

Isothermal Box

Introduction

This example solves the heat transfer in an isothermal box aimed at transporting refrigerated articles such as medical materials for 24 hours. In this case, the box not only has to keep the content cold over a long period of time, but also has to respect a storage temperature restriction. In this model, the restriction interval is between 2 °C and 8 °C.

The box needs an insulating material such as foam to separate the content from the exterior environment. A cold source, for instance ice at nearly -5 °C, is then added. However, to stay above the lower temperature bound of 2 °C, foam is also placed between the ice and the contents.

A thickening agent often increases the water viscosity before freezing it. Once melt, this eutectic mixture is meant to avoid convective motion that may accelerate warming.



Figure 1: Geometry and material distribution of the isothermal box.

Model Definition

Figure 1 illustrates the geometry and material distribution of the isothermal box. Foam isolates the box from the exterior environment. The content is surrounded by four eutectic plates behind foam layers at the vertical boundaries. The remaining space at the corners of the content is filled with air. The content is at an initial temperature of 5 °C.

AMBIENT TEMPERATURE

In this model, the ambient temperature follows the last climate data from ASHRAE. The Sevilla weather station was chosen for this simulation (see Figure 2), with a typical temperature profile of June 1st, starting at 6 a.m.



Figure 2: Typical ambient temperature profile according to ASHRAE climate data, given by the Sevilla weather station from June 1st at 6 a.m. to June 4th at 6 a.m.

Convective cooling conditions with this time-dependent temperature profile apply on the exterior boundaries of the box.

GENERIC MATERIAL FOR THE CONTENT

To simplify the model, you can consider that all the available space for the content is used. This assumption corresponds to cases where overpackaging fills the remaining empty space to attenuate shocks caused by transportation. The content may also change depending on the situations. Hence, a generic material with thermophysical properties stated in Table 1 is used for this simulation.

Thermophysical Property	Value
Thermal conductivity	I W/(m⋅K)
Density	2000 kg/m ³
Heat capacity at constant pressure	800 J/(kg·K)

TABLE I: THERMOPHYSICAL PROPERTIES OF THE GENERIC MATERIAL.

THIN THERMALLY RESISTIVE LAYERS

The eutectic mixture is generally contained in thin plastic packages that behave as resistive layers. The thermal conductivity is set to 0.30 W/(m·K) in this model and the thickness to 1 mm. Similarly, thin air layers between foam, lid, and content (see Figure 3) can be modeled as a thin film of conductivity 0.025 W/(m·K) and thickness 50 μ m.



Figure 3: Selection corresponding to the air thin thermally resistive layers.

ICE-TO-WATER PHASE CHANGE

To keep the medical content refrigerated during transportation, the four lateral eutectic plates act as energy storage that maintain the box at low temperature. Phase change occurs at around 0 °C. As long as the ice is not completely melt, ideally all along the

transportation time, the temperature in the eutectic plates remain stable near 0 °C which protects the content from exceeding the critical temperature.

Results and Discussion

Figure 4 shows several curves representing the evolution of temperature in the box for 72 hours, together with a temperature plot of the eutectic plates.



Figure 4: Temperature variations of the contents (red, green and blue), average temperature of the ice blocks (cyan) and critical values (dotted lines), during 72 hours.

The average temperature of the ice (cyan curve) quickly falls from -5 °C to -1 °C but remains close to 0 °C for nearly 24 hours. The plain green, blue, and red curves respectively show the evolution of average, minimum, and maximum temperature of the content. They remain in the range 2 °C to 8 °C (dotted lines) during the first 24 hours. Between 24 and 48 hours, just after the end of the melting process, the content comes

increasingly closer to the critical temperature of 8 °C. After 48 hours, the whole box is too close or above 8 °C.



Figure 5: Temperature field in the box at time 24 hours.

Figure 5 shows the temperature profile in the box after 24 hours of transportation. Sharp temperature gradients can be observed in the foam insulating layers, which protects the content from outside warmth.

Application Library path: Heat_Transfer_Module/Medical_Technology/ isothermal_box

Modeling Instructions

From the File menu, choose New.

N E W In the New window, click School Model Wizard.

MODEL WIZARD

- I In the Model Wizard window, click 间 3D.
- 2 In the Select Physics tree, select Heat Transfer>Heat Transfer in Solids (ht).
- 3 Click Add.
- 4 Click 🔿 Study.
- 5 In the Select Study tree, select General Studies>Time Dependent.
- 6 Click M Done.

GLOBAL DEFINITIONS

Parameters 1

Start by entering the model parameters.

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

- 2 In the Settings window for Parameters, locate the Parameters section.
- **3** In the table, enter the following settings:

Name	Expression	Value	Description
box_w	40[cm]	0.4 m	Box width
box_d	40[cm]	0.4 m	Box depth
box_h	24[cm]	0.24 m	Box height
content_w	24[cm]	0.24 m	Content width
content_d	24[cm]	0.24 m	Content depth
content_h	20[cm]	0.2 m	Content height
ice_t	2[cm]	0.02 m	Eutectic plates thickness
foam_t	4[cm]	0.04 m	Foam layers thickness
lid_t	4[cm]	0.04 m	Box lid thickness

The next steps create the geometry with cumulative selections.

GEOMETRY I

Block I (blk1)

- I In the **Geometry** toolbar, click 🗍 Block.
- 2 In the Settings window for Block, locate the Size and Shape section.
- 3 In the Width text field, type box_w.
- 4 In the **Depth** text field, type box_d.

- **5** In the **Height** text field, type box_h.
- 6 In the Geometry toolbar, click 🟢 Build All.

Block 2 (blk2)

- I In the **Geometry** toolbar, click 🗍 **Block**.
- 2 In the Settings window for Block, locate the Size and Shape section.
- 3 In the Width text field, type content_w.
- 4 In the **Depth** text field, type content_d.
- **5** In the **Height** text field, type content_h.
- 6 Locate the **Position** section. In the **x** text field, type (box_w-content_w)/2.
- 7 In the y text field, type (box_d-content_d)/2.
- 8 In the z text field, type box_h-content_h.
- **9** Locate the Selections of Resulting Entities section. Find the Cumulative selection subsection. Click New.
- 10 In the New Cumulative Selection dialog box, type Content in the Name text field.

II Click **OK**.

- 12 In the Geometry toolbar, click 🟢 Build All.
- **I3** Click the **Transparency** button in the **Graphics** toolbar.

The Transparency functionality is convenient here to display the interior of the box.

Block 3 (blk3)

- I In the **Geometry** toolbar, click **[]** Block.
- 2 In the Settings window for Block, locate the Size and Shape section.
- 3 In the Width text field, type ice_t.
- 4 In the **Depth** text field, type content_d.
- 5 In the **Height** text field, type content_h.
- 6 Locate the **Position** section. In the **x** text field, type box_w-foam_t-ice_t.
- 7 In the y text field, type (box_d-content_d)/2.
- 8 In the z text field, type box_h-content_h.
- **9** Locate the Selections of Resulting Entities section. Find the Cumulative selection subsection. Click New.
- 10 In the New Cumulative Selection dialog box, type Ice in the Name text field.
- II Click OK.

12 In the Geometry toolbar, click 🟢 Build All.

Block 4 (blk4)

- I Right-click Block 3 (blk3) and choose Duplicate.
- 2 In the Settings window for Block, locate the Position section.
- **3** In the **x** text field, type foam_t.
- **4** In the **Geometry** toolbar, click 🟢 **Build All**.

Block 5 (blk5)

- I In the **Geometry** toolbar, click 🗍 **Block**.
- 2 In the Settings window for Block, locate the Size and Shape section.
- 3 In the Width text field, type content_w.
- 4 In the **Depth** text field, type ice_t.
- 5 In the **Height** text field, type content_h.
- 6 Locate the **Position** section. In the x text field, type (box_w-content_w)/2.
- 7 In the y text field, type foam_t.
- 8 In the z text field, type box_h-content_h.
- **9** Locate the Selections of Resulting Entities section. Find the Cumulative selection subsection. From the Contribute to list, choose Ice.
- 10 In the Geometry toolbar, click 📳 Build All.

Block 6 (blk6)

- I Right-click Block 5 (blk5) and choose Duplicate.
- 2 In the Settings window for Block, locate the Position section.
- **3** In the **y** text field, type box_d-foam_t-ice_t.
- **4** In the **Geometry** toolbar, click 📗 **Build All**.

Block 7 (blk7)

- I In the **Geometry** toolbar, click 🗍 Block.
- 2 In the Settings window for Block, locate the Size and Shape section.
- 3 In the Width text field, type (box_w-content_w)/2-foam_t.
- 4 In the **Depth** text field, type (box_d-content_d)/2-foam_t.
- 5 In the **Height** text field, type content_h.
- 6 Locate the **Position** section. In the **x** text field, type foam_t.
- 7 In the y text field, type foam_t.

- 8 In the z text field, type box_h-content_h.
- **9** Locate the Selections of Resulting Entities section. Find the Cumulative selection subsection. Click New.
- 10 In the New Cumulative Selection dialog box, type Empty Space in the Name text field.

II Click OK.

12 In the Geometry toolbar, click 🟢 Build All.

Block 8 (blk8)

- I Right-click Block 7 (blk7) and choose Duplicate.
- 2 In the Settings window for Block, locate the Position section.
- 3 In the x text field, type (box_w+content_w)/2.
- **4** In the **Geometry** toolbar, click 🟢 **Build All**.

Block 9 (blk9)

- I Right-click Block 8 (blk8) and choose Duplicate.
- 2 In the Settings window for Block, locate the Position section.
- **3** In the **y** text field, type (box_d+content_d)/2.
- **4** In the **Geometry** toolbar, click 🟢 **Build All**.

Block 10 (blk10)

- I Right-click Block 9 (blk9) and choose Duplicate.
- 2 In the Settings window for Block, locate the Position section.
- **3** In the **x** text field, type foam_t.
- **4** In the **Geometry** toolbar, click 📗 **Build All**.

Block II (blkII)

- I In the **Geometry** toolbar, click 🗍 **Block**.
- 2 In the Settings window for Block, locate the Size and Shape section.
- 3 In the Width text field, type box_w.
- 4 In the **Depth** text field, type box_d.
- **5** In the **Height** text field, type lid_t.
- 6 Locate the Position section. In the z text field, type box_h.
- 7 In the Geometry toolbar, click 🟢 Build All.
- 8 Click the 🕂 Zoom Extents button in the Graphics toolbar.

After finalizing the geometry, define a few remaining useful selections to be used in the rest of the model.

DEFINITIONS

Foam

- I In the **Definitions** toolbar, click $\mathbb{V}_{\mathbf{h}}$ **Explicit**.
- 2 In the Settings window for Explicit, type Foam in the Label text field.
- **3** Select Domains 1 and 2 only.

Thin Air Resistive Layers

- I In the Definitions toolbar, click 🐂 Adjacent.
- 2 In the Settings window for Adjacent, type Thin Air Resistive Layers in the Label text field.
- 3 Locate the Input Entities section. Under Input selections, click + Add.
- 4 In the Add dialog box, in the Input selections list, choose Foam and Content.
- 5 Click OK.
- 6 In the Settings window for Adjacent, locate the Output Entities section.
- 7 Clear the **Exterior boundaries** check box.

8 Select the Interior boundaries check box.



Exterior Surfaces

- I In the Definitions toolbar, click 🗞 Explicit.
- 2 In the Settings window for Explicit, type Exterior Surfaces in the Label text field.
- 3 Locate the Input Entities section. Select the All domains check box.
- 4 Locate the **Output Entities** section. From the **Output entities** list, choose **Adjacent boundaries**.

In order to monitor the temperature field inside the box, define now a few probes that would display temperature values during computation.

Content Minimum

- I In the Definitions toolbar, click probes and choose Domain Probe.
- 2 In the Settings window for Domain Probe, type Content Minimum in the Label text field.
- 3 Locate the Probe Type section. From the Type list, choose Minimum.
- 4 Locate the Source Selection section. From the Selection list, choose Content.
- 5 Locate the Expression section. From the Table and plot unit list, choose degC.

Content Average

I In the Definitions toolbar, click probes and choose Domain Probe.

- 2 In the Settings window for Domain Probe, type Content Average in the Label text field.
- 3 Locate the Source Selection section. From the Selection list, choose Content.
- 4 Locate the Expression section. From the Table and plot unit list, choose degC.

Content Maximum

- I In the Definitions toolbar, click probes and choose Domain Probe.
- 2 In the Settings window for Domain Probe, type Content Maximum in the Label text field.
- 3 Locate the Probe Type section. From the Type list, choose Maximum.
- 4 Locate the Source Selection section. From the Selection list, choose Content.
- 5 Locate the Expression section. From the Table and plot unit list, choose degC.

Ice Average

- I In the Definitions toolbar, click probes and choose Domain Probe.
- 2 In the Settings window for Domain Probe, type Ice Average in the Label text field.
- 3 Locate the Source Selection section. From the Selection list, choose Ice.
- 4 Locate the Expression section. From the Table and plot unit list, choose degC.

Before setting up the material properties, specify the boundaries which are modeled as thin layers or as thin films, and which domains that are solid or changing phase. Using this information, COMSOL Multiphysics can detect which material properties that are needed.

HEAT TRANSFER IN SOLIDS (HT)

Fluid I

- I In the Model Builder window, under Component I (compl) right-click Heat Transfer in Solids (ht) and choose Fluid.
- 2 In the Settings window for Fluid, locate the Domain Selection section.
- **3** From the **Selection** list, choose **Ice**.

Phase Change Material I

In the Physics toolbar, click 戻 Attributes and choose Phase Change Material.

Thin Film 1

- I In the Physics toolbar, click 🔚 Boundaries and choose Thin Film.
- 2 In the Settings window for Thin Film, locate the Boundary Selection section.
- 3 From the Selection list, choose Thin Air Resistive Layers.

Thin Layer 1

- I In the Physics toolbar, click 📄 Boundaries and choose Thin Layer.
- 2 In the Settings window for Thin Layer, locate the Boundary Selection section.
- **3** From the **Selection** list, choose **Ice**.

MATERIALS

You can now define the material properties.

Foam

- I In the Materials toolbar, click 🚦 Blank Material.
- 2 In the Settings window for Material, type Foam in the Label text field.
- 3 Locate the Geometric Entity Selection section. From the Selection list, choose Foam.
- 4 Locate the Material Contents section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	0.03	W/(m·K)	Basic
Density	rho	25	kg/m³	Basic
Heat capacity at constant pressure	Ср	2	J/(kg·K)	Basic

Content Material

- I In the Materials toolbar, click 🚦 Blank Material.
- 2 In the Settings window for Material, type Content Material in the Label text field.
- **3** Locate the Geometric Entity Selection section. From the Selection list, choose Content.
- 4 Locate the Material Contents section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	1	W/(m·K)	Basic
Density	rho	2000	kg/m³	Basic
Heat capacity at constant pressure	Ср	800	J/(kg·K)	Basic

ADD MATERIAL

I 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 Built-in>Air.
- 4 Click Add to Component in the window toolbar.
- 5 In the Materials toolbar, click 🙀 Add Material to close the Add Material window.

MATERIALS

Air (mat3)

- I In the Settings window for Material, locate the Geometric Entity Selection section.
- 2 From the Selection list, choose Empty Space.

Water

- I In the Materials toolbar, click 🚦 Blank Material.
- 2 In the Settings window for Material, type Water in the Label text field.
- 3 Locate the Geometric Entity Selection section. From the Selection list, choose Ice.
- 4 Locate the Material Contents section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	0.6	W/(m·K)	Basic
Density	rho	1000	kg/m³	Basic
Heat capacity at constant pressure	Ср	4200	J/(kg·K)	Basic
Ratio of specific heats	gamma	1.1	1	Basic

Ice

I In the Materials toolbar, click 🚦 Blank Material.

2 In the Settings window for Material, type Ice in the Label text field.

3 Locate the Geometric Entity Selection section. From the Selection list, choose Ice.

4 Locate the Material Contents section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	2.3	W/(m·K)	Basic
Density	rho	1000	kg/m³	Basic

Property	Variable	Value	Unit	Property group
Heat capacity at constant pressure	Ср	2050	J/(kg·K)	Basic
Ratio of specific heats	gamma	1	I	Basic

Eutectic Plates Package

- I In the Materials toolbar, click 🚦 Blank Material.
- 2 In the Settings window for Material, type Eutectic Plates Package in the Label text field.
- **3** Locate the **Geometric Entity Selection** section. From the **Geometric entity level** list, choose **Boundary**.
- 4 From the Selection list, choose Ice.
- 5 Locate the Material Contents section. In the table, enter the following settings:

Property	Variable	Value	Unit	P roperty group
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	0.3	W/(m·K)	Basic
Density	rho	1050	kg/m³	Basic
Heat capacity at constant pressure	Ср	20	J/(kg·K)	Basic
Thickness	lth	300[um]	m	Shell

ADD MATERIAL

- I 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 Built-in>Air.
- 4 Click Add to Component in the window toolbar.
- 5 In the Materials toolbar, click 👯 Add Material to close the Add Material window.

MATERIALS

Air Boundaries

- I In the Settings window for Material, type Air Boundaries in the Label text field.
- **2** Locate the Geometric Entity Selection section. From the Geometric entity level list, choose Boundary.

- **3** From the Selection list, choose Thin Air Resistive Layers.
- 4 Locate the Material Contents section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Thickness	lth	50[um]	m	Shell

In the subsequent instructions you will define the ambient temperature using the ASHRAE climate data at a given weather station and set up the domain and boundary conditions.

DEFINITIONS (COMPI)

Ambient Properties 1 (ampr1)

- I In the Physics toolbar, click **E** Shared Properties and choose Ambient Properties.
- 2 In the Settings window for Ambient Properties, locate the Ambient Settings section.
- 3 From the Ambient data list, choose Meteorological data (ASHRAE 2017).
- 4 Locate the Location section. Click Set Weather Station.
- 5 In the Weather Station dialog box, select Europe>Spain>SEVILLA (083910) in the tree.
- 6 Click OK.
- 7 In the Settings window for Ambient Properties, locate the Time section.

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

Hour	Minute	Second
10	00	00

HEAT TRANSFER IN SOLIDS (HT)

Phase Change Material I

- I In the Model Builder window, under Component I (compl)>Heat Transfer in Solids (ht)> Fluid I click Phase Change Material I.
- 2 In the Settings window for Phase Change Material, locate the Phase Change section.
- **3** In the $\Delta T_{1 \rightarrow 2}$ text field, type **3.5**.
- 4 Locate the Phase I section. From the Material, phase I list, choose Ice (mat5).
- 5 Locate the Phase 2 section. From the Material, phase 2 list, choose Water (mat4).
- 6 In the Model Builder window, click Heat Transfer in Solids (ht).
- 7 In the Settings window for Heat Transfer in Solids, locate the Physical Model section.
- 8 Select the Isothermal domain check box.

Isothermal Domain Interface 1

- I In the Model Builder window, click Isothermal Domain Interface I.
- 2 In the Settings window for Isothermal Domain Interface, locate the Isothermal Domain Interface section.
- **3** From the Interface type list, choose Convective heat flux.
- **4** In the *h* text field, type **5**.

Isothermal Domain I

- I In the Physics toolbar, click 🔚 Domains and choose Isothermal Domain.
- 2 In the Settings window for Isothermal Domain, locate the Domain Selection section.
- 3 From the Selection list, choose Empty Space.

Initial Values 1

- I In the Model Builder window, click Initial Values I.
- 2 In the Settings window for Initial Values, locate the Initial Values section.
- **3** In the *T* text field, type 20[degC].

Initial Values 2

- I In the Physics toolbar, click 🔚 Domains and choose Initial Values.
- 2 In the Settings window for Initial Values, locate the Domain Selection section.
- **3** From the Selection list, choose Content.
- 4 Locate the **Initial Values** section. In the *T* text field, type 5[degC].

Initial Values 3

- I In the Physics toolbar, click 📄 Domains and choose Initial Values.
- 2 In the Settings window for Initial Values, locate the Domain Selection section.
- **3** From the **Selection** list, choose **Ice**.
- **4** Locate the **Initial Values** section. In the T text field, type -5[degC].

Heat Flux 1

- I In the Physics toolbar, click 🔚 Boundaries and choose Heat Flux.
- 2 In the Settings window for Heat Flux, locate the Boundary Selection section.
- **3** From the Selection list, choose Exterior Surfaces.
- 4 Locate the Heat Flux section. Click the Convective heat flux button.
- **5** In the *h* text field, type **5**.
- **6** From the T_{ext} list, choose **Ambient temperature (amprl)**.

MESH I

For phase change materials, a finer mesh is necessary in order to accurately model the melting front. In the following steps, build a finer mesh within the ice domains compared to the remaining parts of the box.

Free Tetrahedral I

- I In the Mesh toolbar, click \land Free Tetrahedral.
- 2 In the Settings window for Free Tetrahedral, locate the Domain Selection section.
- 3 From the Geometric entity level list, choose Domain.
- **4** From the **Selection** list, choose **Ice**.

Size 1

- I In the Mesh toolbar, click Size Attribute and choose Extra Fine.
- 2 In the Settings window for Size, click 📗 Build Selected.

Free Tetrahedral 2

- I In the Mesh toolbar, click \land Free Tetrahedral.
- 2 Click 📗 Build Mesh.

The model is now ready for computation.

STUDY I

Step 1: Time Dependent

- I In the Model Builder window, under Study I click Step I: Time Dependent.
- 2 In the Settings window for Time Dependent, locate the Study Settings section.
- **3** From the **Time unit** list, choose **h**.
- 4 Click Range.
- 5 In the Range dialog box, type 3 in the Step text field.
- 6 In the **Stop** text field, type 72.
- 7 Click Replace.

For more robust convergence, tighten the relative tolerance, which controls the size of the time steps taken by the solver.

- 8 In the Settings window for Time Dependent, locate the Study Settings section.
- 9 From the Tolerance list, choose User controlled.
- **IO** In the **Relative tolerance** text field, type 1e-3.
- II In the Home toolbar, click **=** Compute.

RESULTS

Temperature (ht)

The first default plot shows the temperature profile over time.

- I In the Settings window for 3D Plot Group, locate the Data section.
- 2 From the Time (h) list, choose 24.

Surface 1

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

Surface 2

- I In the Model Builder window, click Surface 2.
- 2 In the Settings window for Surface, locate the Expression section.
- 3 From the Unit list, choose degC.

The following steps add a plot of the phase change front.

Temperature (ht)

In the Model Builder window, click Temperature (ht).

Isosurface I

- I In the Temperature (ht) toolbar, click in Isosurface.
- In the Settings window for Isosurface, click Replace Expression in the upper-right corner of the Expression section. From the menu, choose Component I (compl)>
 Heat Transfer in Solids>Phase change>ht.alpha12 Phase transition between phase I and phase 2.
- 3 Locate the Levels section. From the Entry method list, choose Levels.
- 4 In the Levels text field, type 0.5.
- 5 Locate the Coloring and Style section. From the Coloring list, choose Uniform.
- 6 From the Color list, choose White.
- 7 Clear the Color legend check box.

8 In the **Temperature (ht)** toolbar, click **I** Plot.



This graph shows the temperature values caught by the previously defined probes during computation. Complete it by displaying the temperature restriction interval.

Content Temperature

I In the Model Builder window, under Results click Probe Plot Group 3.

0

- 2 In the Settings window for ID Plot Group, type Content Temperature in the Label text field.
- 3 Locate the Plot Settings section. Select the x-axis label check box.
- 4 Select the y-axis label check box.
- **5** In the associated text field, type Temperature (degC).
- 6 Locate the Data section. From the Dataset list, choose Probe Solution 2 (soll).
- 7 Locate the Legend section. From the Position list, choose Upper middle.

Probe Table Graph 1

- I In the Model Builder window, expand the Content Temperature node, then click Probe Table Graph I.
- 2 In the Settings window for Table Graph, locate the Coloring and Style section.
- 3 In the Width text field, type 2.

20

15

10

5

Content Temperature

In the Model Builder window, click Content Temperature.

Global I

- I In the Content Temperature toolbar, click (Global.
- 2 In the Settings window for Global, locate the y-Axis Data section.
- **3** In the table, enter the following settings:

Expression	Unit	Description
2[degC]	degC	Temperature restriction, lower bound

- 4 Click to expand the Title section. From the Title type list, choose None.
- 5 Click to expand the Coloring and Style section. Find the Line style subsection. From the Line list, choose Dotted.
- 6 From the Color list, choose Blue.
- 7 Click to expand the Legends section. Clear the Show legends check box.
- 8 In the Content Temperature toolbar, click **O** Plot.

Content Temperature

In the Model Builder window, click Content Temperature.

Global 2

- I In the Content Temperature toolbar, click (Global.
- 2 In the Settings window for Global, locate the y-Axis Data section.
- **3** In the table, enter the following settings:

Expression	Unit	Description
8[degC]	degC	Temperature restriction, upper bound

- 4 Locate the Title section. From the Title type list, choose None.
- **5** Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dotted**.
- 6 From the Color list, choose Red.
- 7 Locate the Legends section. Clear the Show legends check box.

8 In the Content Temperature toolbar, click **O** Plot.



Volume Average 1

- I In the Results toolbar, click 8.85 e-12 More Derived Values and choose Average> Volume Average.
- **2** Select Domain 4 only.
- 3 In the Settings window for Volume Average, locate the Expressions section.
- **4** In the table, enter the following settings:

Expression	Unit	Description
ht.theta1	1	

5 Click **=** Evaluate.

Ice fraction

- I In the Results toolbar, click \sim ID Plot Group.
- 2 In the Settings window for ID Plot Group, type Ice fraction in the Label text field.
- 3 Locate the Plot Settings section. Select the y-axis label check box.
- **4** In the associated text field, type Volume fraction.
- 5 Click to expand the Title section. From the Title type list, choose Manual.

6 In the Title text area, type Ice fraction in eutectic plates.

Table Graph 1

- I Right-click Ice fraction 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** In the **Ice fraction** toolbar, click **I Plot**.

Create a new plot group showing the ambient temperature provided by the built-in climate data.

Ambient Temperature

- I In the Home toolbar, click 🚛 Add Plot Group and choose ID Plot Group.
- 2 In the Settings window for ID Plot Group, type Ambient Temperature in the Label text field.
- 3 Locate the Legend section. Clear the Show legends check box.

Global I

- I In the Ambient Temperature toolbar, click 🔁 Global.
- In the Settings window for Global, click Replace Expression in the upper-right corner of the y-Axis Data section. From the menu, choose Component I (compl)>Ambient data> amprl.T_amb Ambient temperature K.
- 3 Locate the y-Axis Data section. In the table, enter the following settings:

Expression	Unit	Description
ampr1.T_amb	degC	Ambient temperature



