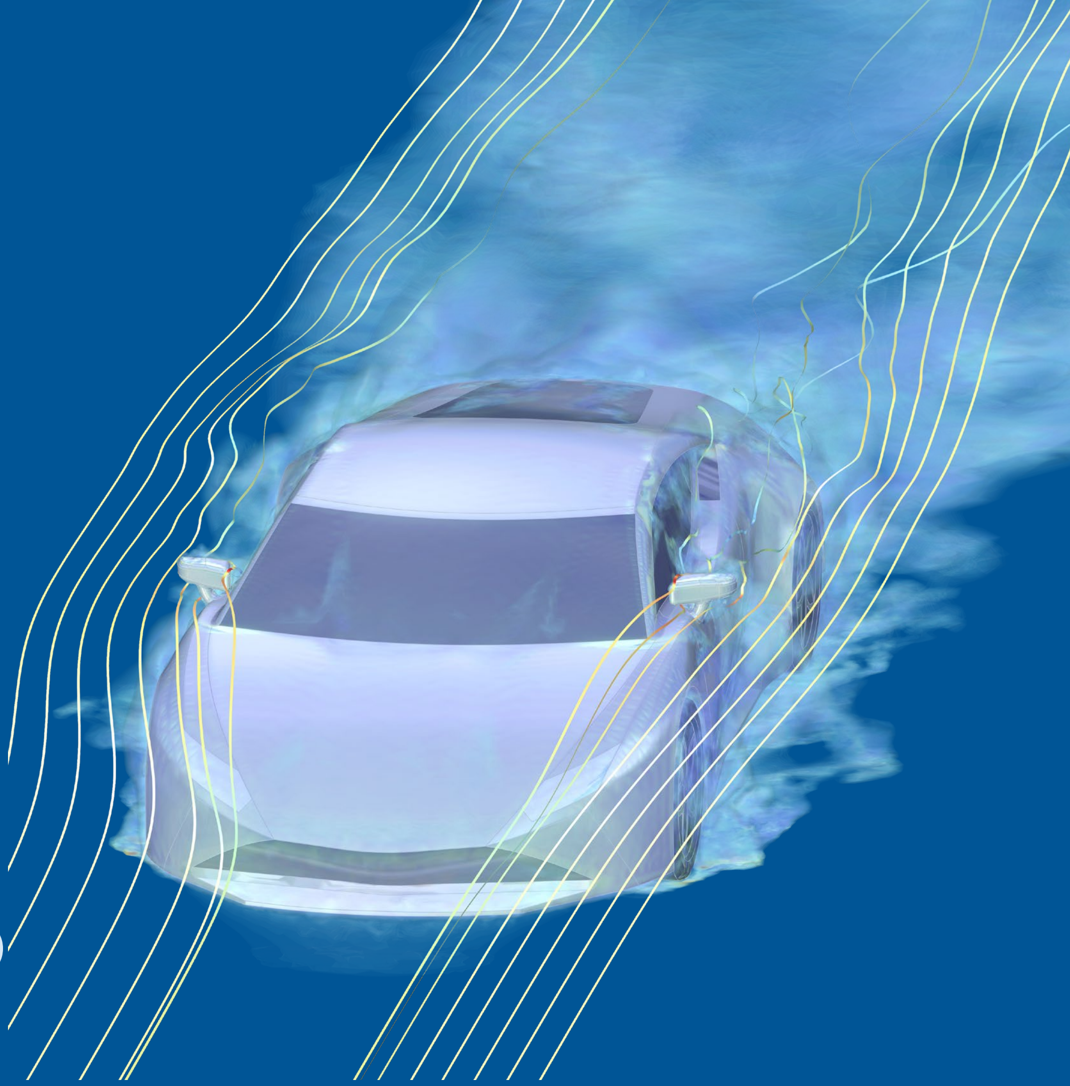
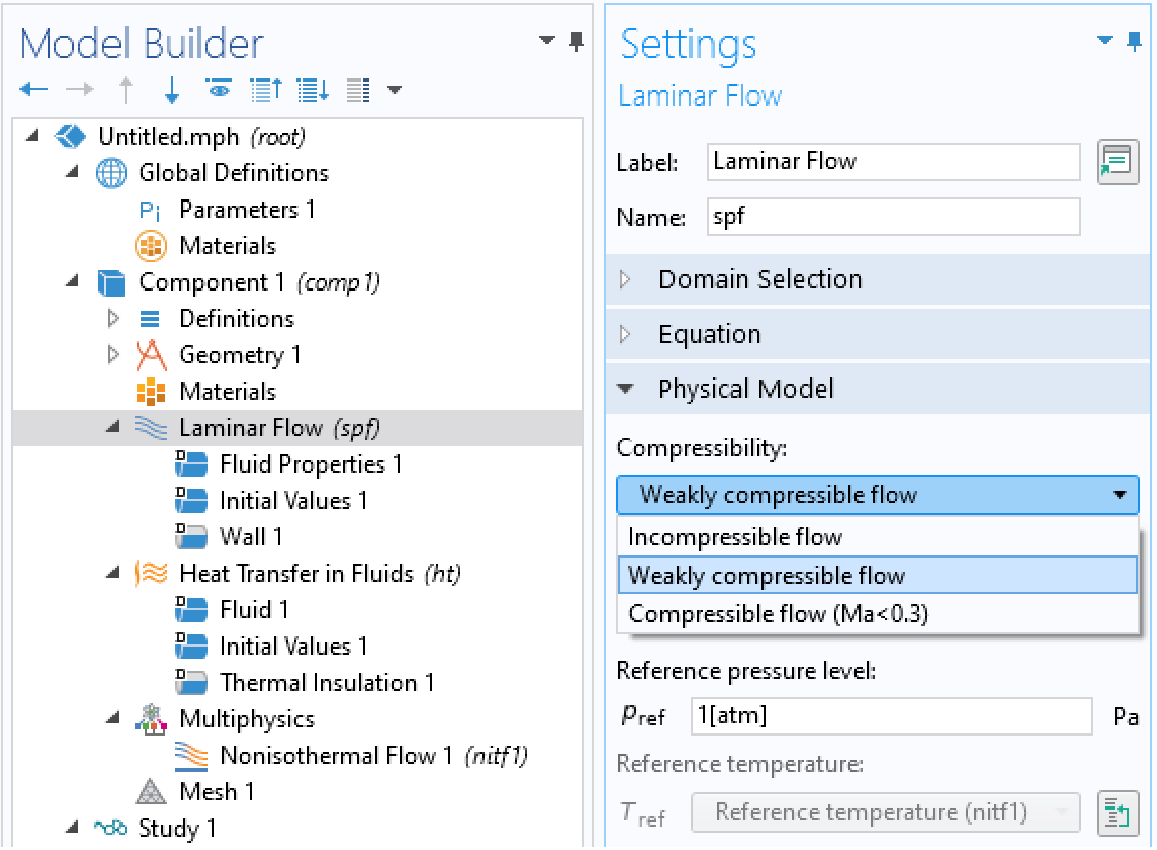


COMSOL Multiphysics®
Conjugate Heat Transfer

Flow Interfaces, Settings

- Incompressible flow: constant density
- Weakly compressible flow: density is computed at reference pressure but may otherwise depend on other variables
- Compressible flow: density may depend on pressure and of any other dependent variable



The laminar (shown above) and turbulent flow interfaces allow you to select compressibility option: Incompressible, weakly compressible, or compressible flow.

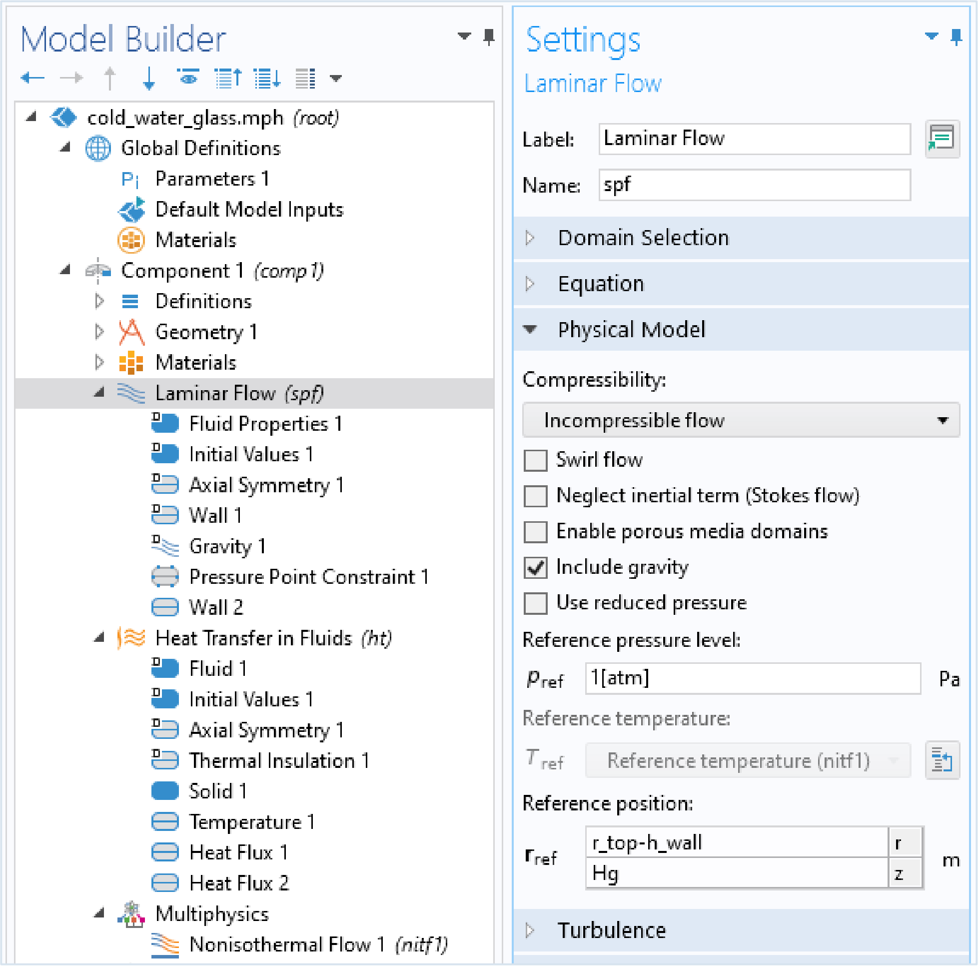
COMSOL

Gravity Property

- Includes a volume force on all domains,

$$\boldsymbol{F} = \rho \boldsymbol{g}$$

- Boussinesq approximation for incompressible flow
- For weakly compressible and compressible flow, density varies in all instances in the flow equations
- For compressible flow, the full pressure field is used to describe density



$$\rho = \rho_0 \left(1 - \alpha_p(T_0)(T - T_0)\right) \qquad \rho = f(T)$$

For incompressible flow, density variations are only included in the volume force term in the Navier-Stokes equations. These can be accounted for through a linearized expression (left). For weakly compressible and compressible flow, density variations are introduced in all the instances in the flow equations using a generical density function (right). Note that other variables can be used for density variations, for example composition. For compressible flow, density is also a function of pressure.

Gravity Property

- Includes a volume force on all domains,
  $$\boldsymbol{F} = \rho \boldsymbol{g}$$
- Boussinesq approximation for incompressible flow
- For weakly compressible and compressible flow, density varies in all instances in the flow equations
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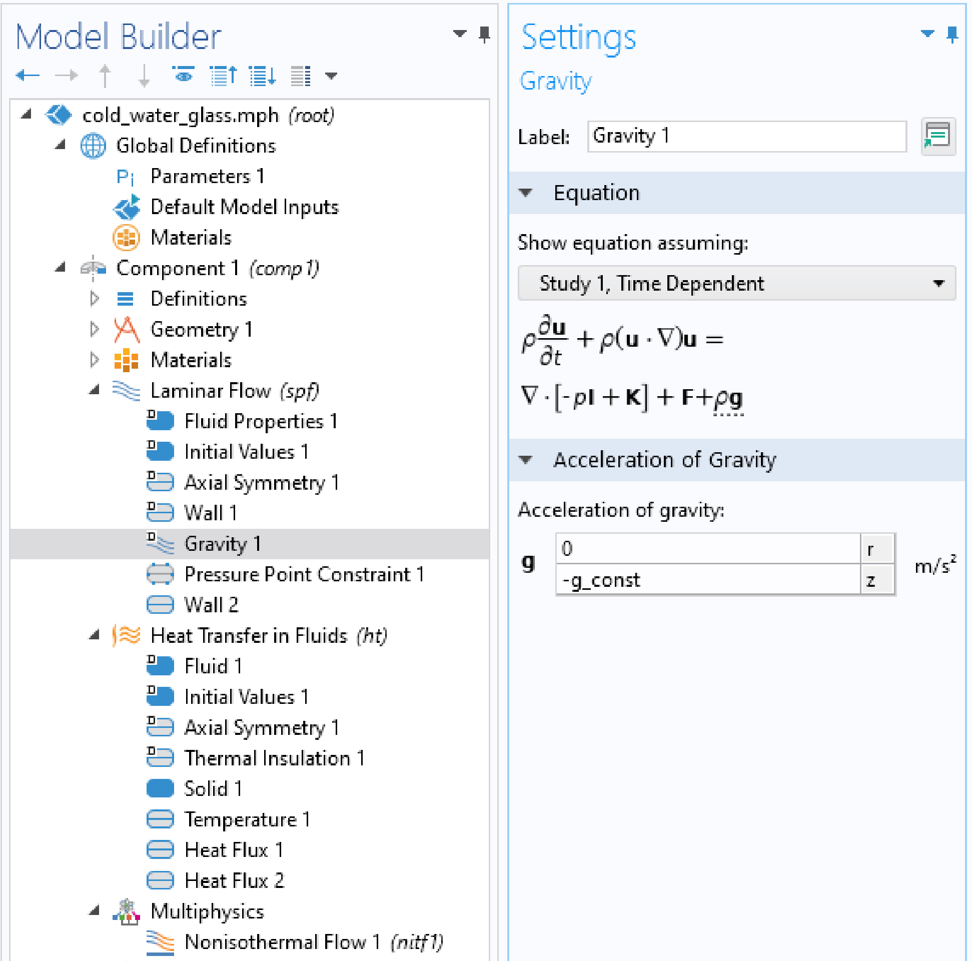

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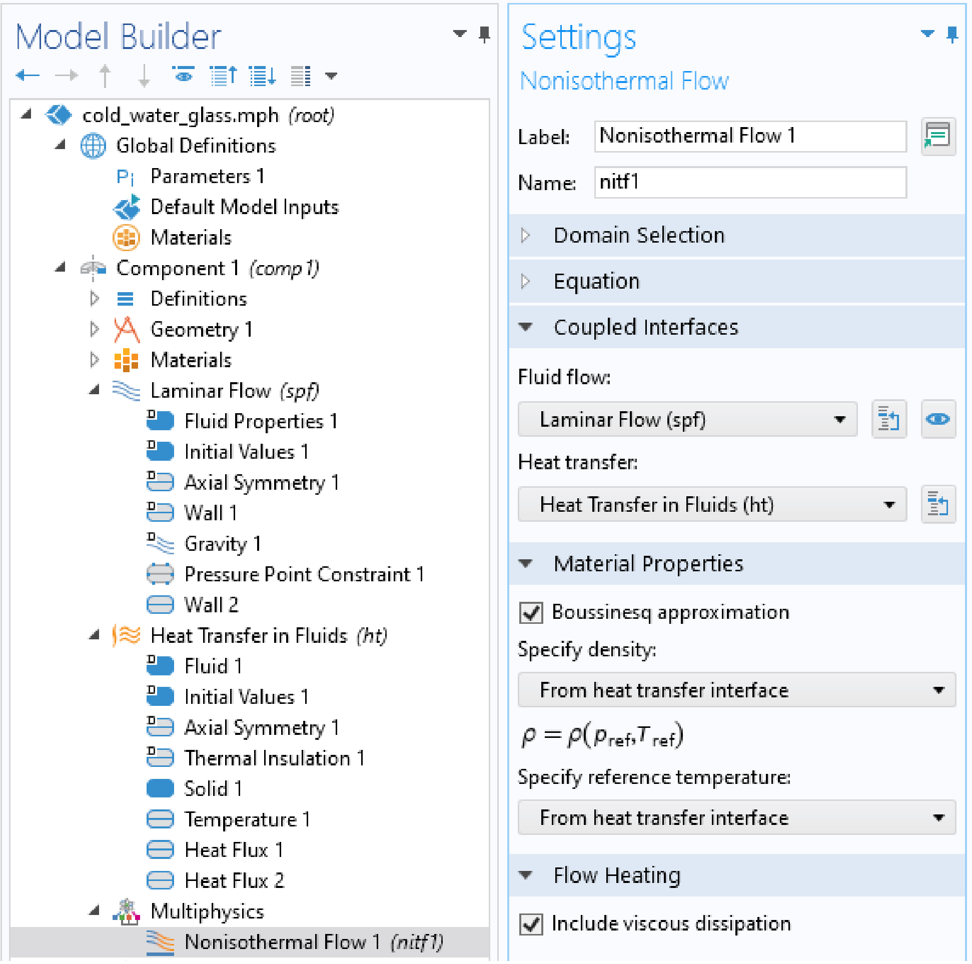

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For incompressible flow, density variations are only included in the volume force term in the Navier-Stokes equations. These can be accounted for through a linearized expression (left). For weakly compressible and compressible flow, density variations are introduced in all the instances in the flow equations using a generical density function (right). Note that other variables can be used for density variations, for example composition. For compressible flow, density is also a function of pressure.

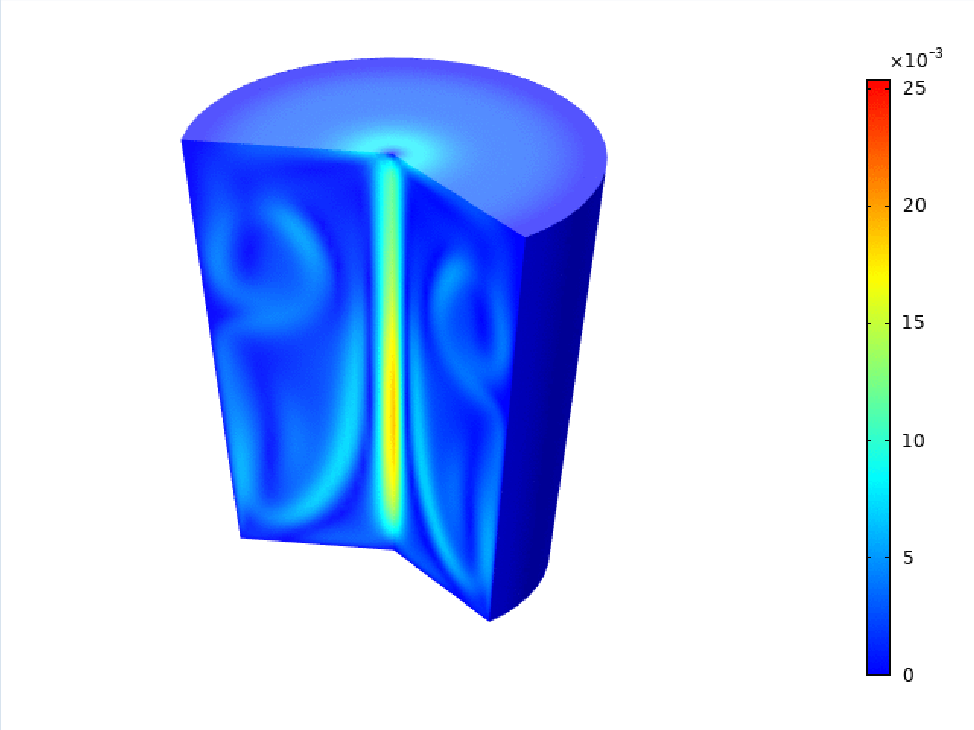
Incompressible Flow

- Introduces a volume force in the momentum equations:

$$\boldsymbol{F} = \rho \boldsymbol{g}$$

- Boussinesq approximation:

$$\rho = \rho_0 \left(1 - \alpha_p(T_0)(T - T_0)\right)$$

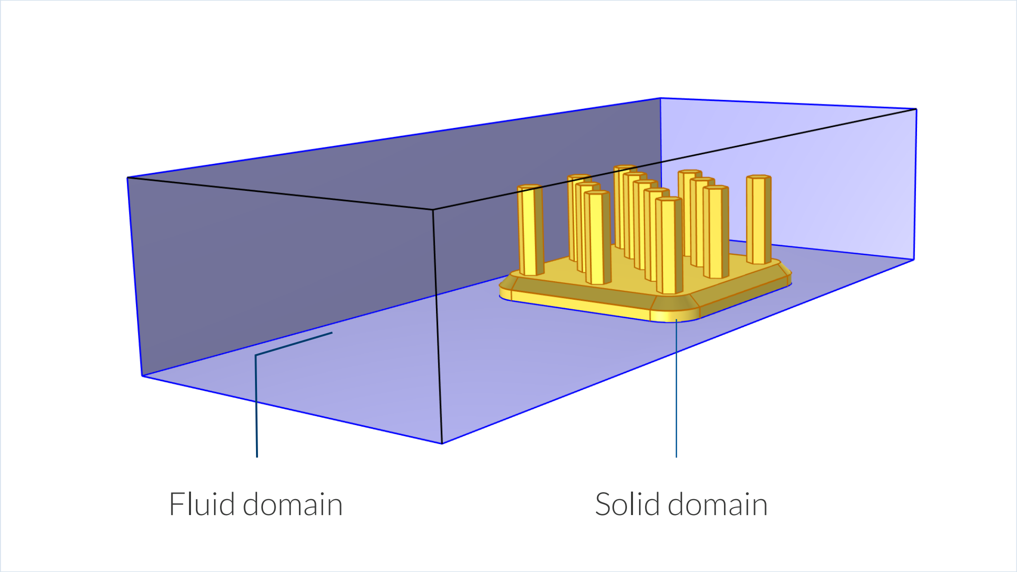


Free convection in a water glass solved using incompressible flow. This assumption is appropriate for small density variations.

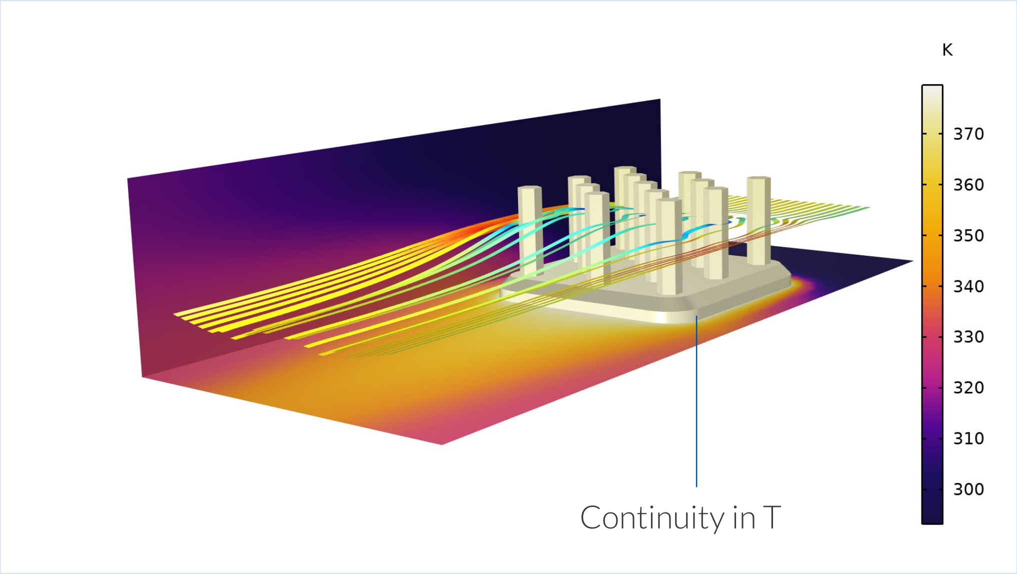
Conjugate Heat Transfer

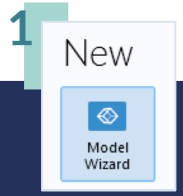
Conjugate Heat Transfer with Laminar Flow

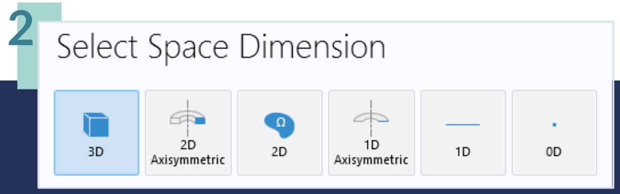
- Fluid flow, conduction, and convection in the fluid domain
- Conduction in the solid domain
- Heat transfer between fluid and solid domain:
  - No-slip condition gives continuity in heat flux and temperature at the fluid-solid interface

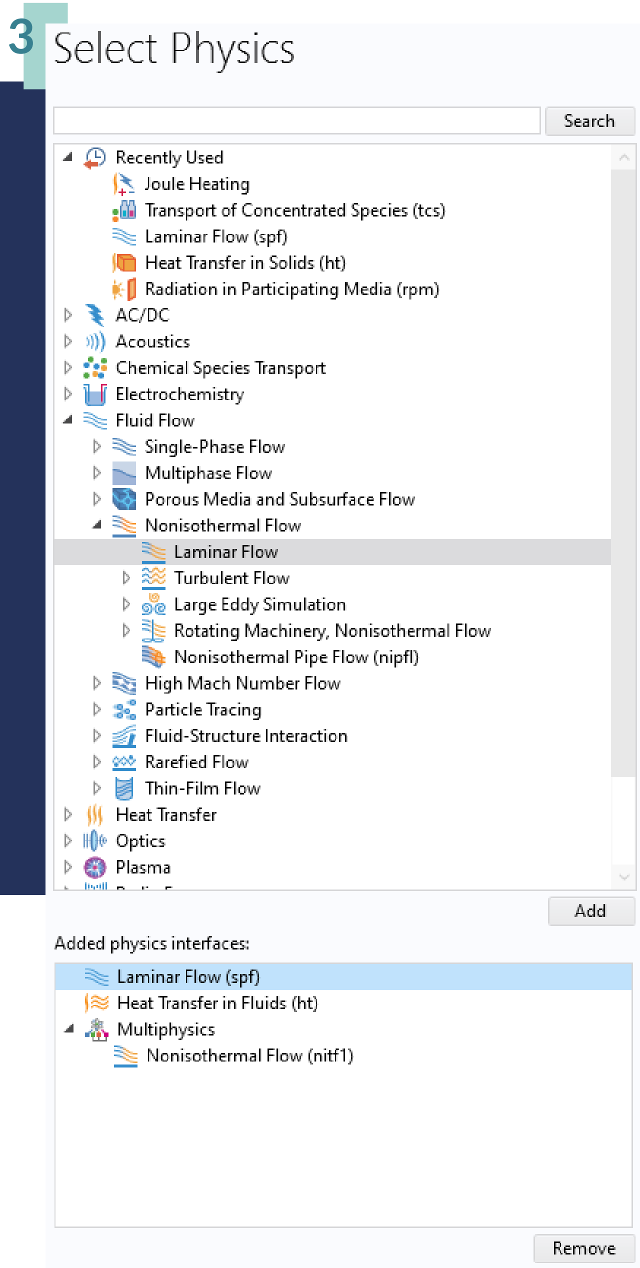


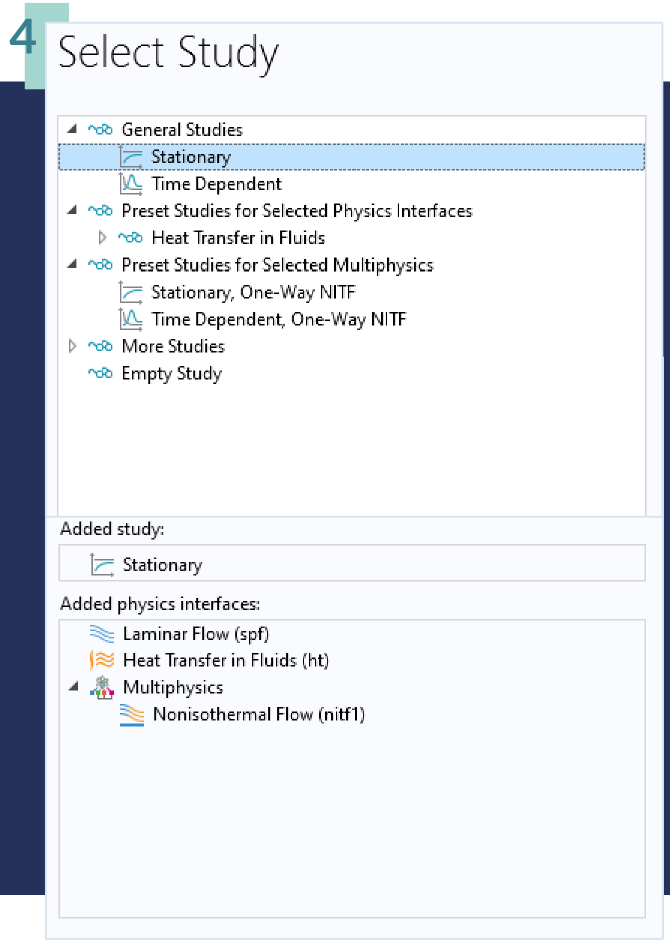
There is a continuity in temperature over the solid-fluid interface.











THE FIRST STEP

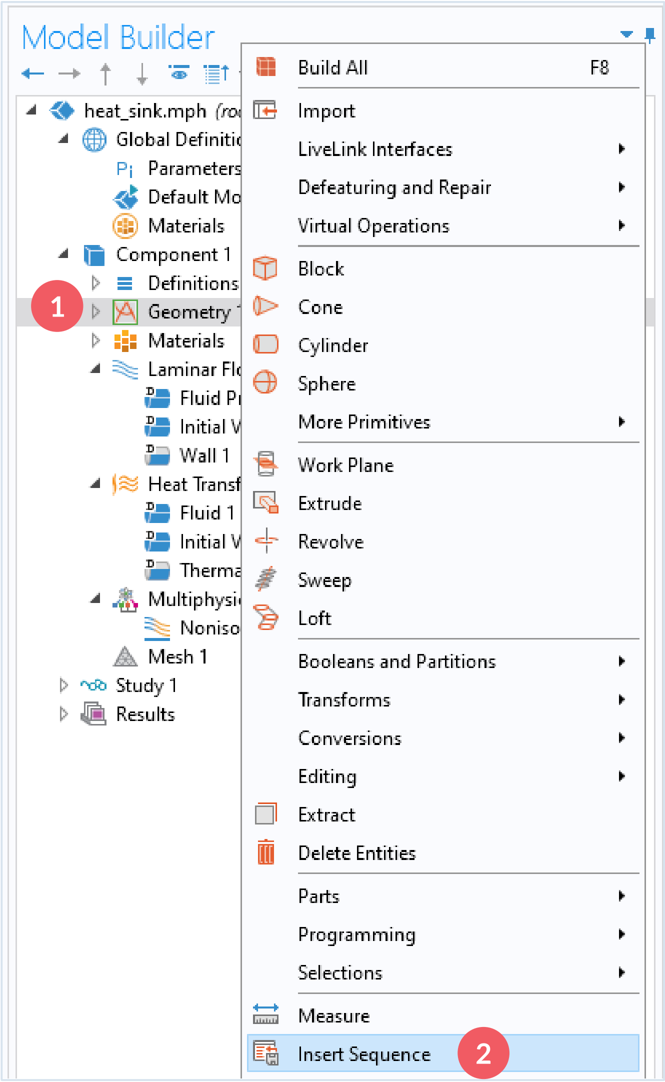
The Model Wizard

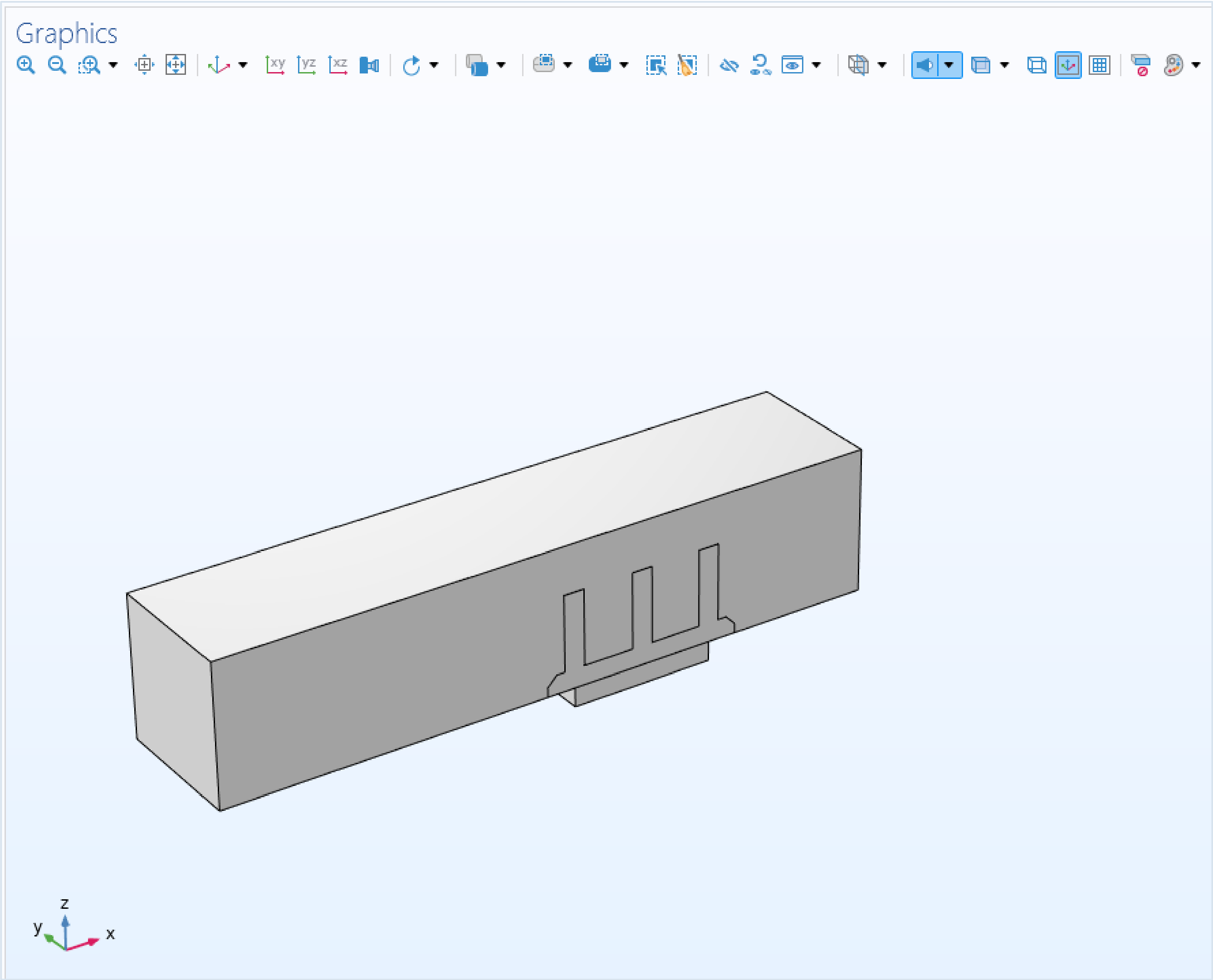
When creating a new model, the Model Wizard assists with selecting:

- Dimension (3D, 2D, 1D, or 0D)
- Physics interface(s) from the physics list
- Study for the physics interfaces

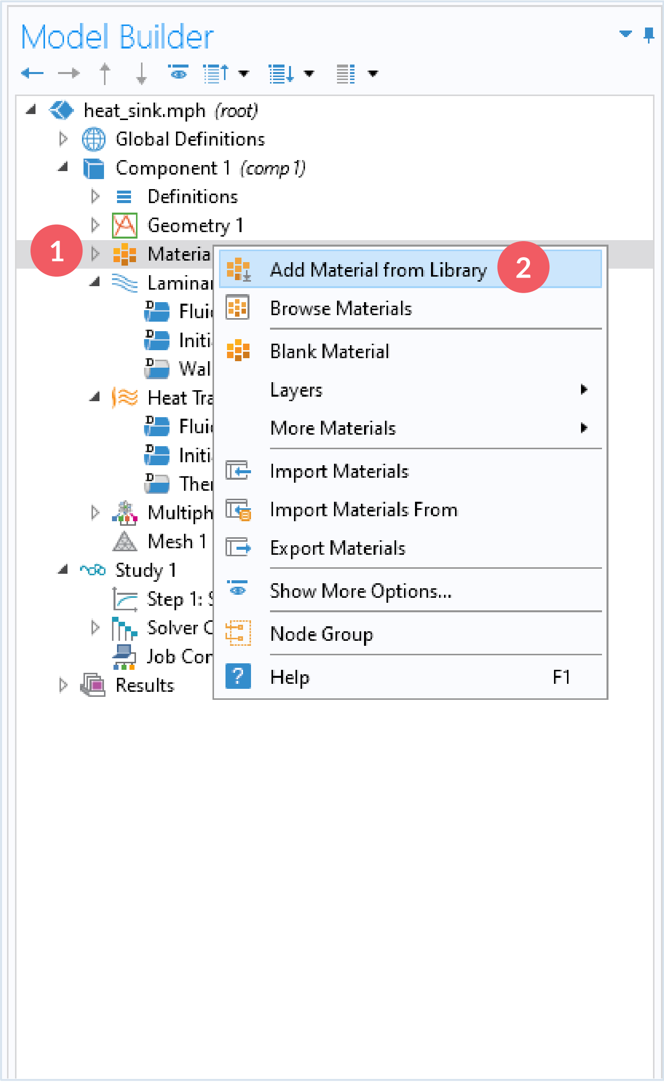
1. Select *Model Wizard*.
2. Select space dimension.
3. Select physics interfaces.
4. Select study.

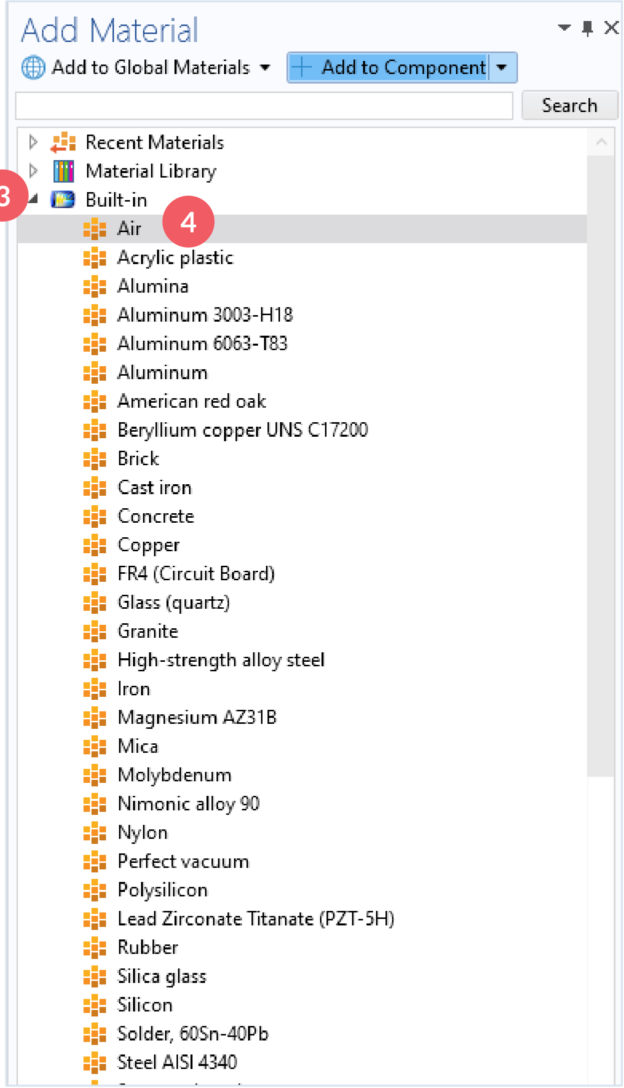
Geometry (right click) -> Insert Sequence -> “cht_laminar_demo” model





HEAT SINK: MATERIALS



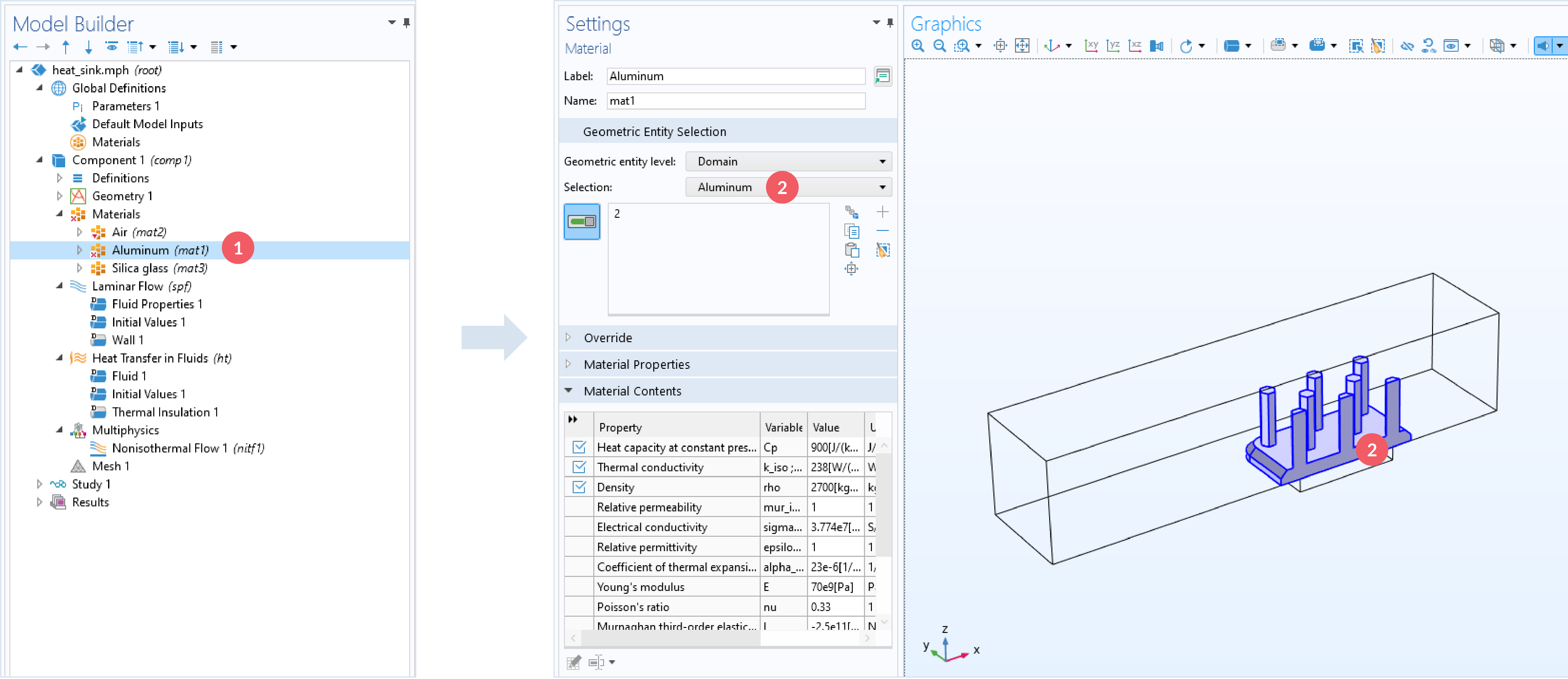


Also add Aluminum and Silica Glass Materials from Built-in Library

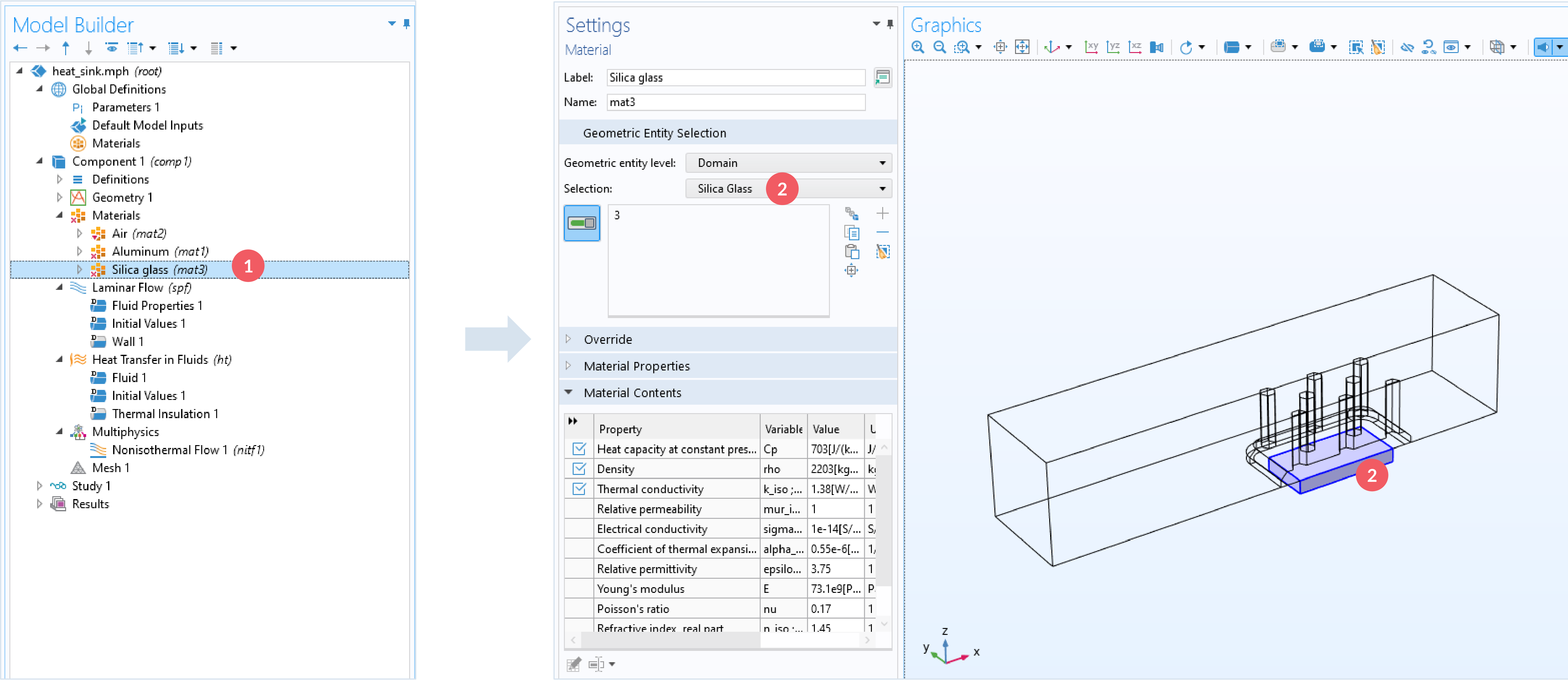
Aluminum -> Add to Component

Silica Glass -> Add to Component

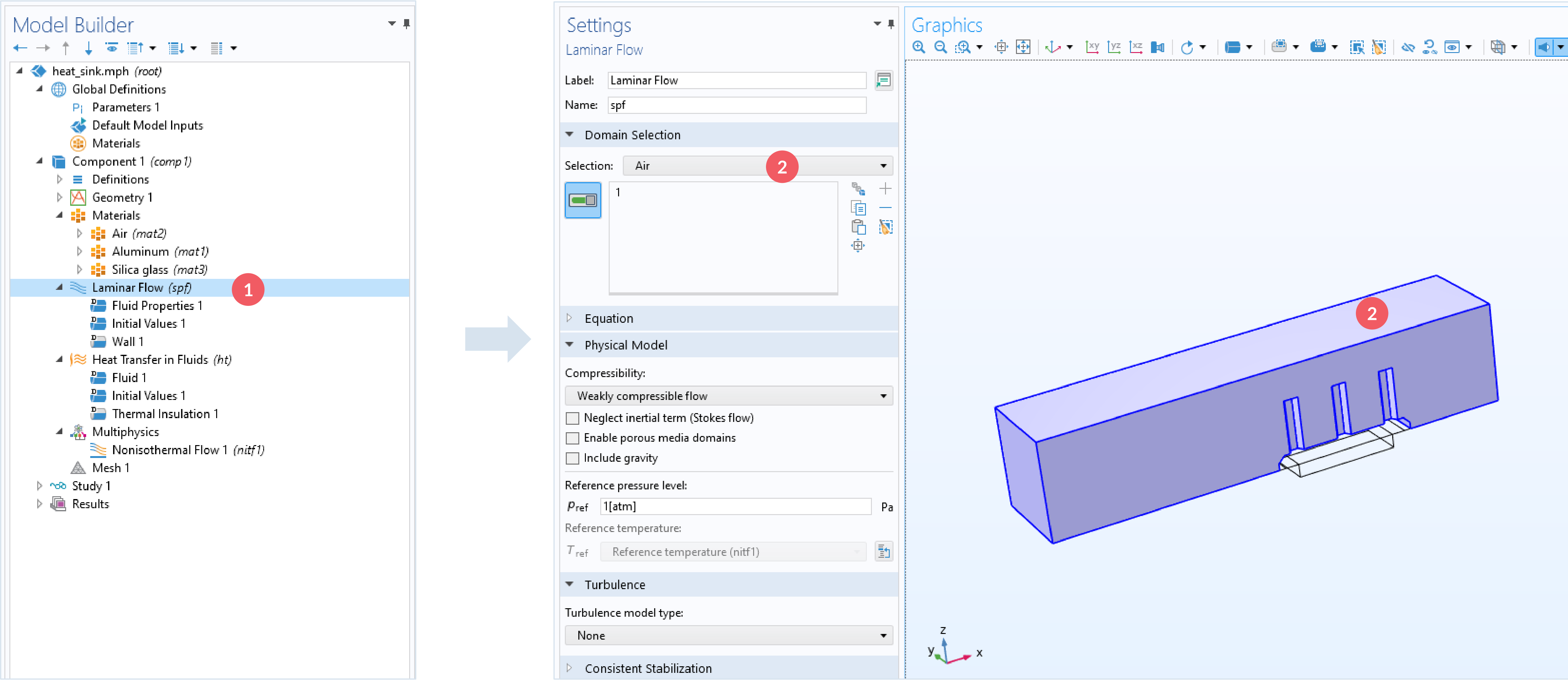
Heat Sink: Specify Material Domains



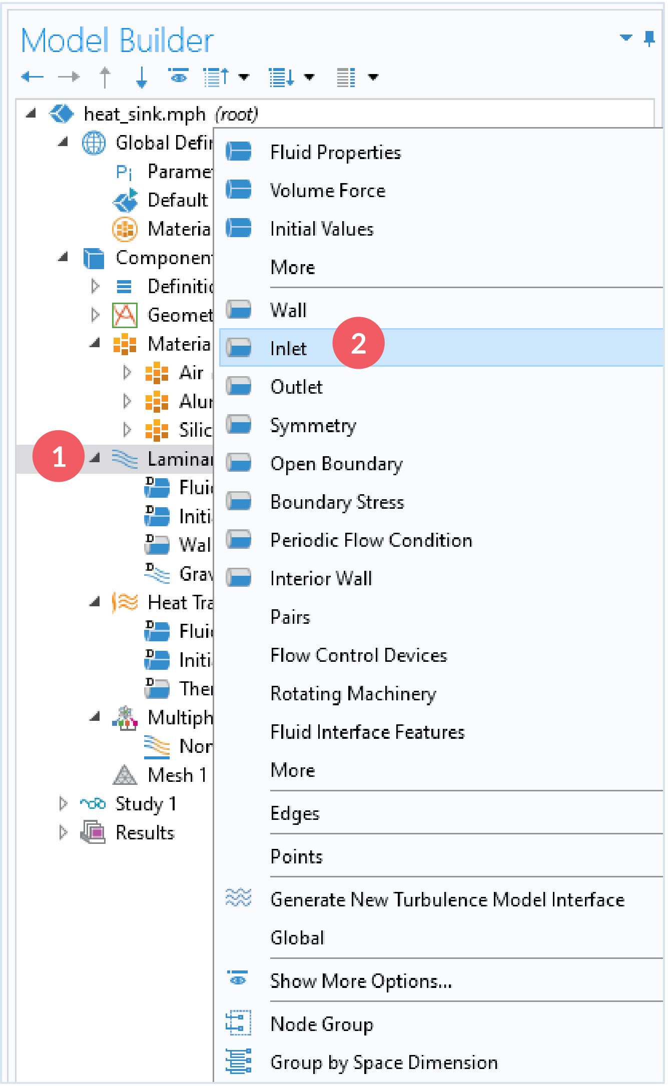
HEAT SINK: SPECIFY MATERIAL DOMAINS

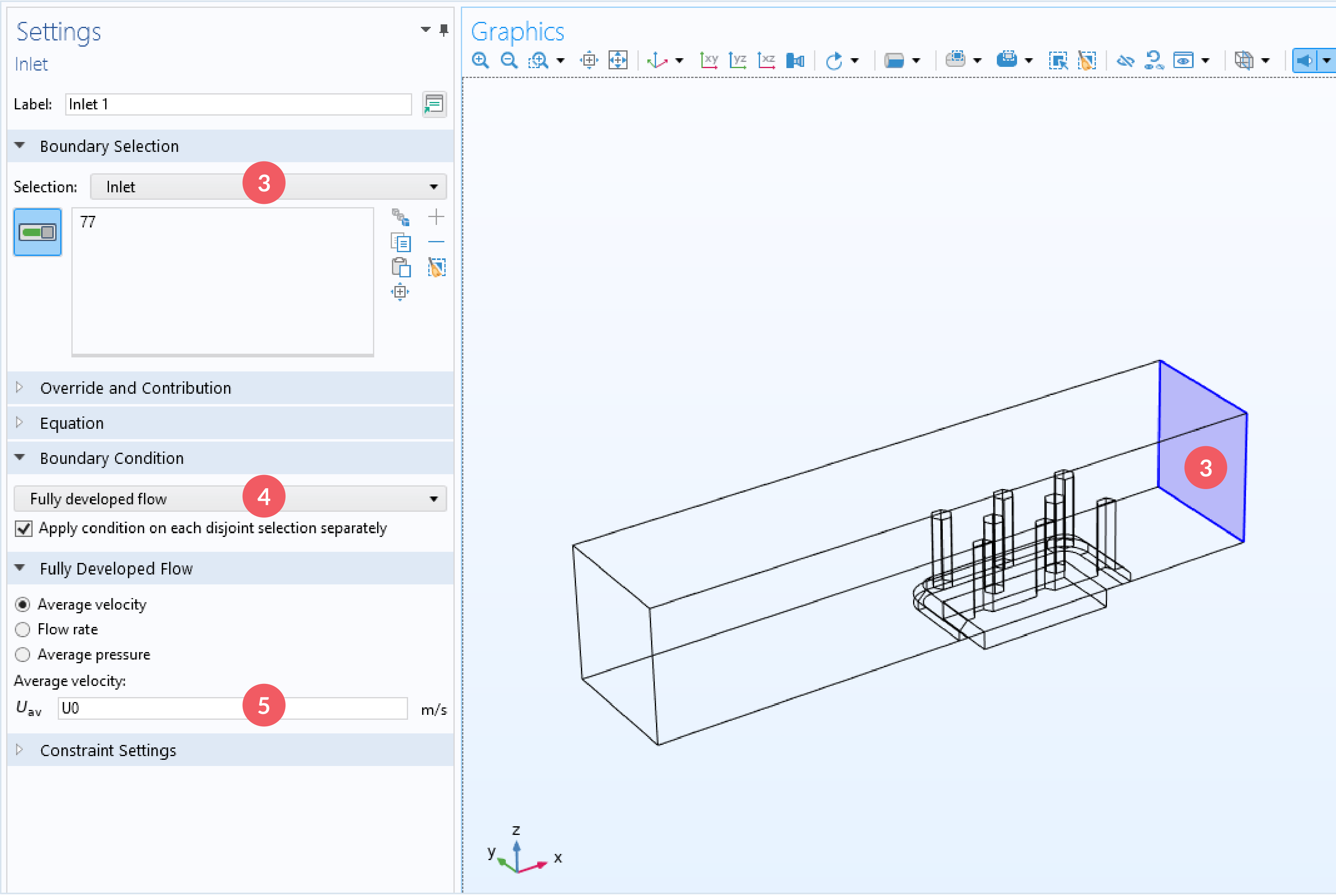


HEAT SINK: LAMINAR FLOW — DOMAIN SELECTION

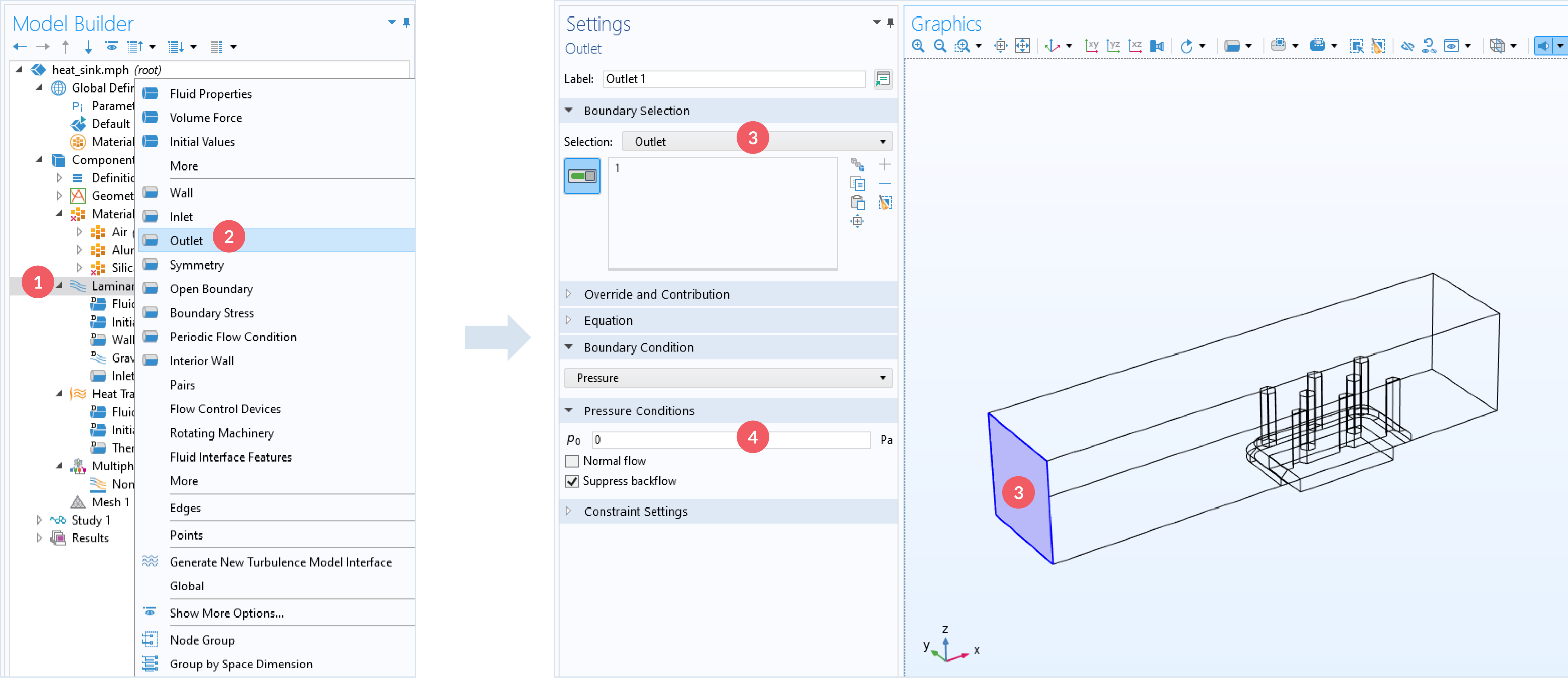


HEAT SINK: LAMINAR FLOW — INLET

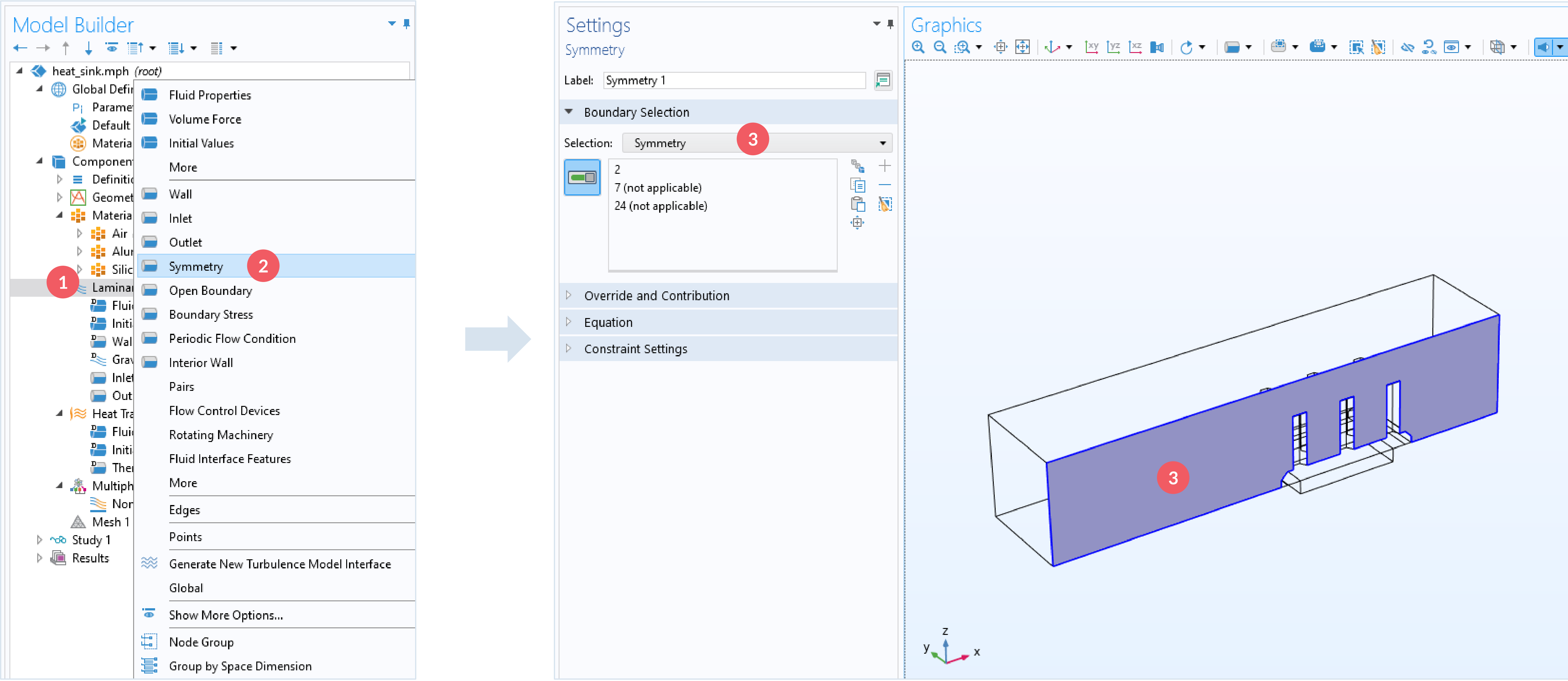




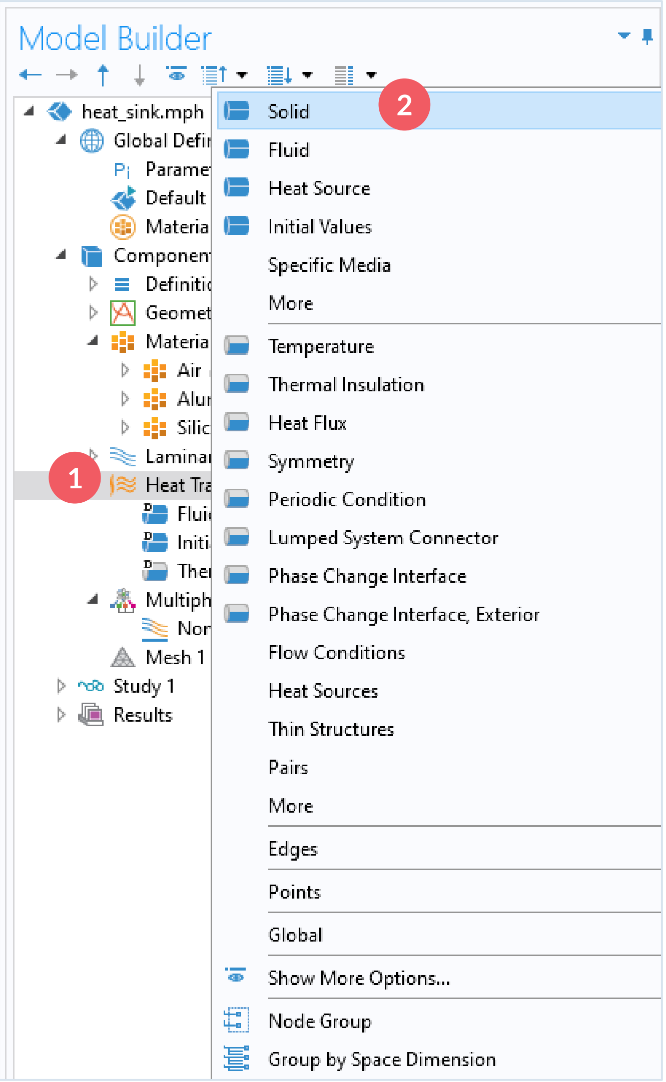
HEAT SINK: LAMINAR FLOW — OUTLET

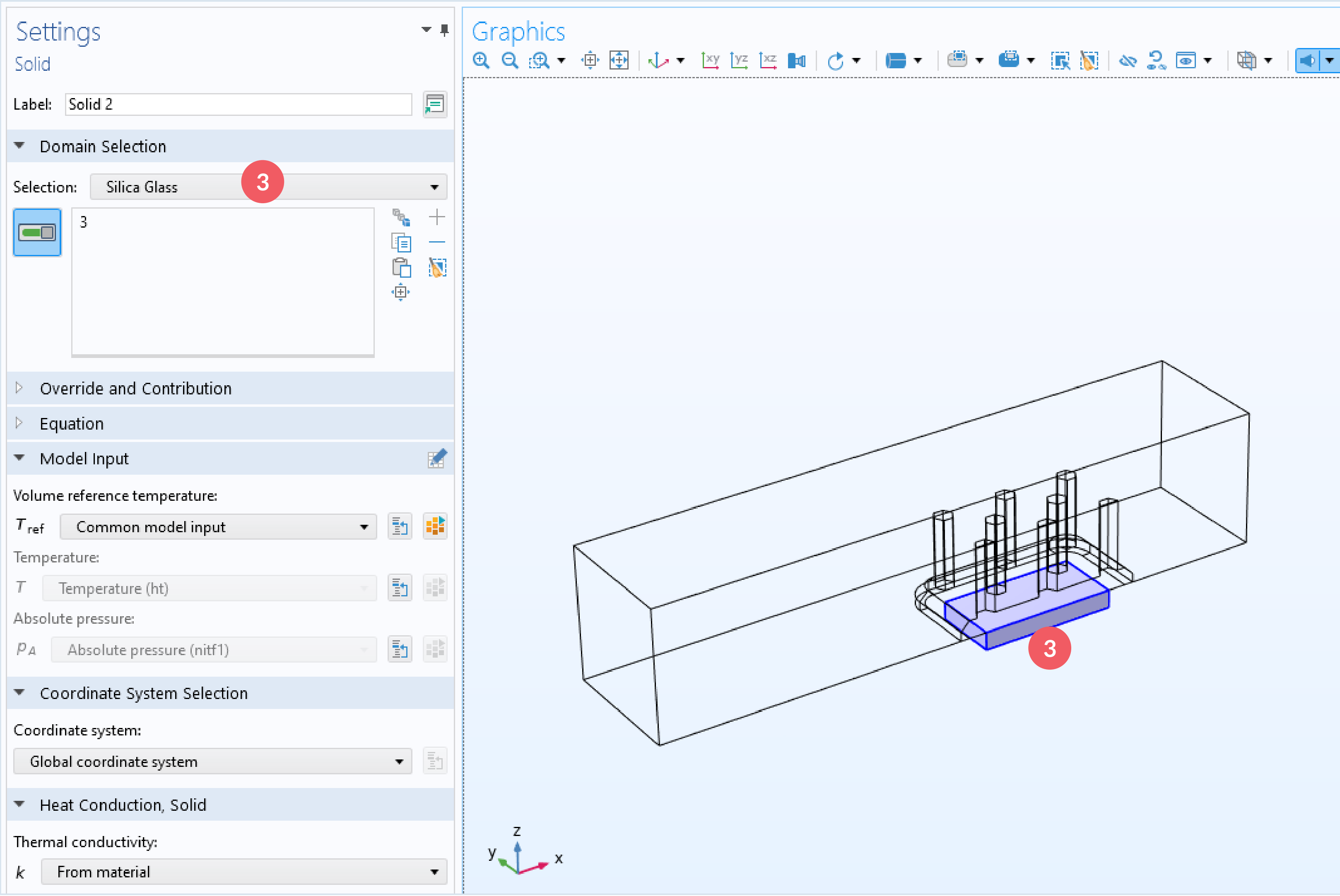


HEAT SINK: LAMINAR FLOW — SYMMETRY

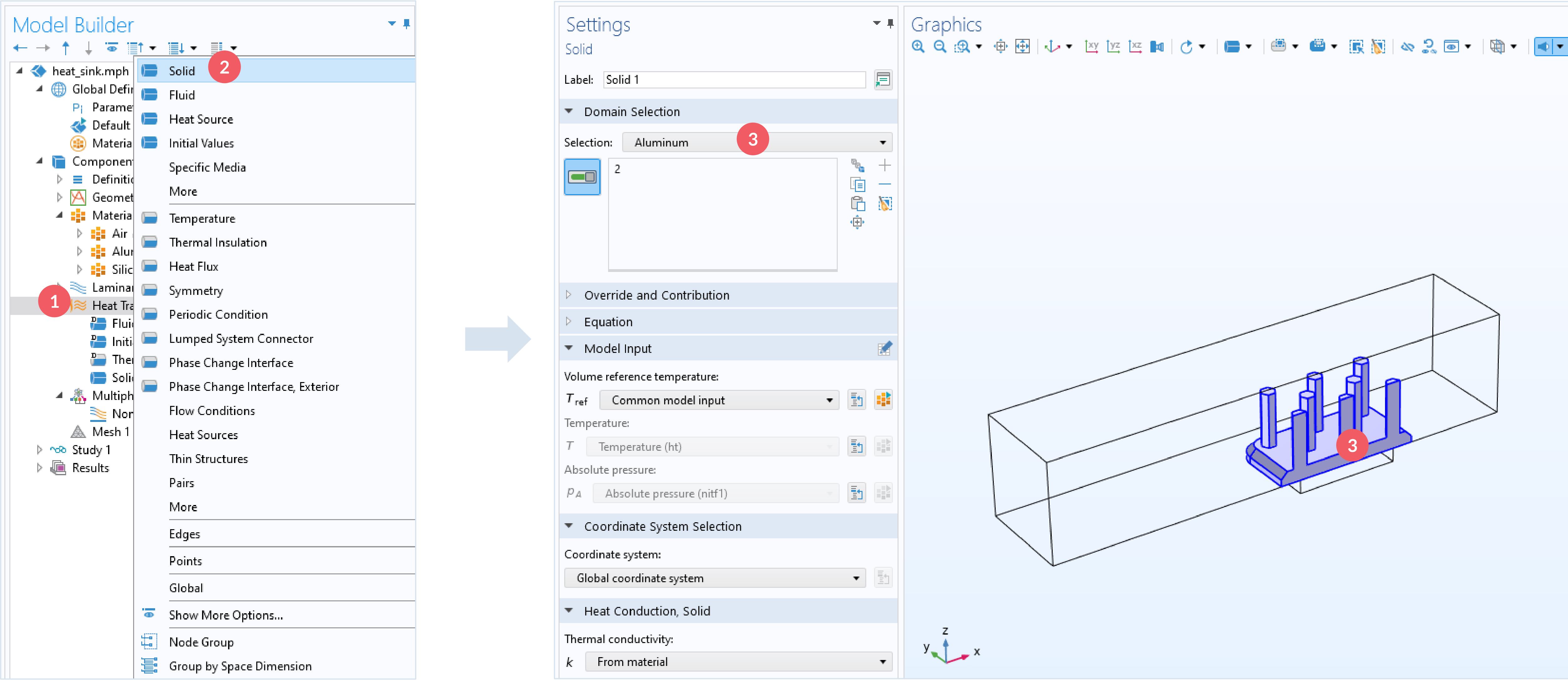


Heat Sink: Heat Transfer – Solid Domains

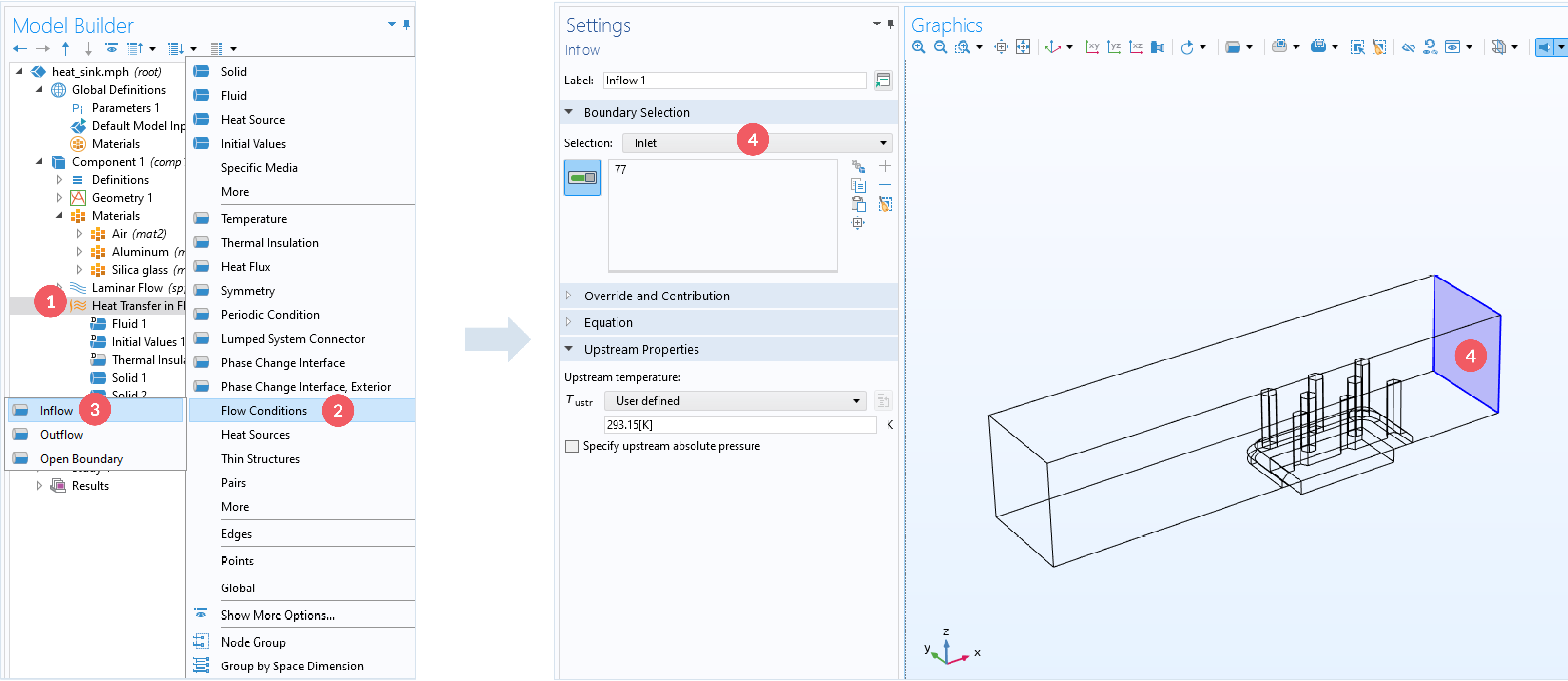




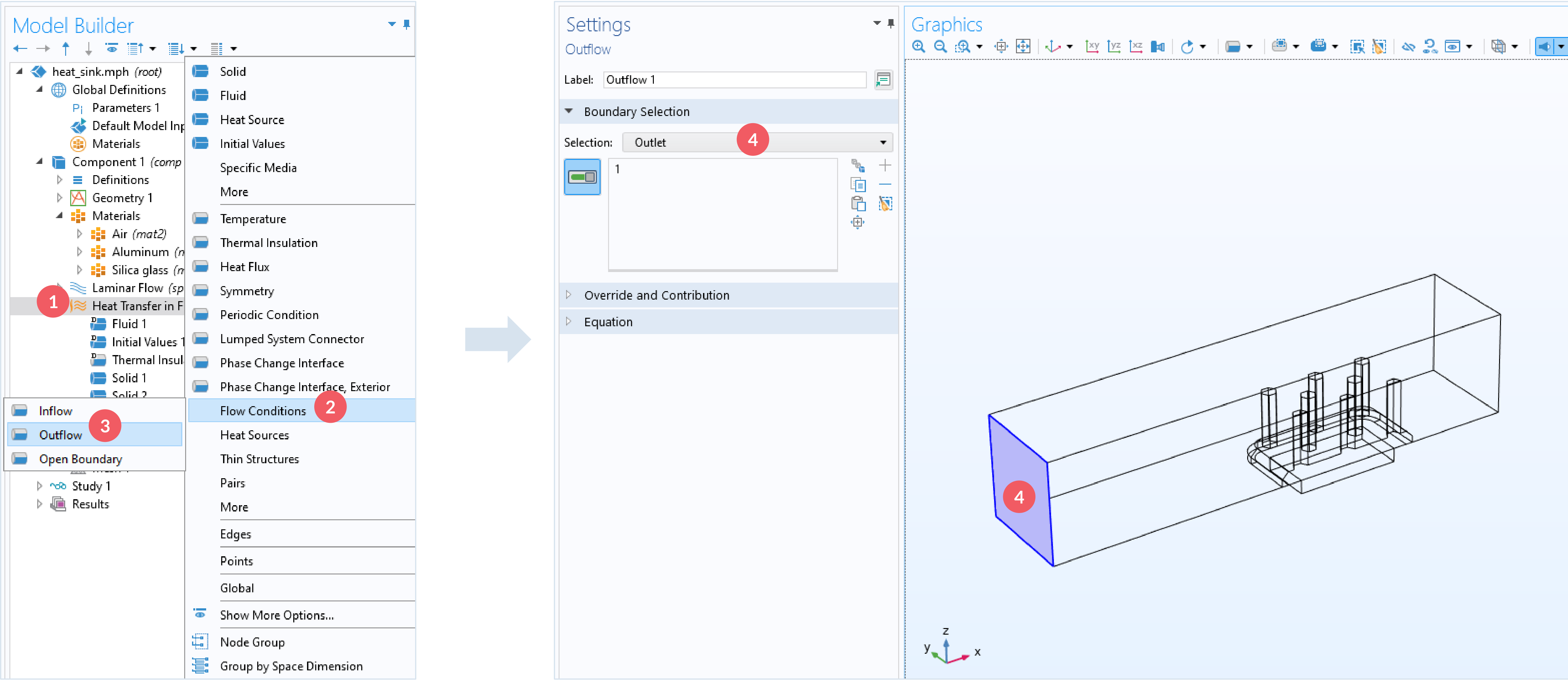
HEAT SINK: HEAT TRANSFER — SOLID DOMAINS



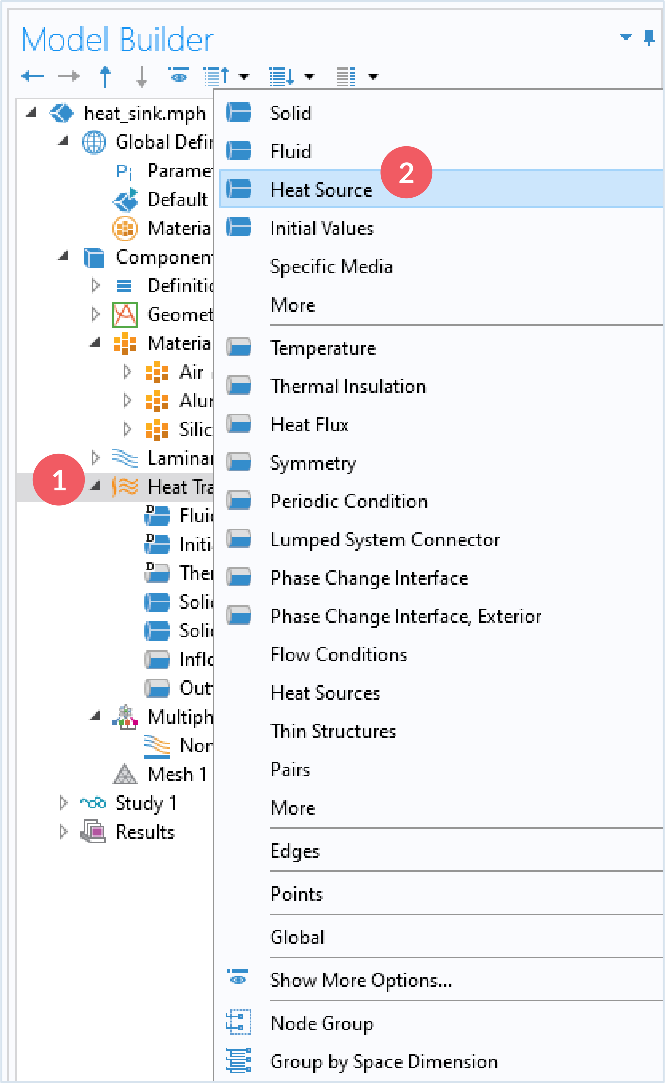
HEAT SINK: HEAT TRANSFER — INFLOW

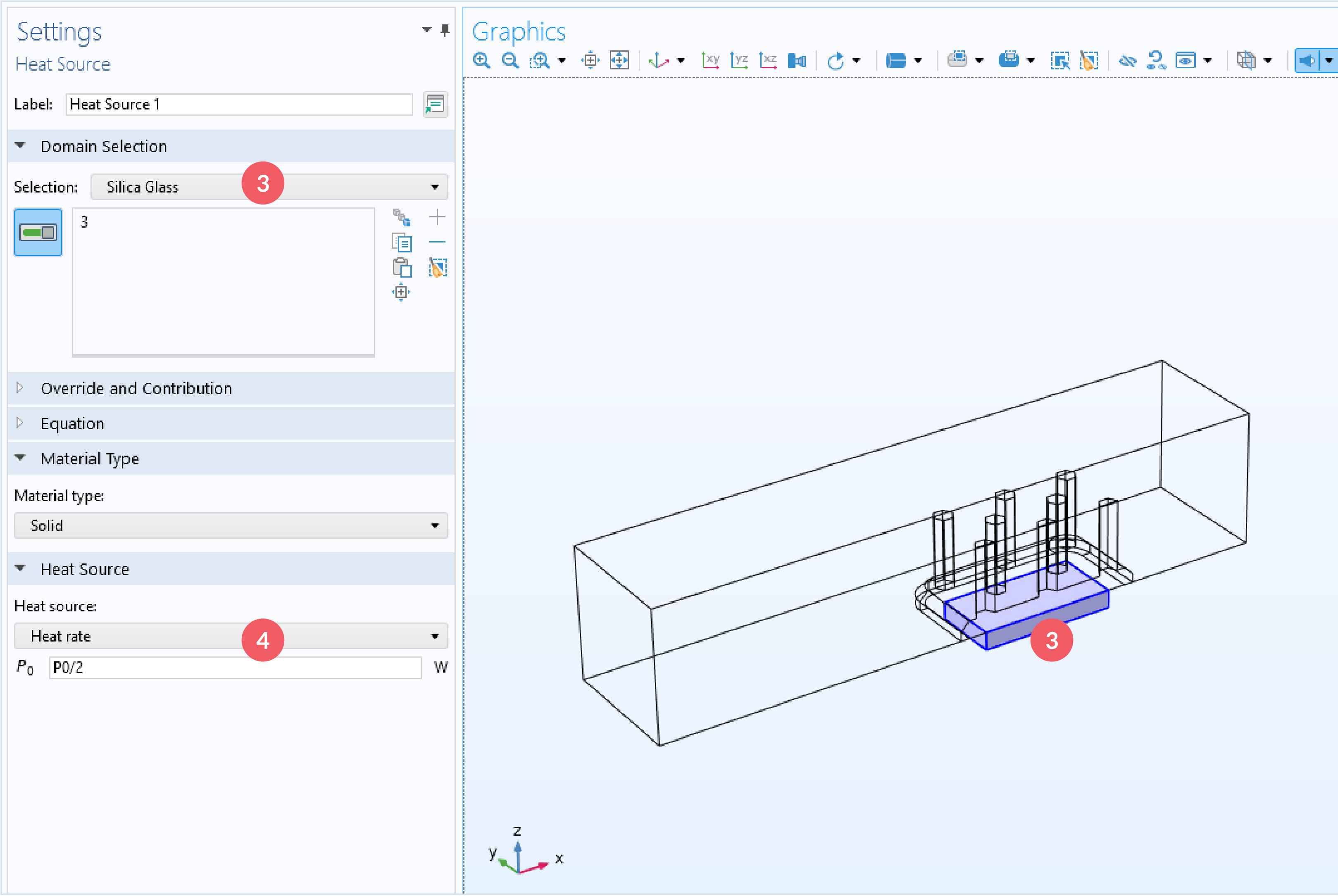


HEAT SINK: HEAT TRANSFER — OUTFLOW

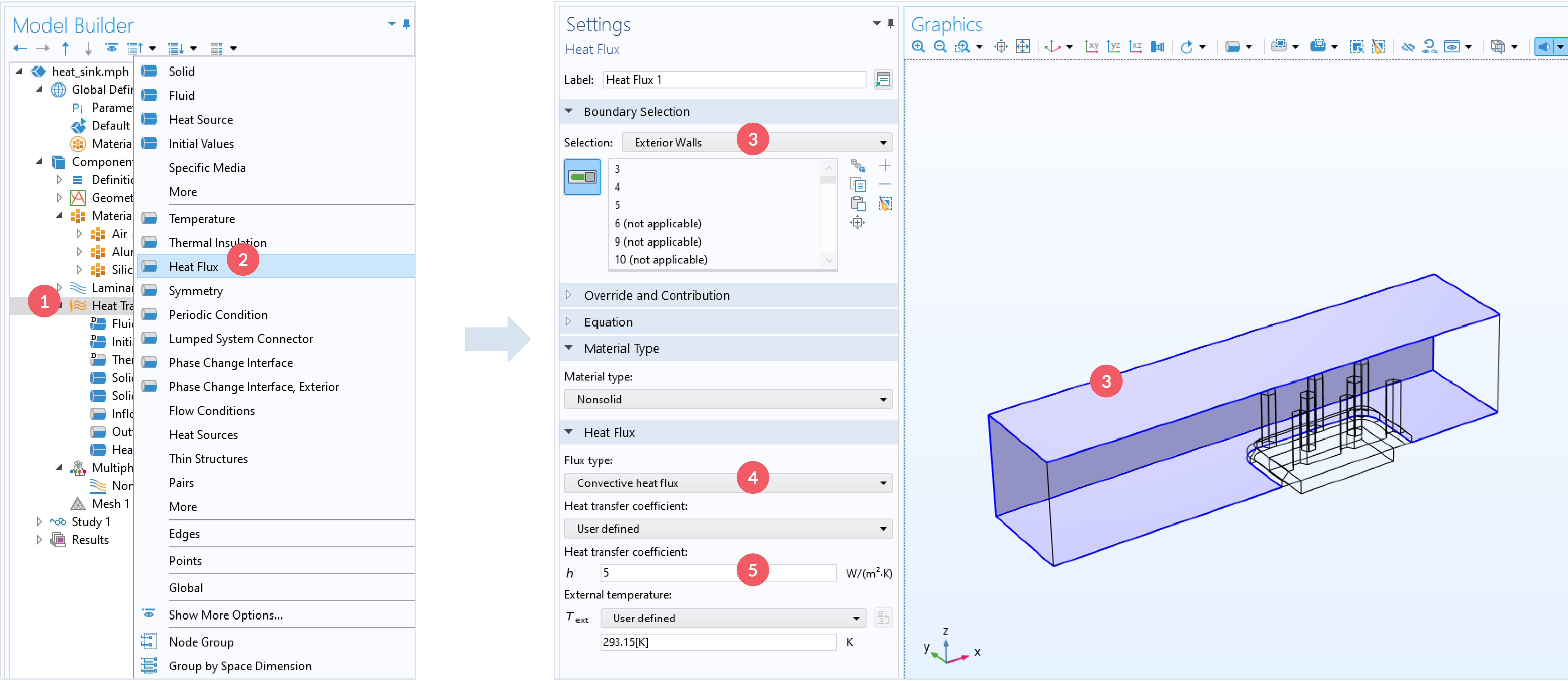


HEAT SINK: HEAT TRANSFER — HEAT SOURCE

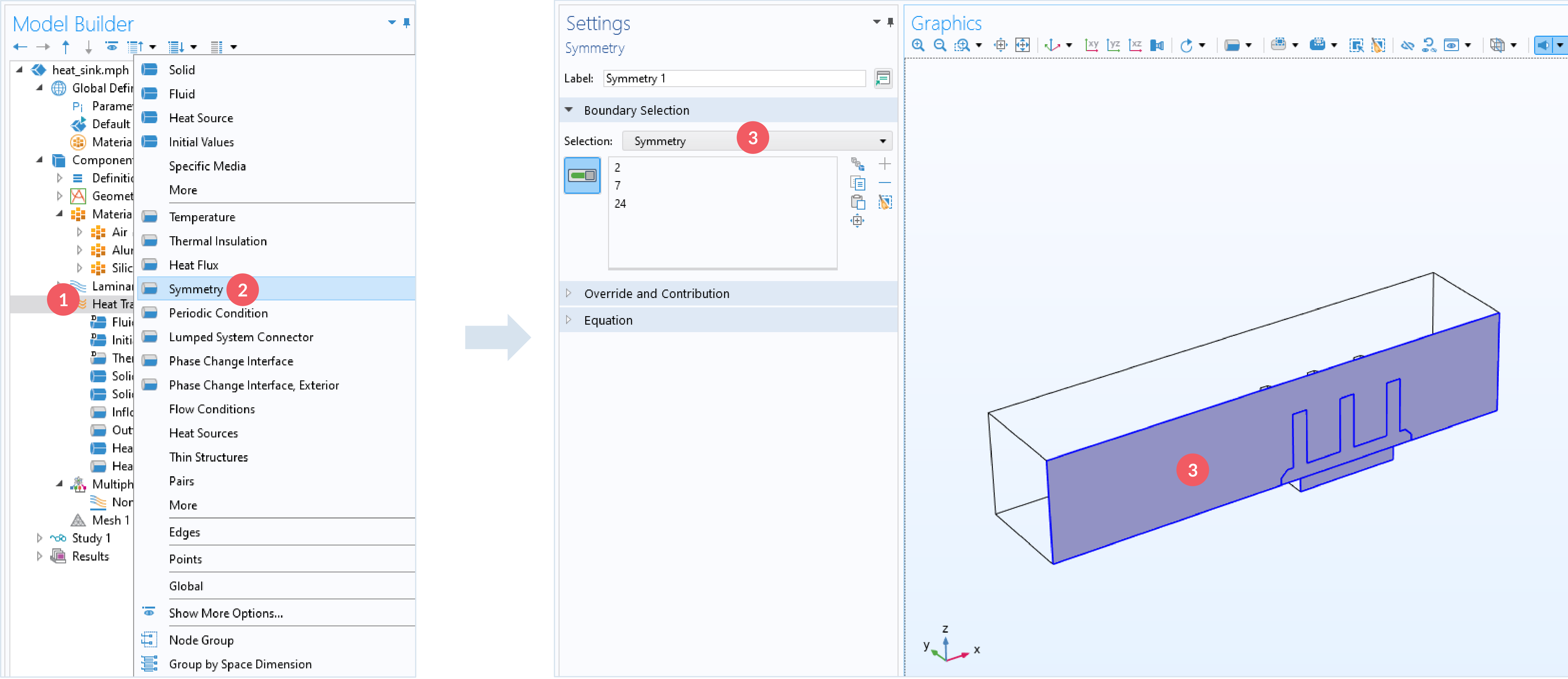




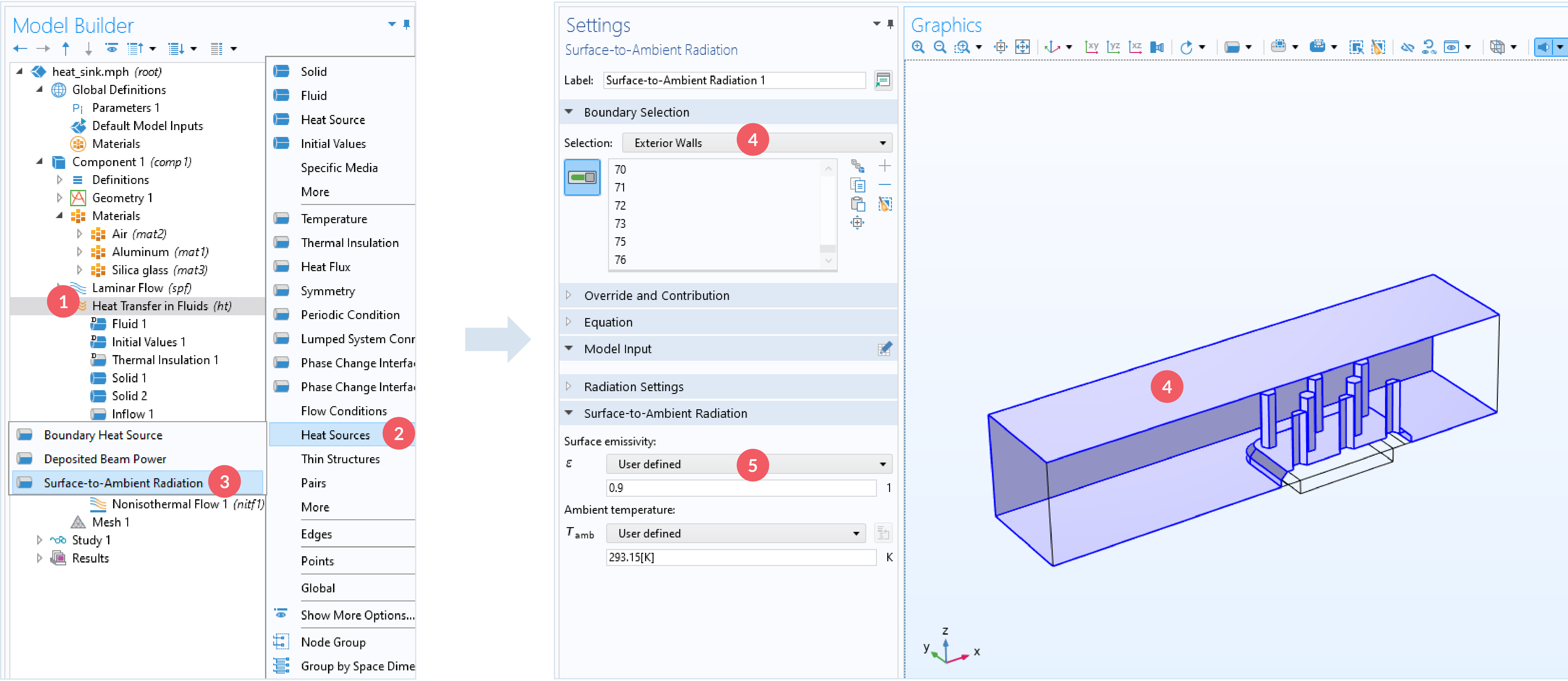
HEAT SINK: HEAT TRANSFER — HEAT FLUX



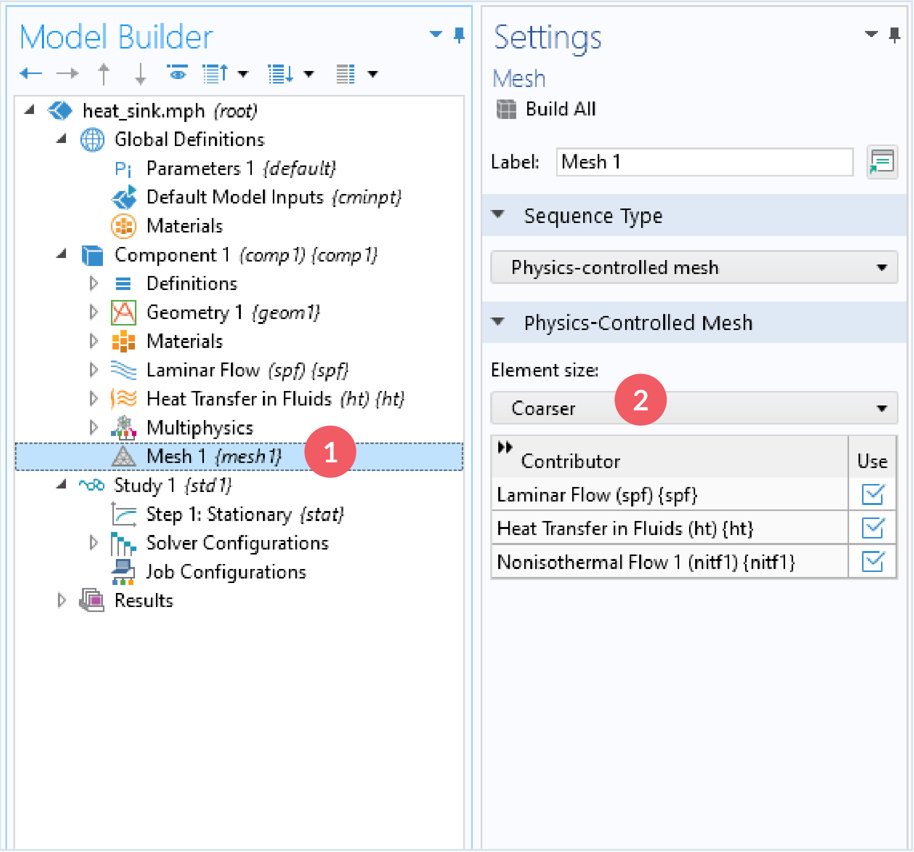
HEAT SINK: HEAT TRANSFER — SYMMETRY

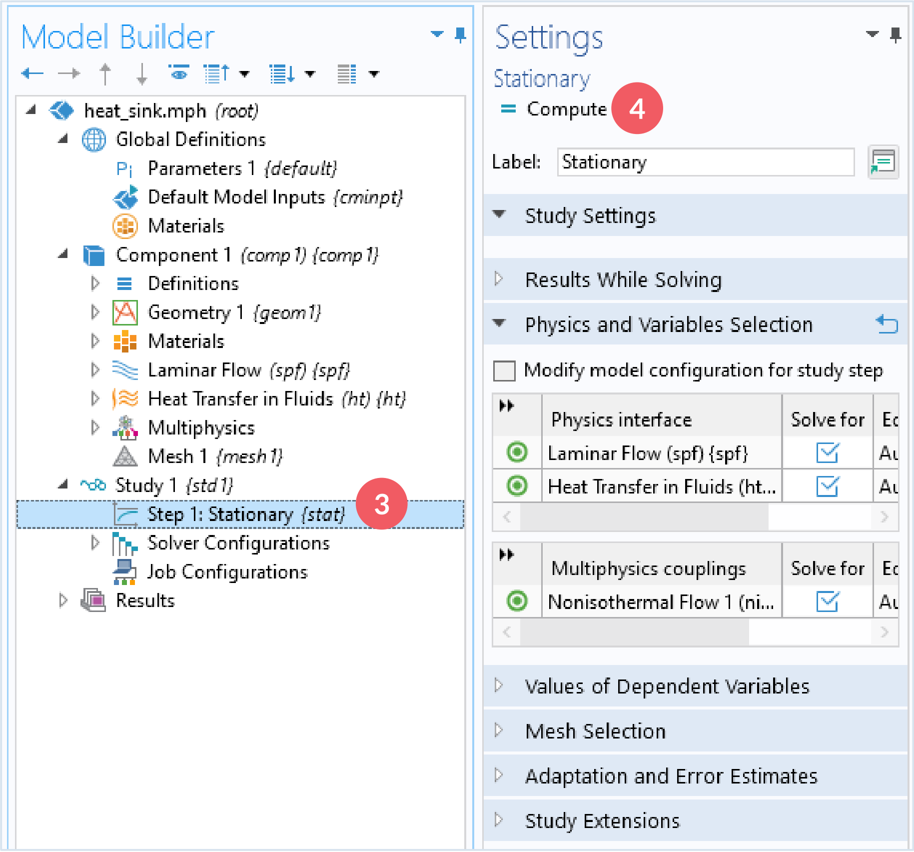


HEAT SINK: HEAT TRANSFER — SURFACE TO AMBIENT RADIATION

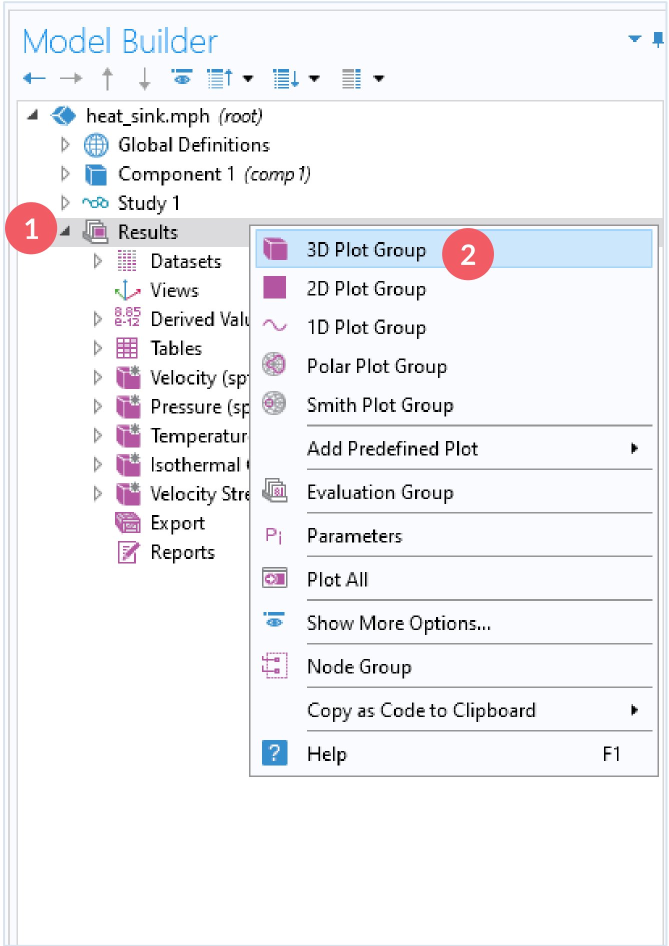


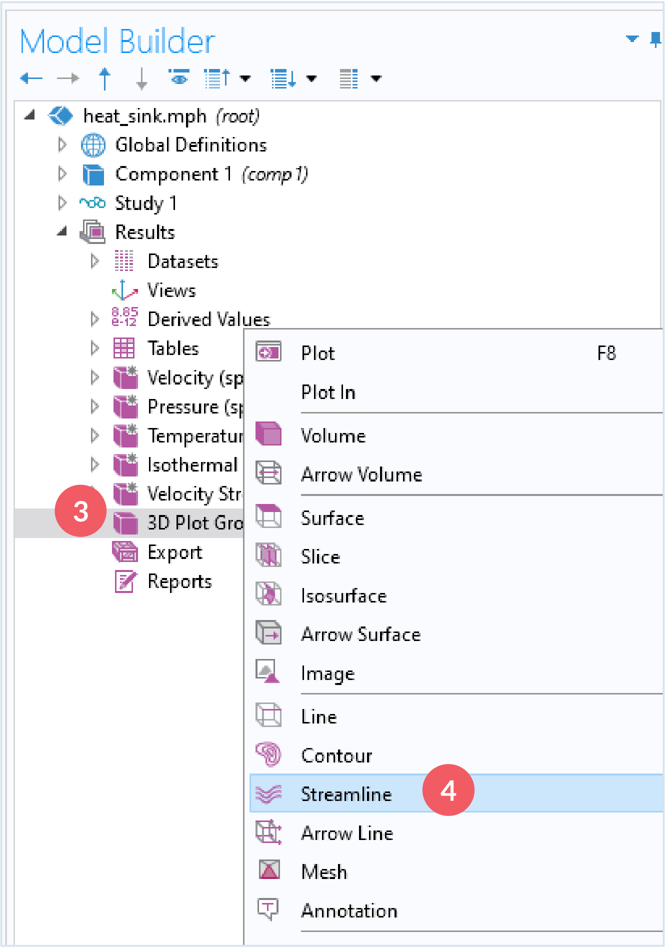
HEAT SINK: MESH & STUDY SETTINGS

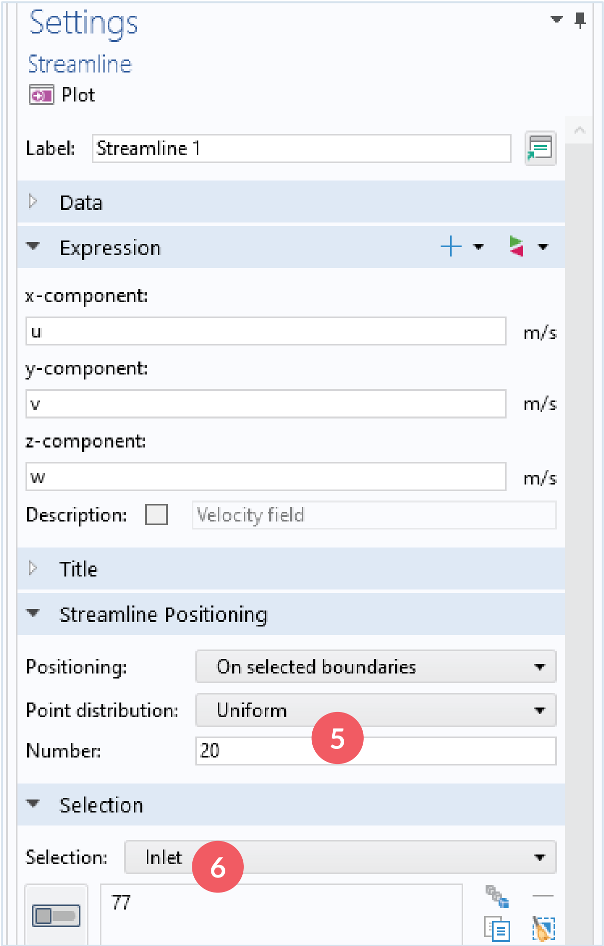


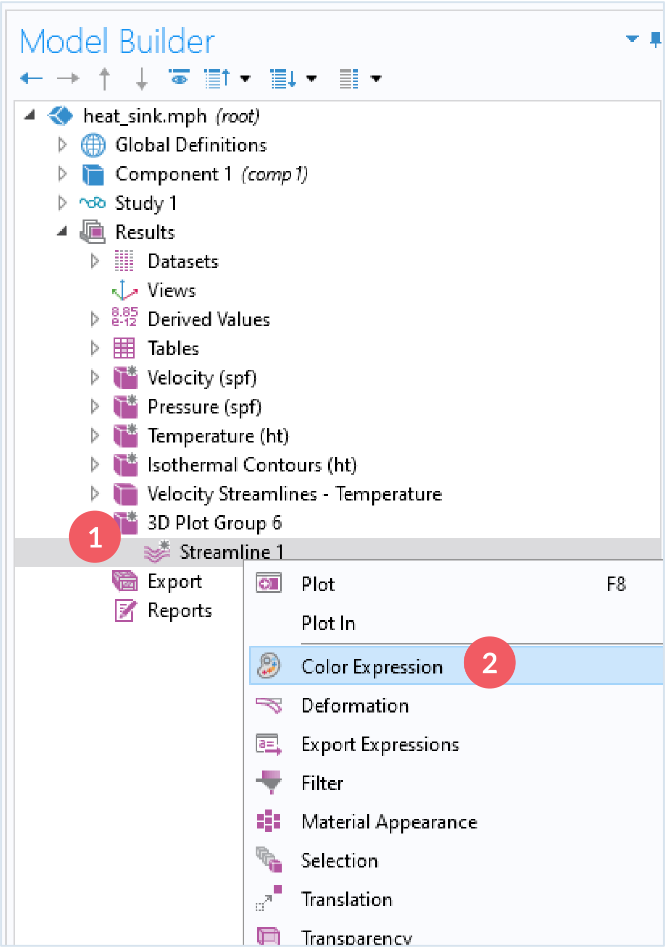


HEAT SINK: POSTPROCESSING





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heat_sink.mph (root)
Global Definitions
Component 1 (comp 1)
Study 1
Results
Datasets
Views
Derived Values
Tables
Velocity (spf)
Pressure (spf)
Temperature (ht)
Isothermal Contours (ht)
Velocity Streamlines - Temperature
3D Plot Group 6
Streamline 1
Export
Reports
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Plot
F8
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Color Expression
2
Deformation
Export Expressions
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Material Appearance
Selection
Translation
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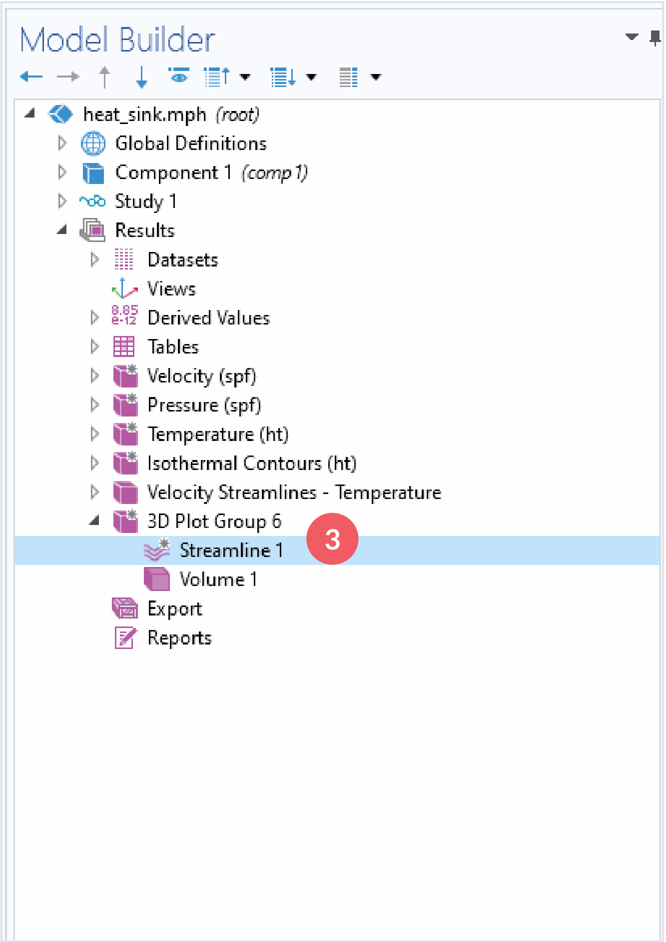
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heat_sink.mph (root)
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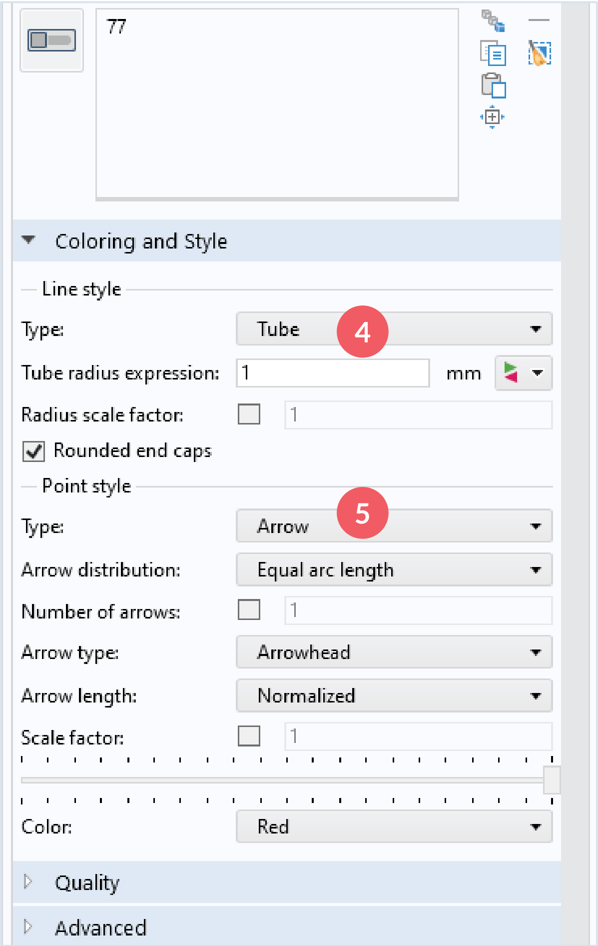
Component 1 (comp 1)
Study 1
Results
Datasets
Views
Derived Values
Tables
Velocity (spf)
Pressure (spf)
Temperature (ht)
Isothermal Contours (ht)
Velocity Streamlines - Temperature
3D Plot Group 6
Streamline 1
3
Volume 1
Export
Reports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Coloring and Style
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Tube
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Tube radius expression:
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Radius scale factor:
1
Rounded end caps
Point style
Type:
Arrow
5
Arrow distribution:
Equal arc length
Number of arrows:
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Arrow type:
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Normalized
Scale factor:
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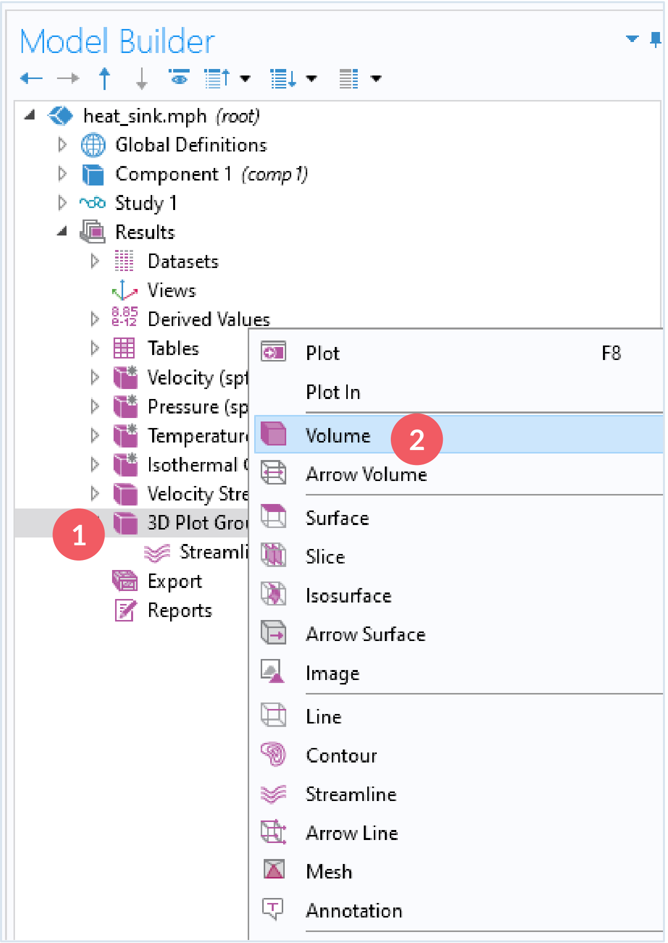
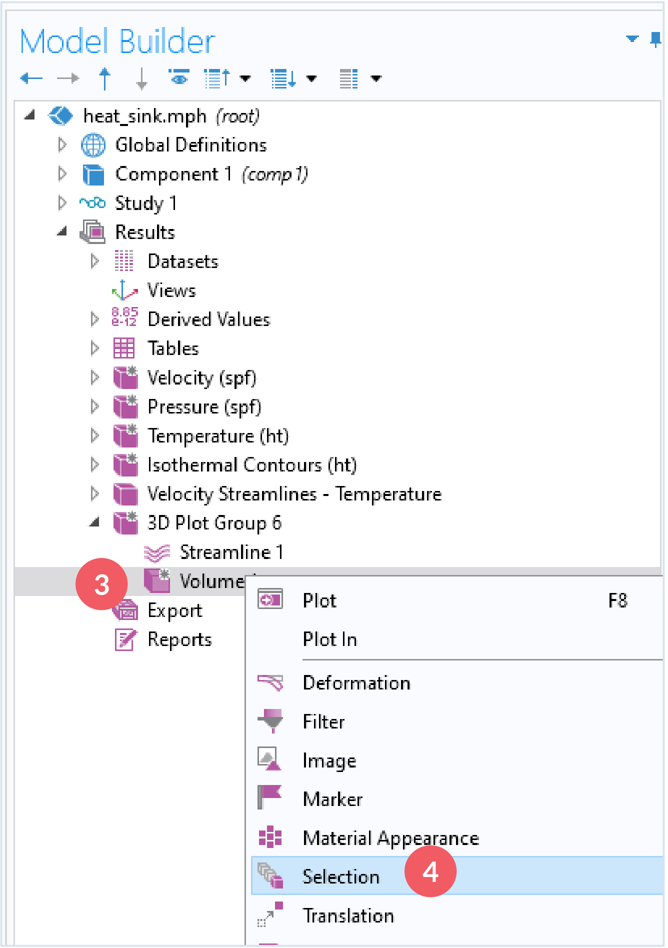
Color:
Red
Quality
Advanced

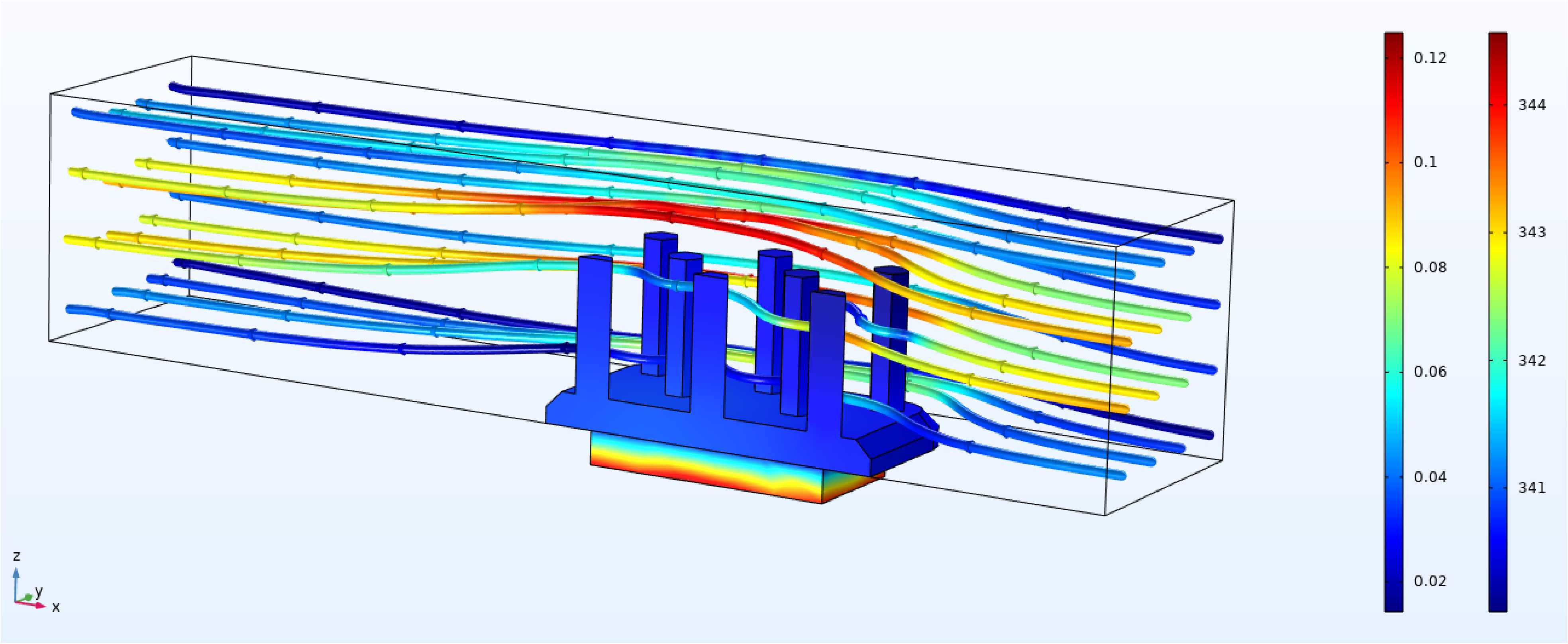
HEAT SINK: POSTPROCESSING





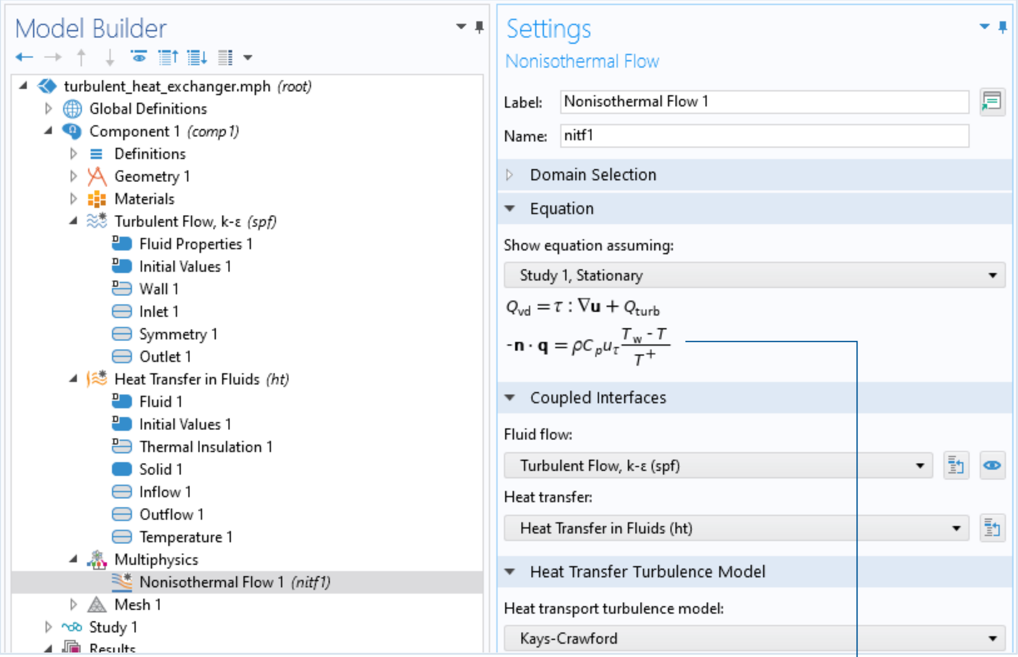
Plot variable “T” in domains 2 and 3

HEAT SINK: POSTPROCESSING — STREAMLINE PLOT

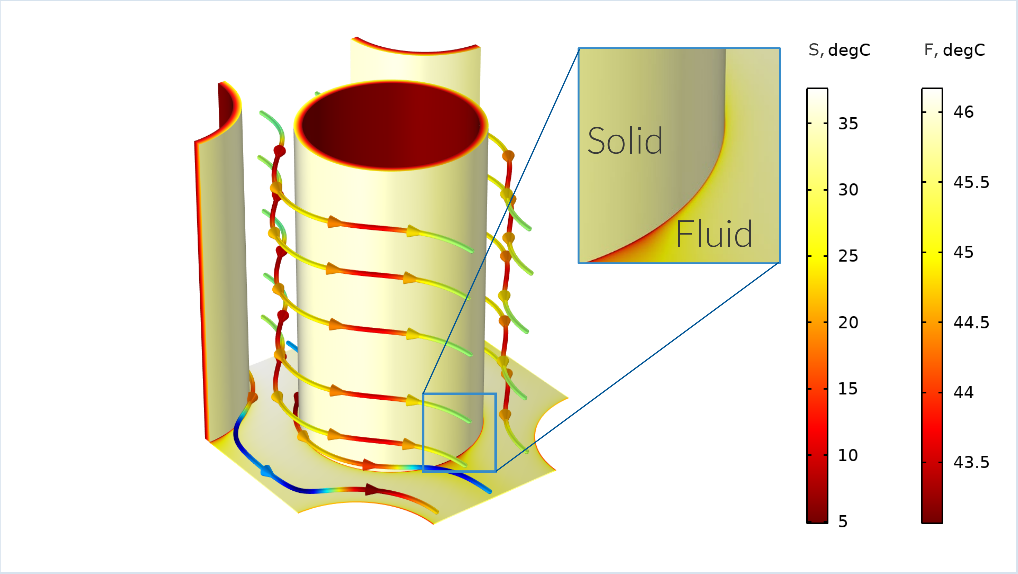


Conjugate Heat Transfer with Turbulent Flow

- Fluid flow, conduction, and convection in the fluid domain
- Turbulence diffusivity added to thermal conductivity in the fluid, *e.g.* Kays-Crawford
- Conduction in the solid domain
- Heat transfer over the fluid-solid interface:
  - For no-slip, low Re and algebraic turbulence models give continuity in temperature
  - Wall functions result in a discontinuity in temperature, since the boundary layer is not resolved
  - Both give continuity in heat flux



There is a discontinuity in temperature over the solid-fluid interface (T_w-T).

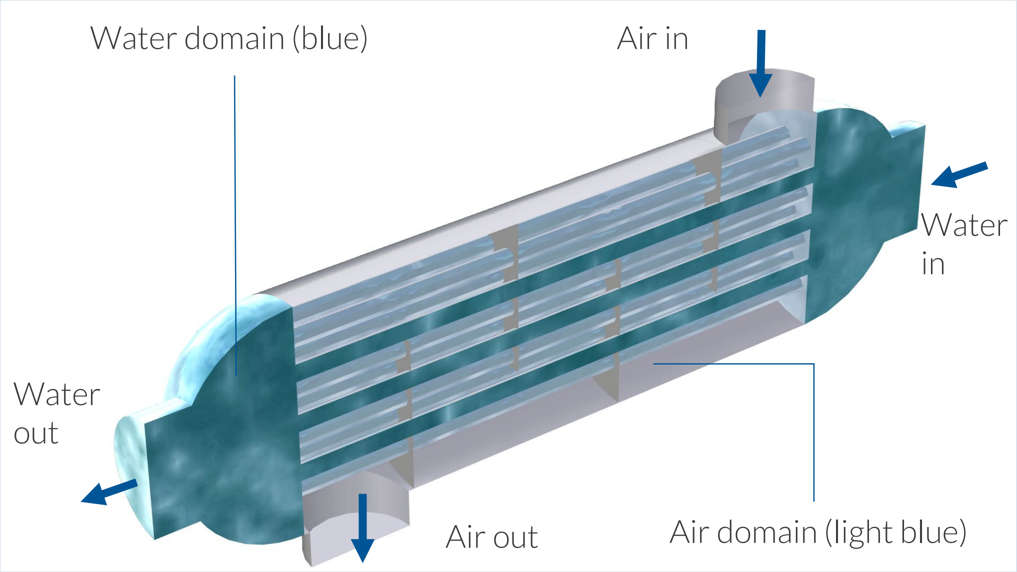


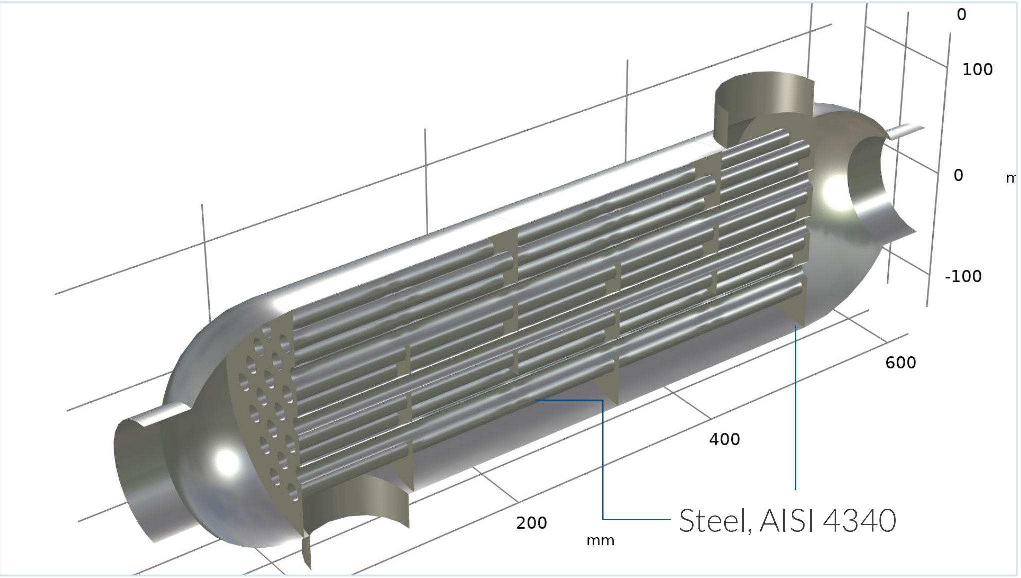
Demo

Shell & Tube Heat Exchanger

Problem Definition

- Conjugate heat transfer with turbulent flow where the solid domain is represented by shells
- Separated water and air domains
- Shells
  - Interior walls for flow separate the water and air domains
  - Thin layer for heat transfer defined on all shells
- Wall functions and heat transfer coefficients for turbulent flow:
  - Discontinuous temperature, since the boundary layer is not resolved

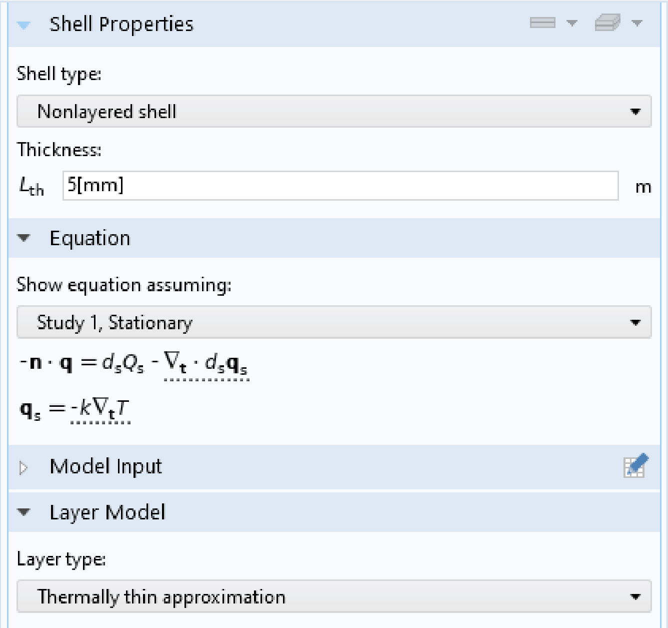


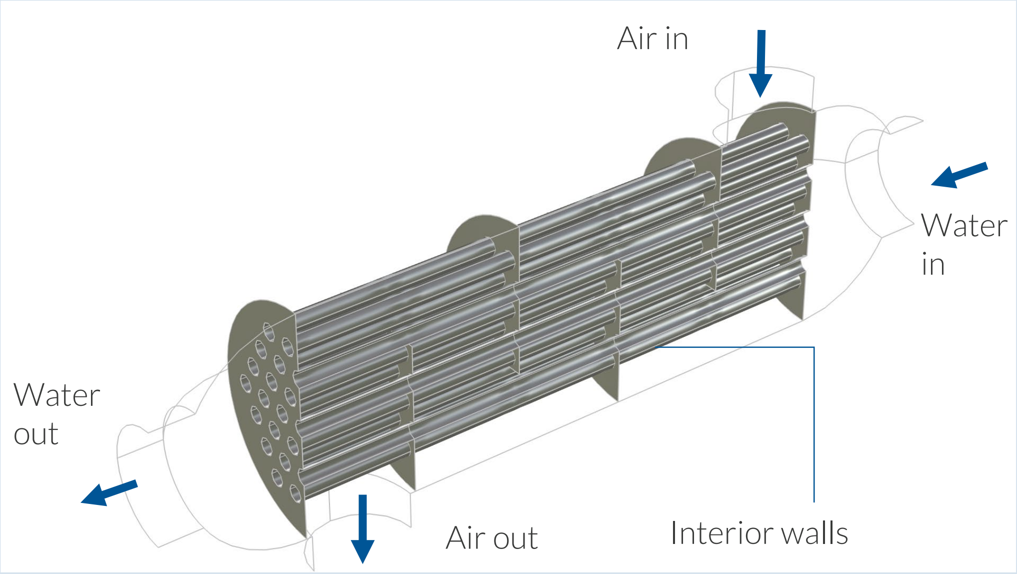


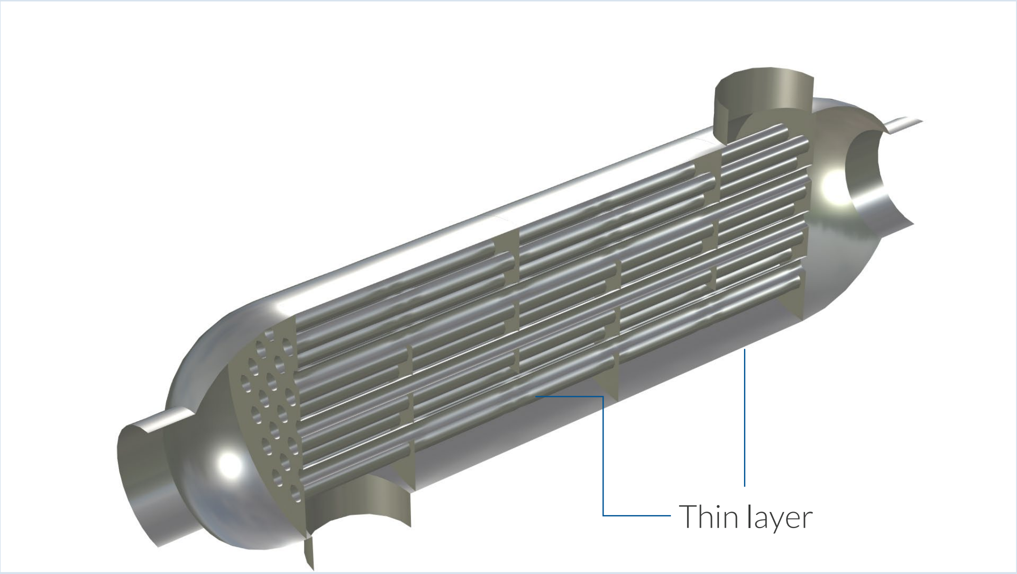
Problem Definition

Shells

- Interior walls for flow separate the water and air domains
- Thin layer for heat transfer defined on all shells

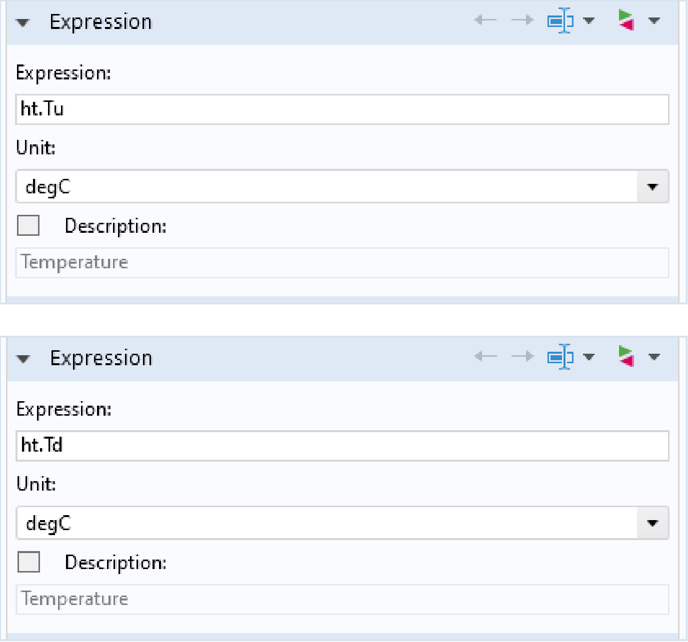




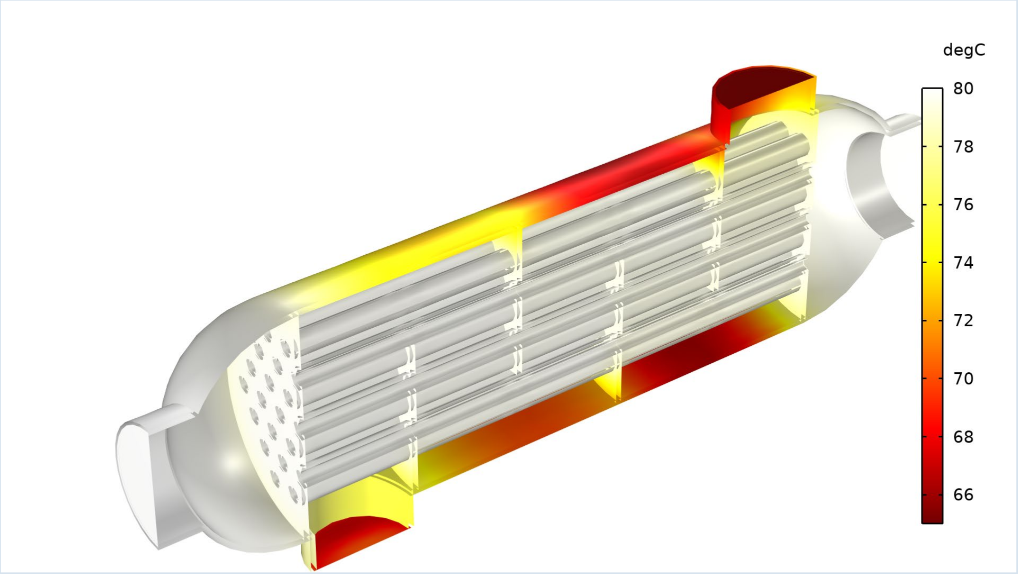


Results

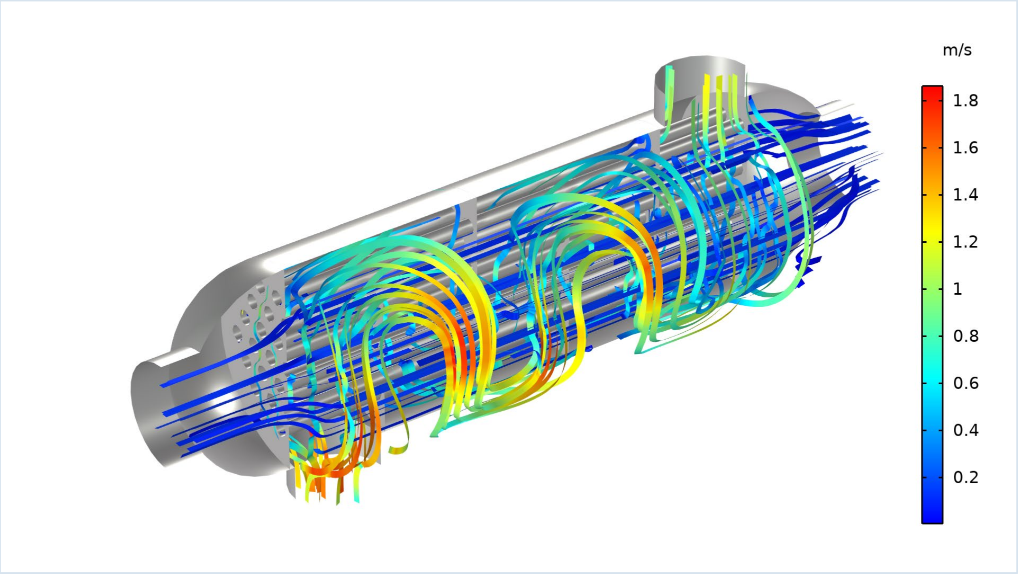
Evaluation on up and down-side of the thin layer:



Temperature variable for up (top) and down-sides (bottom) of the thin layers.



Temperature on up (top) and down-sides (bottom) of the thin layers.



Velocity streamlines.