Created in COMSOL Multiphysics 6.2

Heat and Moisture Transport in a Semi-Infinite Wall

Introduction

This tutorial shows how to simulate coupled heat and moisture transport in a building component. The 1D model is a benchmark test defined in Norm EN 15026 for the validation of a software computing moisture transfer by numerical simulation. You can verify that the numerical results obtained with COMSOL Multiphysics are within the validity ranges specified in the norm. See Ref. 1 for details about the norm.

Model Definition

The model geometry consists of a single segment for the building component. Its size is taken large enough to represent it as a semi-infinite region for the simulation time-scale. A relative humidity of 50% and a temperature of 20°C are set as initial conditions, while on the left boundary the relative humidity is set to 95% and the temperature is 30°C.

The time-dependent study is run over one year, with a control of the temperature and relative humidity distributions at 7, 30, and 365 days.

MOISTURE TRANSPORT

The Moisture Transport in Building Materials interface is used to model the moisture storage and the moisture transport by vapor diffusion and capillary flow.

HEAT TRANSFER

The Heat Transfer in Building Materials interface computes the latent heat transfer due to vapor diffusion. In addition, moisture-dependent material properties are used to account for the effects of moisture content on thermal conduction and heat storage.

MATERIAL DATA

The hygroscopic and thermal material data needed in the equations solved by the Moisture Transport and Heat Transfer interfaces are defined in Norm EN 15026.

Hygroscopic Properties

The moisture storage function w (SI unit: $\mathrm{kg/m^3}$) is given by the following sorption isotherm:

$$w = \frac{146}{\left(1+\left(-8\times10^{-8}\cdot R_{\mathrm{H2O}}T_{\mathrm{ref}}\rho_{\mathrm{w}}\ln(\phi)\right)^{1.6}\right)^{0.375}}$$

where ϕ (dimensionless) is the relative humidity, R_{H2O} = 462 J/(kg·K), T_{ref} = 293.15 K, and ρ_{w} = 1000 $\mathrm{kg/m^3}$.

The moisture diffusivity D_w (SI unit: m^2/s), used for the expression of the liquid water flux, is defined as:

$$D_w = -K\frac{\partial s}{\partial w}$$

where the suction stress s (SI unit: Pa) is defined as:

$$s = 0.125 \times 10^8 \left(\left(\frac{146}{w}\right)^{\frac{1}{0.375}} - 1 \right)^{0.625}$$

and the liquid water permeability K (SI unit: kg/(m·s·Pa)) is defined as:

$$K = \exp(-39.2619 + 0.0704 \cdot (w-73) - 1.742 \times 10^{-4} \cdot (w-73)^2$$
$$-2.7953 \times 10^{-6} \cdot (w-73)^3 - 1.1566 \times 10^{-7} \cdot (w-73)^4 + 2.5969 \times 10^{-9} \cdot (w-73)^5)$$

The vapor permeability δ_p (SI unit: s) used for the expression of the vapor flux, is defined as:

$$\delta_p = \frac{M_w}{R_{H2O}T_{ref}} \cdot \frac{26.1 \times 10^{-6}}{200} \cdot \frac{1 - \frac{w}{146}}{0.503\left(1 - \frac{w}{146}\right)^2 + 0.497}$$

Thermal Properties

The equivalent thermal conductivity k_{eff} (SI unit: W/(m·K)) is defined as moisture-dependent, with the following expression:

$$k_{eff} = 1.5 + \frac{15.8}{1000}w$$

Finally, from the following data given by the norm for dry material:

$$\rho_s C_{p,s} = 1.824 \times 10^6$$

the density ρ_s of dry material is set to 2145.88 kg/m^3, which corresponds to a value of $C_{p,s}$ = 850 J/(kg·K), which is a typical value for concrete. Then the moisture-dependent equivalent heat capacity is defined as:

$$(\rho C_p)_{eff} = \rho_s C_{p,s} + w C_{p,w}$$

where $C_{p,w}$ is the (temperature dependent) water heat capacity at constant pressure.

Results and Discussion

The image below shows the temperature distribution at 7, 30, and 365 days, close to the left boundary of the domain. The norm data are represented by asterisks. You can verify that the numerical results are within the validity ranges for all control times.

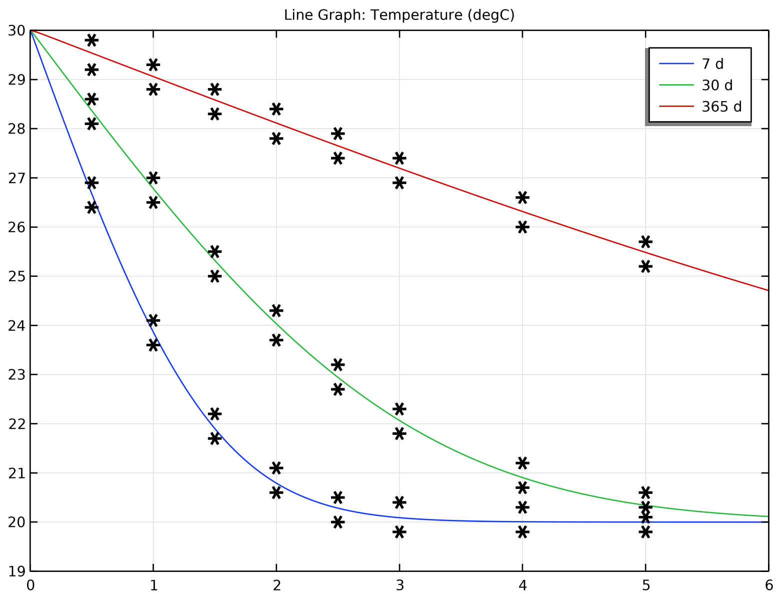


Figure 1: Temperature distribution at 7, 30, and 365 days with Norm 15026 validity ranges.

The image below shows the moisture storage function distribution at 7, 30, and 365 days, close to the left boundary of the domain. The norm data are represented by asterisks. You can verify that the numerical results are within the validity ranges for all control times.

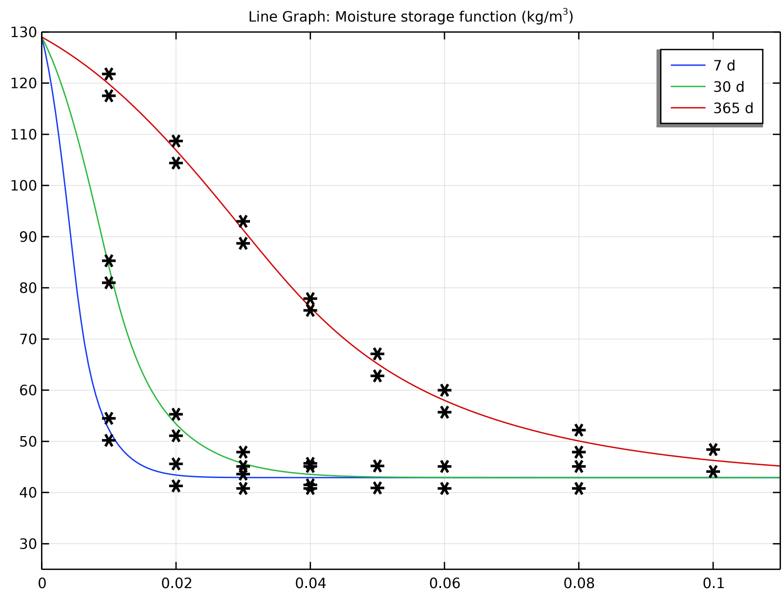


Figure 2: Moisture storage function distribution at 7, 30, and 365 days with Norm 15026 validity ranges.

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/Verification_Examples/semi_infinite_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 **1D**.

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>Time Dependent**.

6 Click **Done**.

GLOBAL DEFINITIONS

Parameters 1

Define parameters for the temperature and relative humidity conditions on boundaries.

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
T_e	30[degC]	303.15 K	Exterior temperature
phi_e	0.95	0.95	Exterior relative humidity
T_i	20[degC]	293.15 K	Interior temperature
phi_i	0.5	0.5	Interior relative humidity

Next, set the geometry.

GEOMETRY 1

Interval 1 (i1)

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Geometry 1** and choose **Interval**.

2 In the **Settings** window for **Interval**, locate the **Interval** section.

3 In the table, enter the following settings:

Coordinates (m)
0
20

Next, set the hygroscopic and thermal properties for the material specified in Norm 15026.

MATERIALS

Material - Norm 15026

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.
2 In the **Settings** window for **Material**, type `Material - Norm 15026` in the **Label** text field.
3 In the **Model Builder** window, expand the **Component 1 (comp1)>Materials>Material - Norm 15026 (mat1)** node.

   Set the relative humidity as a physical quantity to be used in the material properties.
4 In the **Model Builder** window, under **Component 1 (comp1)>Materials>Material - Norm 15026 (mat1)** click **Basic (def)**.
5 In the **Settings** window for **Basic**, locate the **Model Inputs** section.
6 Click **Select Quantity**.
7 In the **Physical Quantity** dialog box, type `relative humidity` in the text field.
8 Click **Filter**.
9 In the tree, select **General>Relative humidity (1)**.
10 Click **OK**.

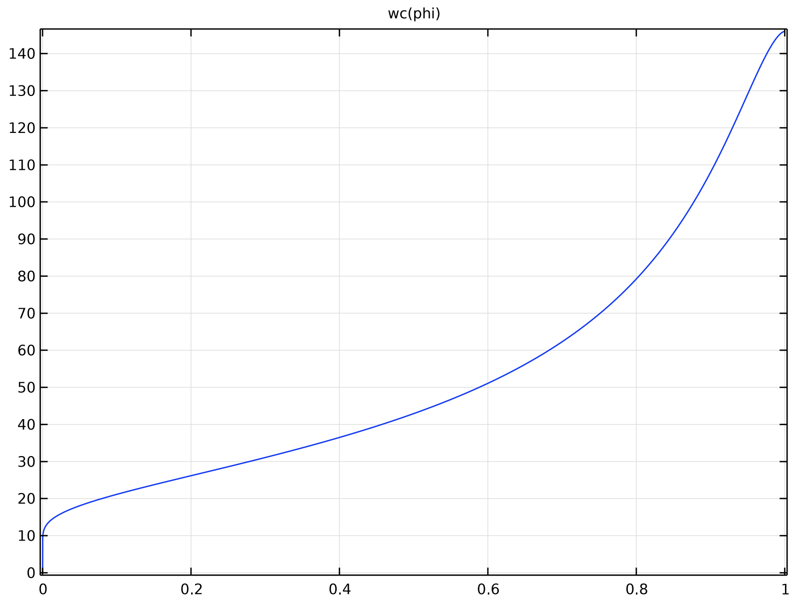
Set the moisture content as a function of relative humidity.

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 `146/(1+(-8e-8*462*293.15*1000*log(phi))^1.6)^0.375`.
5 In the **Arguments** text field, type `phi`.

6 Click **Plot**.

You obtain the graph below.



Material - Norm 15026 (mat1)

Set the thermal conductivity as a function of the moisture content.

Analytic: k

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

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

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

4 Locate the **Definition** section. In the **Expression** text field, type `1.5+15.8e-3*w`.

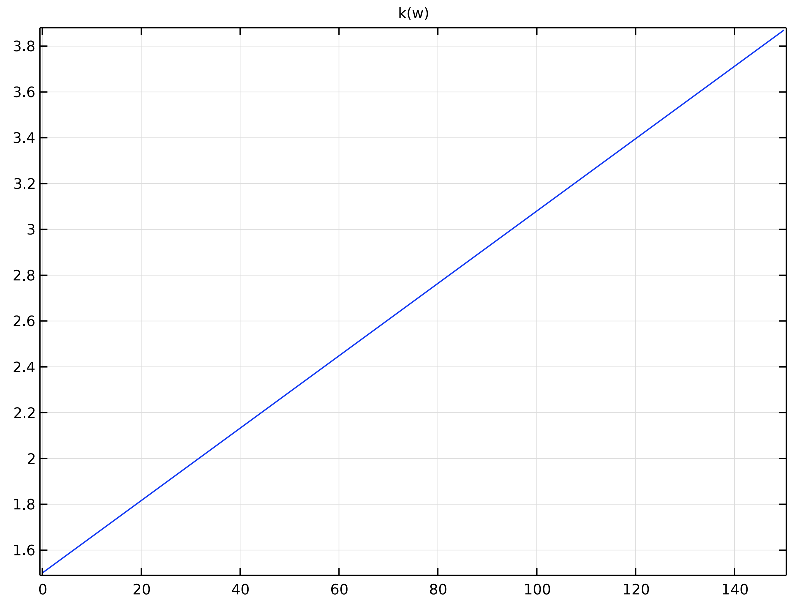
5 In the **Arguments** text field, type `w`.

6 Locate the **Plot Parameters** section. In the table, enter the following settings:

Plot	Argument	Lower limit	Upper limit	Fixed value	Unit
√	w	0	150	0	

7 Click **Plot**.

You obtain the graph below.



Material - Norm 15026 (mat1)

Set the suction stress as a function of the moisture content.

Analytic: s

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

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

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

4 Locate the **Definition** section. In the **Expression** text field, type `0.125e8*((146/w)^(1/0.375)-1)^0.625`.

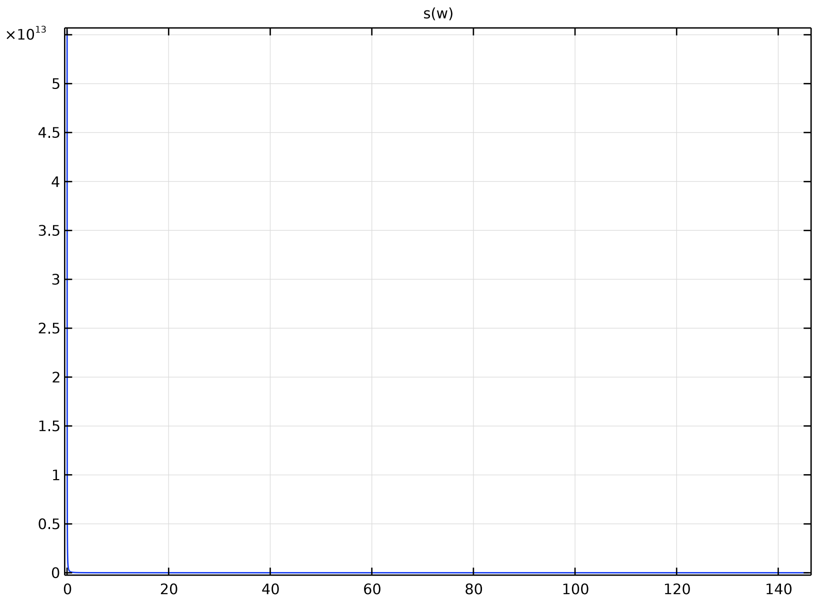
5 In the **Arguments** text field, type `w`.

6 Locate the **Plot Parameters** section. In the table, enter the following settings:

Plot	Argument	Lower limit	Upper limit	Fixed value	Unit
√	w	0	150	0	

7 Click **Plot**.

You obtain the graph below.



Material - Norm 15026 (mat1)

Set the liquid water permeability as a function of the moisture content.

Analytic: K

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

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

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

4 Locate the **Definition** section. In the **Expression** text field, type `exp(-39.2619+0.0704*(w-146/2)-1.7420e-4*(w-146/2)^2-2.7953e-6*(w-146/2)^3-1.1566e-7*(w-146/2)^4+2.5969e-9*(w-146/2)^5)`.

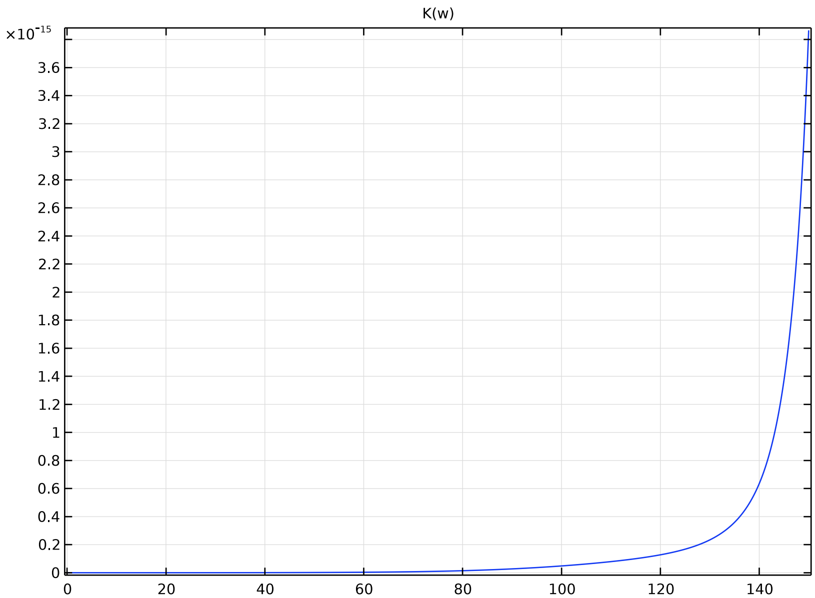
5 In the **Arguments** text field, type `w`.

6 Locate the **Plot Parameters** section. In the table, enter the following settings:

Plot	Argument	Lower limit	Upper limit	Fixed value	Unit
√	w	0	150	0	

7 Click **Plot**.

You obtain the graph below.



Material - Norm 15026 (mat1)

Set the moisture diffusivity as a function of the suction stress and the liquid water permeability.

Analytic: Dw

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

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

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

4 Locate the **Definition** section. In the **Expression** text field, type `-d(s(w),w)*K(w)`.

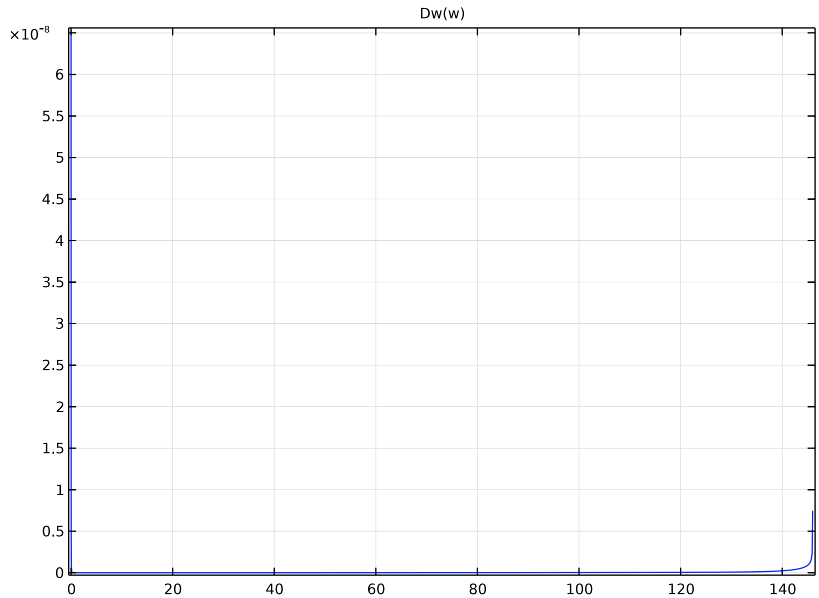
5 In the **Arguments** text field, type `w`.

6 Locate the **Plot Parameters** section. In the table, enter the following settings:

Plot	Argument	Lower limit	Upper limit	Fixed value	Unit
√	w	0	150	0	

7 Click **Plot**.

You obtain the graph below.



Material - Norm 15026 (mat1)

Finally, set the vapor permeability as a function of the moisture content.

Analytic: delta_p

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

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

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

4 Locate the **Definition** section. In the **Expression** text field, type `(0.01801528/R_const/293.15*26.1e-6/200*(1-w/146)/((1-0.497)*(1-w/146)^2+0.497))`.

5 In the **Arguments** text field, type `w`.

6 Locate the **Plot Parameters** section. In the table, enter the following settings:

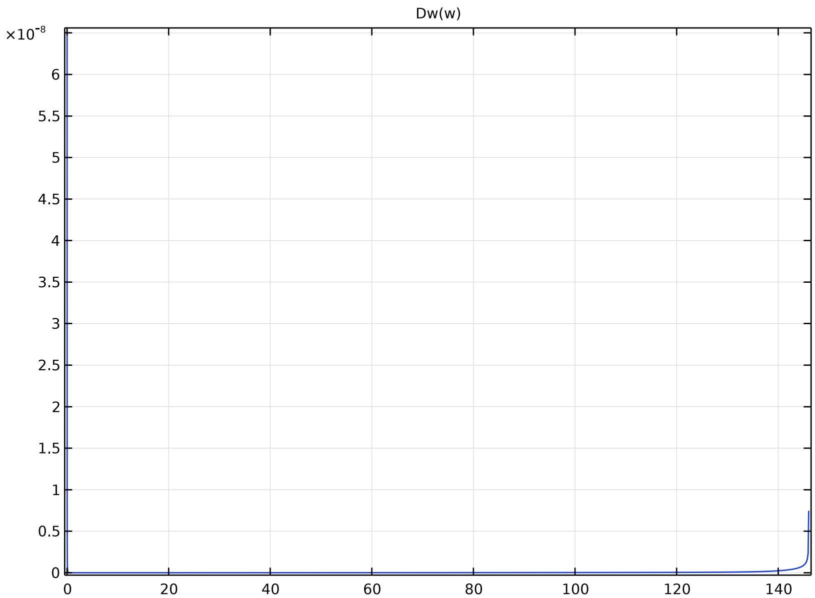
Plot	Argument	Lower limit	Upper limit	Fixed value	Unit
√	w	0	150	0	

Analytic: Dw (Dw)

1 In the **Model Builder** window, click **Analytic: Dw (Dw)**.

2 In the **Settings** window for **Analytic**, click **Plot**.

You obtain the graph below.



Material - Norm 15026 (mat1)

1 In the **Model Builder** window, under **Component 1 (comp1)>Materials** click **Material - Norm 15026 (mat1)**.

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(wc(phi))`	W/(m·K)	Basic
Density	rho	`2145.88`	kg/m³	Basic
Heat capacity at constant pressure	Cp	`850`	J/(kg·K)	Basic
Diffusion coefficient	D_iso ; Dii = D_iso, Dij = 0	`Dw(wc(phi))`	m²/s	Basic

Property	Variable	Value	Unit	Property group
Water content	w_c	`wc(phi)`	kg/m³	Basic
Vapor permeability	delta_p_iso ; delta_pii = delta_p_iso, delta_pij = 0	`delta_p(wc(phi))`	s	Basic

Define a ramp function used to set a temperature and a relative humidity boundary condition consistent with the initial condition on the left boundary of the domain.

DEFINITIONS

Ramp 1 (rm1)

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

2 In the **Settings** window for **Ramp**, locate the **Parameters** section.

3 In the **Location** text field, type `100`.

4 In the **Slope** text field, type `1e-3`.

5 Select the **Cutoff** check box.

6 Click to expand the **Smoothing** section. Select the **Size of transition zone at start** check box.

7 Select the **Size of transition zone at cutoff** check box.

8 In the **Size of transition zone at start** text field, type `100`.

9 In the **Size of transition zone at cutoff** text field, type `100`.

Now, set up the physics interfaces.

HEAT TRANSFER IN BUILDING MATERIALS (HT)

Initial Values 1

1 In the **Model Builder** window, under **Component 1 (comp1)> Heat Transfer in Building Materials (ht)** 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_i`.

Temperature 1

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

2 Select Boundary 1 only.

3 In the **Settings** window for **Temperature**, locate the **Temperature** section.

4 In the T_0 text field, type `T_i+(T_e-T_i)*rm1(t[1/s])`.

Temperature 2

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

2 Select Boundary 2 only.

3 In the **Settings** window for **Temperature**, locate the **Temperature** section.

4 In the T_0 text field, type `T_i`.

MOISTURE TRANSPORT IN BUILDING MATERIALS (MT)

Initial Values 1

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

Moisture Content 1

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

2 Select Boundary 1 only.

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

4 In the T_0 text field, type `T_i+(T_e-T_i)*rm1(t[1/s])`.

5 In the $\phi_{w,0}$ text field, type `phi_i+(phi_e-phi_i)*rm1(t[1/s])`.

Moisture Content 2

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

2 Select Boundary 2 only.

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

4 In the T_0 text field, type `T_i`.

5 In the $\phi_{w,0}$ text field, type `phi_i`.

Refine the mesh close to the boundary where exterior conditions are imposed.

MESH 1

Edge 1

In the **Mesh** toolbar, click **Edge**.

Distribution 1

1 Right-click **Edge 1** and choose **Distribution**.

2 In the **Settings** window for **Distribution**, locate the **Distribution** section.

3 From the **Distribution type** list, choose **Predefined**.

4 In the **Number of elements** text field, type `1000`.

5 In the **Element ratio** text field, type `25`.

6 Click **Build All**.

Set the time-dependent study and compute.

STUDY 1

Step 1: Time Dependent

1 In the **Model Builder** window, under **Study 1** click **Step 1: Time Dependent**.

2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.

3 From the **Time unit** list, choose **d**.

4 In the **Output times** text field, type `range(0,1,365)`.

5 From the **Tolerance** list, choose **User controlled**.

6 In the **Relative tolerance** text field, type `1e-3`.

7 In the **Home** toolbar, click **Compute**.

You can compare the results for the temperature and moisture storage function with the data of Norm EN 15026. First, import the validity ranges from the norm in tables.

RESULTS

Table 1

1 In the **Results** toolbar, click **Table**.

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

3 Click **Import**.

4 Browse to the model's Application Libraries folder and double-click the file `semi_infinite_wall_temperature.txt`.

Table 2

1 In the **Results** toolbar, click **Table**.

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

3 Click **Import**.

4 Browse to the model's Application Libraries folder and double-click the file `semi_infinite_wall_moisture_storage_function.txt`.

To visualize the temperature distribution as in Figure 1, follow the next steps.

Temperature (ht)

1 In the **Model Builder** window, under **Results** click **Temperature (ht)**.
2 In the **Settings** window for **1D Plot Group**, locate the **Axis** section.
3 Select the **Manual axis limits** check box.
4 In the **x minimum** text field, type `0`.
5 In the **x maximum** text field, type `6`.
6 In the **y minimum** text field, type `19`.
7 In the **y maximum** text field, type `30`.
8 Locate the **Data** section. From the **Time selection** list, choose **From list**.
9 In the **Times (d)** list, choose **7**, **30**, and **365**.

Line Graph 1

1 In the **Model Builder** window, expand the **Temperature (ht)** node, then click **Line Graph 1**.
2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.
3 From the **Unit** list, choose **degC**.
4 Click to expand the **Legends** section. Select the **Show legends** check box.
5 In the **Temperature (ht)** toolbar, click **Plot**.

Table Graph 1

1 In the **Model Builder** window, right-click **Temperature (ht)** and choose **Table Graph**.
2 In the **Settings** window for **Table Graph**, locate the **Coloring and Style** section.
3 Find the **Line style** subsection. From the **Line** list, choose **None**.
4 From the **Color** list, choose **From theme**.
5 Find the **Line markers** subsection. From the **Marker** list, choose **Asterisk**.
6 In the **Temperature (ht)** toolbar, click **Plot**.

To visualize the moisture storage function distribution as in Figure 2, follow the next steps.

Moisture storage function

1 In the **Model Builder** window, under **Results** click **Relative Humidity (mt)**.
2 In the **Settings** window for **1D Plot Group**, type `Moisture storage function` in the **Label** text field.
3 Locate the **Axis** section. Select the **Manual axis limits** check box.

4 In the **x minimum** text field, type `0`.

5 In the **x maximum** text field, type `0.11`.

6 In the **y minimum** text field, type `25`.

7 In the **y maximum** text field, type `130`.

8 Locate the **Data** section. From the **Time selection** list, choose **From list**.

9 In the **Times (d)** list, choose **7**, **30**, and **365**.

Line Graph 1

1 In the **Model Builder** window, expand the **Moisture storage function** node, then click **Line Graph 1**.

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

3 From the **Selection** list, choose **All domains**.

4 In the **Model Builder** window, click **Line Graph 1**.

5 Locate the **y-Axis Data** section. In the **Expression** text field, type `mt.wc`.

6 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

7 In the **Expression** text field, type `x`.

8 Locate the **Legends** section. Select the **Show legends** check box.

9 In the **Moisture storage function** toolbar, click **Plot**.

Table Graph 1

1 In the **Model Builder** window, right-click **Moisture storage function** and choose **Table Graph**.

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

3 From the **Table** list, choose **Table 2**.

4 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **None**.

5 From the **Color** list, choose **From theme**.

6 Find the **Line markers** subsection. From the **Marker** list, choose **Asterisk**.

7 In the **Moisture storage function** toolbar, click **Plot**.

You can check that the results fit in the validity ranges given by the norm.