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 $\beta_p$ text field, type $\beta_{ext}$.
5 In the $T_{ext}$ text field, type $T_{ext}$.
6 In the $\phi_{w,ext}$ 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 $\beta_p$ text field, type $\beta_{int}$.
5 In the $T_{ext}$ text field, type $T_{int}$.
6 In the $\phi_{w,ext}$ 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 $\phi_{w,0}$ 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 Add Study 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 table, clear the Solve for check boxes for Heat Transfer in Building Materials (ht) and Moisture Transport in Building Materials (mt).
3. In the table, clear the Solve for check box 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 Home 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).
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)
In the Model Builder window, right-click Wood (without vapor barrier) and choose Duplicate.

Cellulose (without vapor barrier)
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.
5 Locate the Legends section. In the table, enter the following settings:

<table>
<thead>
<tr>
<th>Legends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood (Glaser method)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Legends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose (Glaser method)</td>
</tr>
</tbody>
</table>

7 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)**
In the **Model Builder** window, right-click **Wood (without vapor barrier)** and choose **Duplicate**.

**Cellulose (without vapor barrier)**
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**.

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

<table>
<thead>
<tr>
<th>Legends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood (Glaser method)</td>
</tr>
</tbody>
</table>

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

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 \text{mt2}.phi.

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

6 Locate the Legends section. In the table, enter the following settings:

<table>
<thead>
<tr>
<th>Legends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose (Glaser method)</td>
</tr>
</tbody>
</table>

7 In the Relative Humidity Across the Wall (Comparison) toolbar, click \text{Plot}.

Finally, use typical weather data 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 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. Click Set Weather Station.

5 In the Weather Station dialog box, select Europe>Ireland>DUBLIN AP (039690) in the tree.

6 Click OK.

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

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

<table>
<thead>
<tr>
<th>Day</th>
<th>Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>04</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Hour</th>
<th>Minute</th>
<th>Second</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>00</td>
<td>00</td>
</tr>
</tbody>
</table>

**ADD STUDY**

1 In the Home toolbar, click \text{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 Add Study 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)**

1 In the Model Builder window, click Study 4.

2 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 table, clear the Solve for check boxes 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 Compute.

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

Ambient Data
1 In the Home toolbar, click Add Plot Group and choose 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 From the Unit list, choose degC.
6 Click to expand the Legends section. Select the Show legends check box.
7 From the Legends list, choose Manual.
8 In the table, enter the following settings:

<table>
<thead>
<tr>
<th>Legends</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
</tr>
</tbody>
</table>

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 check box.
6 From the Legends list, choose Manual.
7 In the table, enter the following settings:

<table>
<thead>
<tr>
<th>Legends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative humidity</td>
</tr>
</tbody>
</table>

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** check box.

4 In the table, select the **Plot on secondary y-axis** check box 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 16.

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 check box. 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:

<table>
<thead>
<tr>
<th>Legends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point: (0.4, 0.14675)</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Legends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point: (0.4, 0.1265)</td>
</tr>
</tbody>
</table>
5 In the **Relative Humidity Over Two Days** toolbar, click ![Plot](image).

![Relative humidity over two days](image)

**Mass Balance**

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

1 In the **Results** toolbar, click ![Global Evaluation](image).

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**

1 Go to the **Table** window.

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

**RESULTS**

*Mass Balance*

1 In the **Model Builder** window, under **Results** click **1D Plot Group 17**.

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** check box.

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. 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. Click **Change Color Table**.
5. In the **Color Table** dialog box, select **Aurora>JupiterAuroraBorealis** in the tree.
6. Click **OK**.
7. In the **Settings** window for **Surface**, locate the **Coloring and Style** section.
8. From the **Color table transformation** list, choose **Reverse**.
9. In the **Relative Humidity 3D** toolbar, click **Plot**.