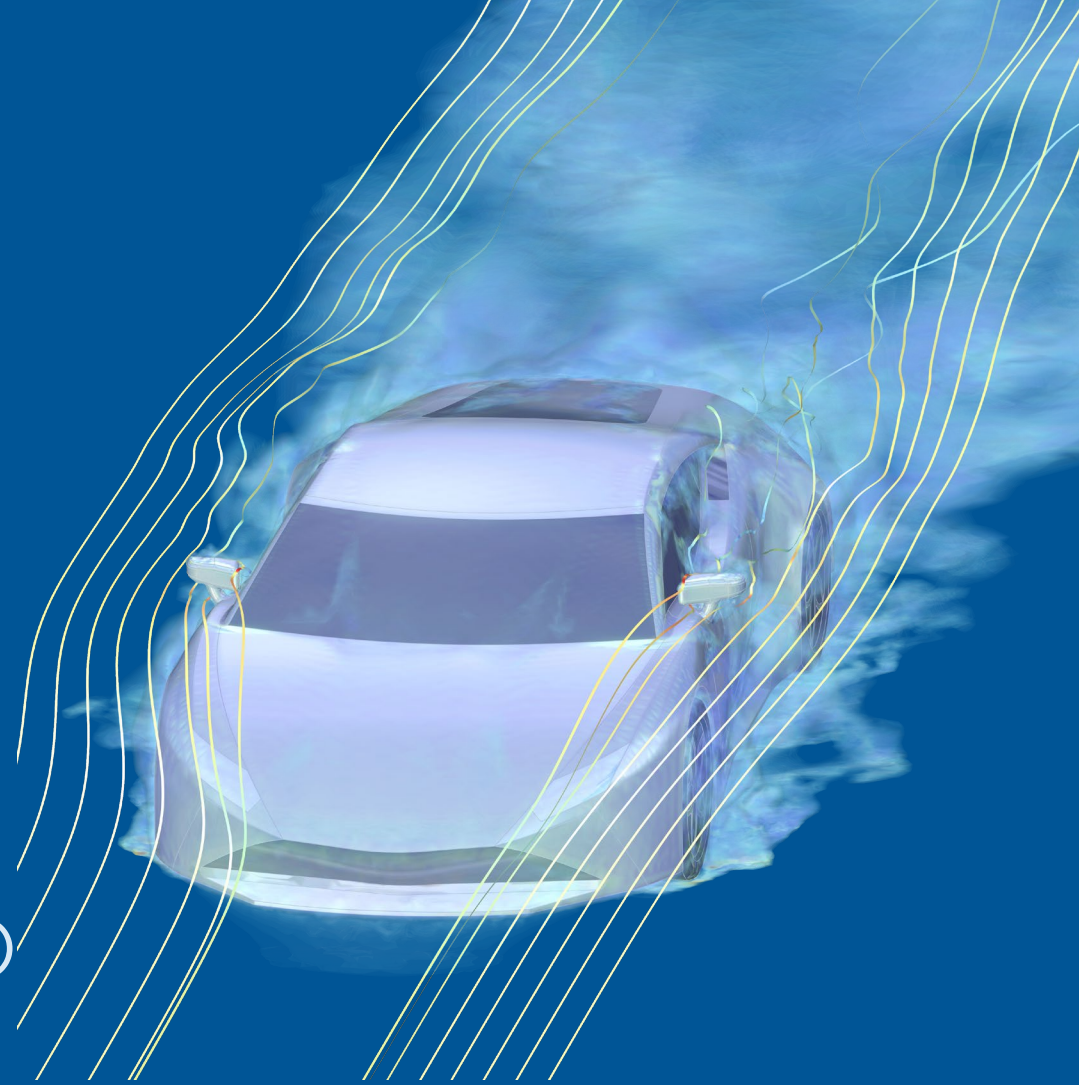
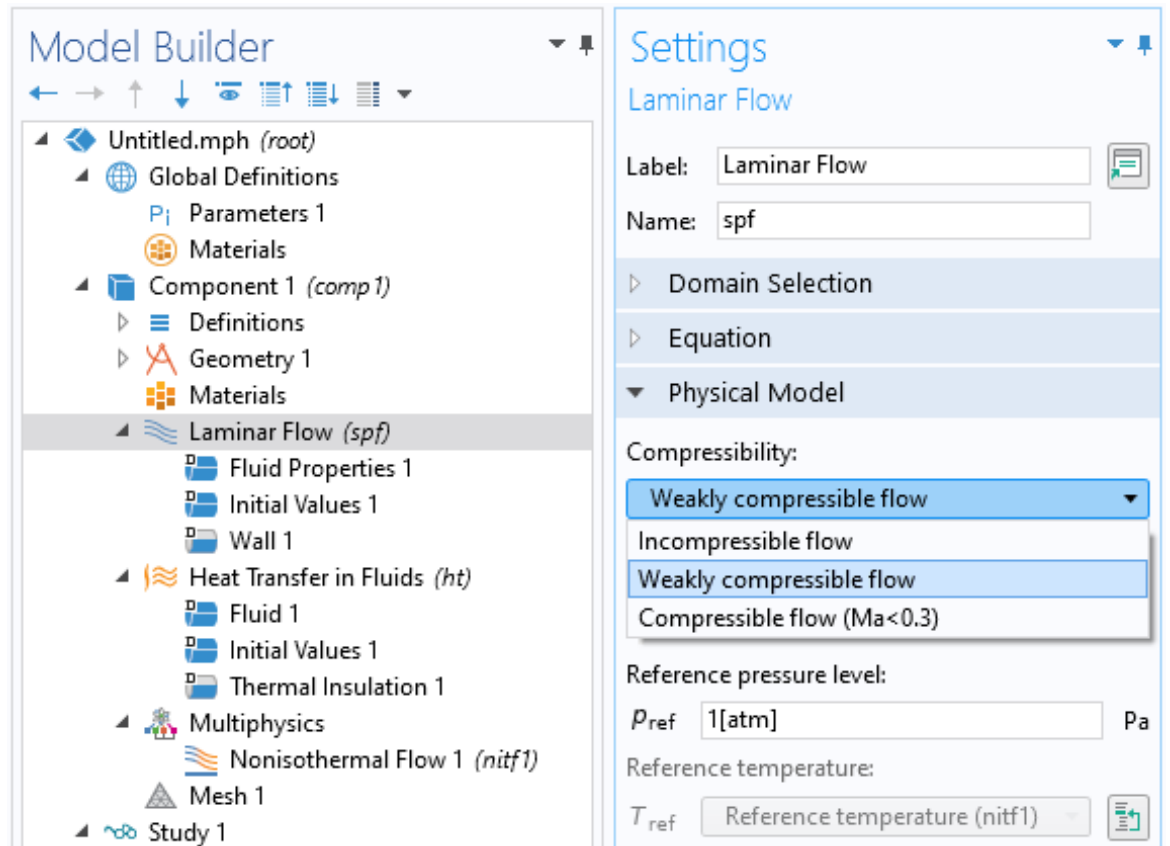


# COMSOL Multiphysics® Conjugate Heat Transfer



# 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



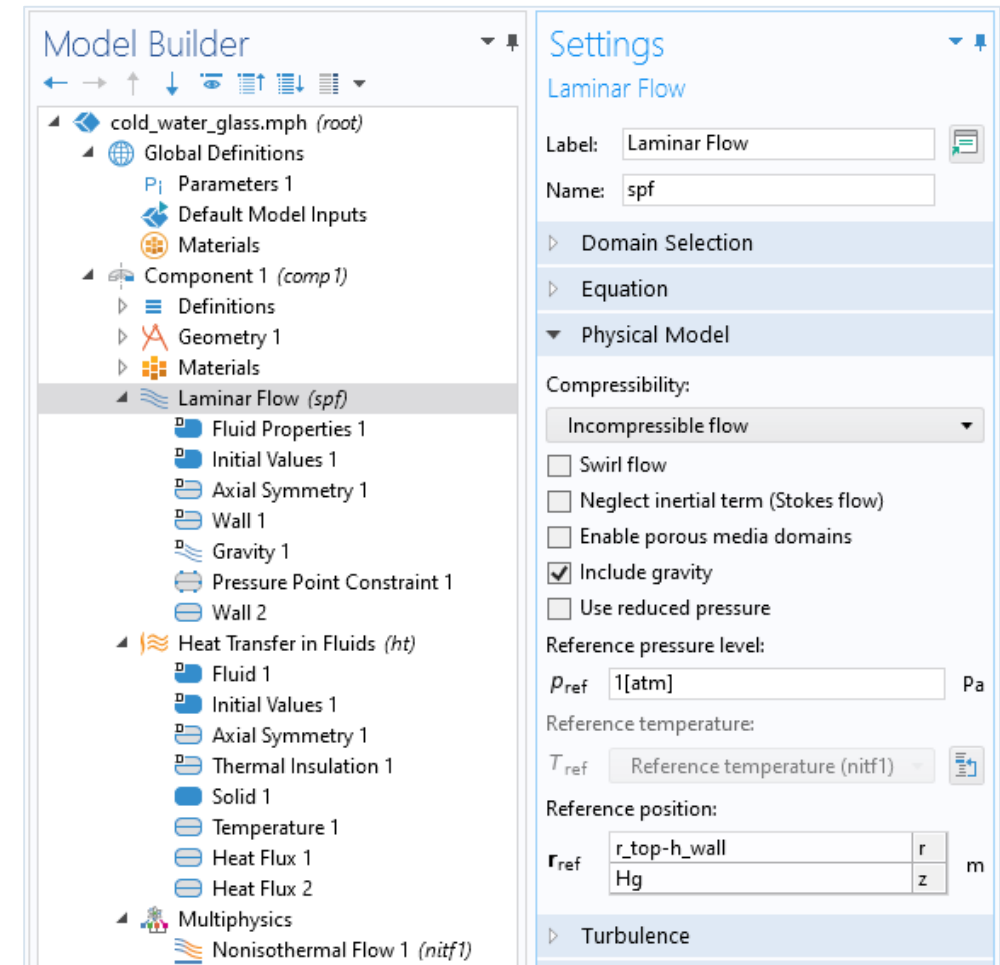
The laminar (shown above) and turbulent flow interfaces allow you to select compressibility option: Incompressible, weakly compressible, or compressible flow.

# Gravity Property

- Includes a volume force on all domains,

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

- 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



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

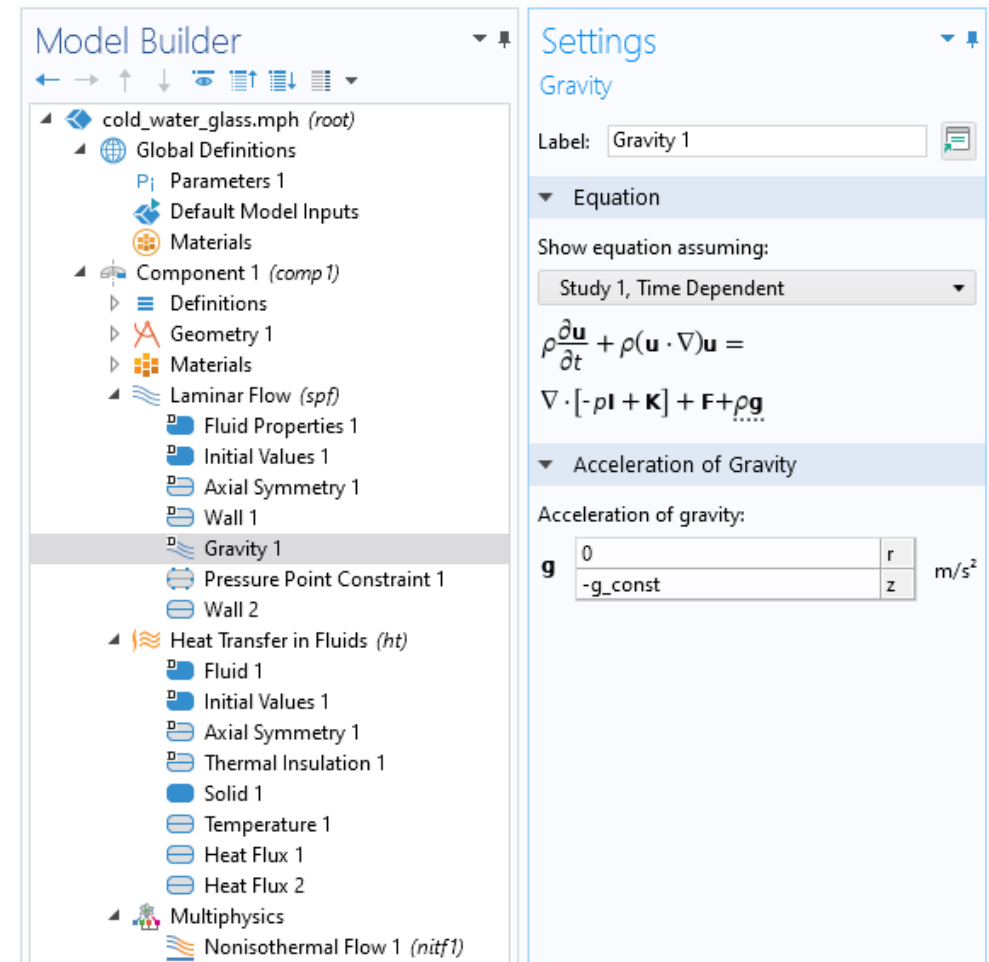
For incompressible flow, density variations are only included in the volume force term in the Navier-Stokes equations. These can be accounted for through a linearized expression (left). For weakly compressible and compressible flow, density variations are introduced in all the instances in the flow equations 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.

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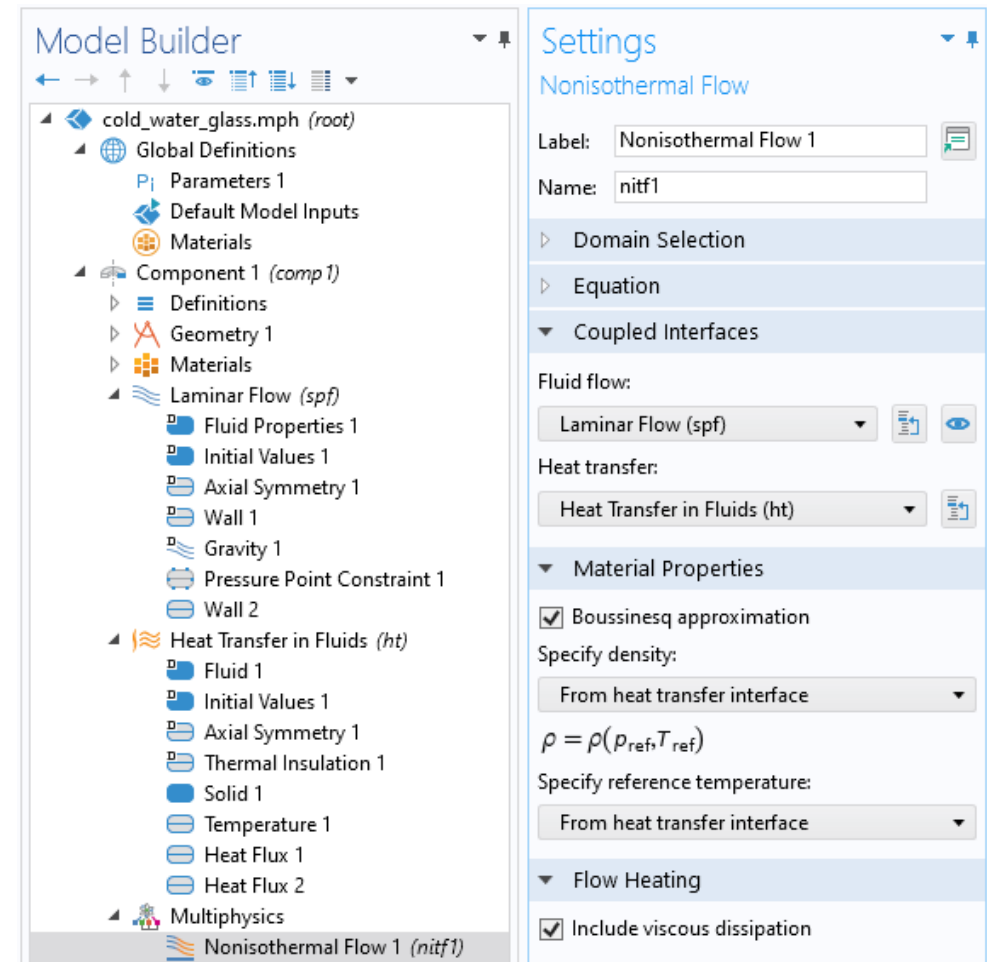
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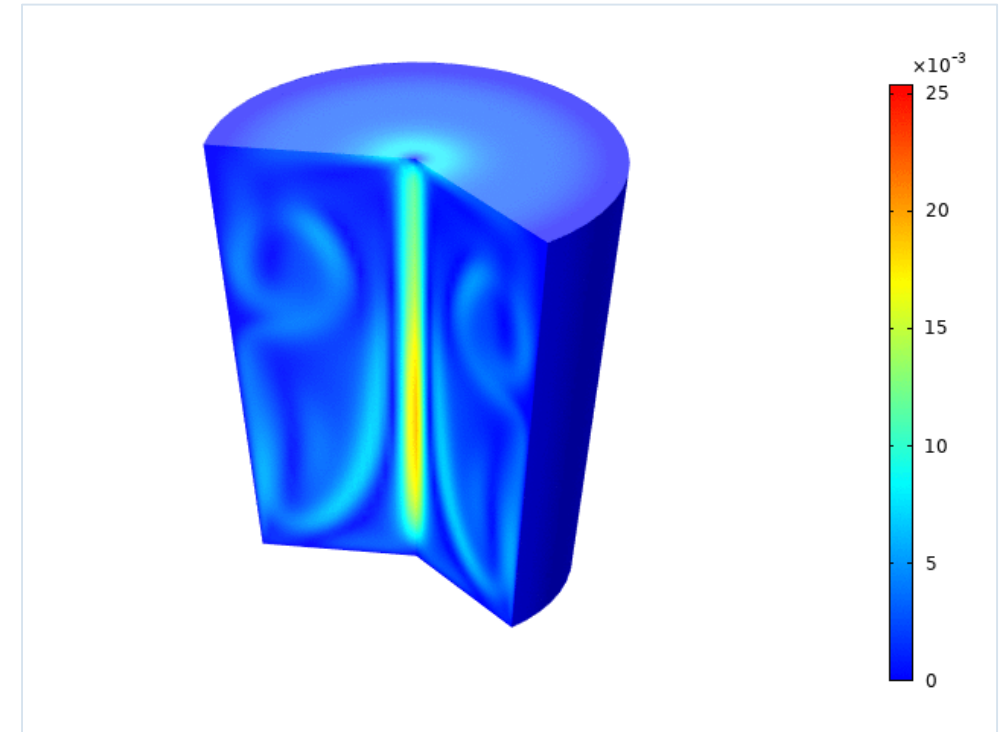
# Incompressible Flow

- Introduces a volume force in the momentum equations:

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

- Boussinesq approximation:

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

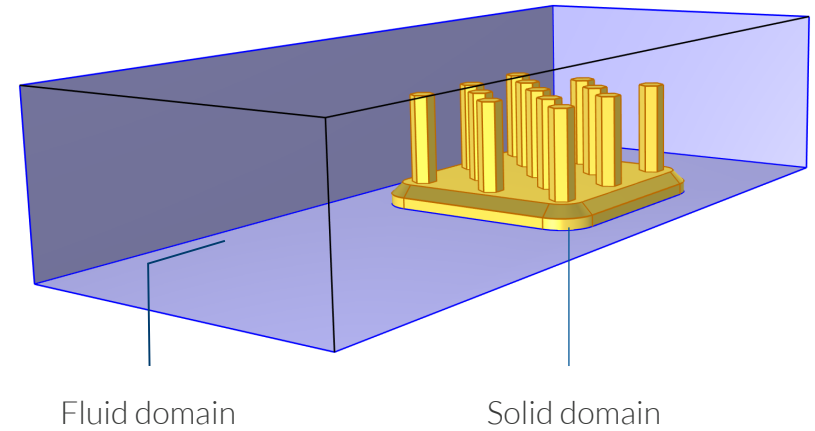


Free convection in a water glass solved using incompressible flow.  
This assumption is appropriate for small density variations.

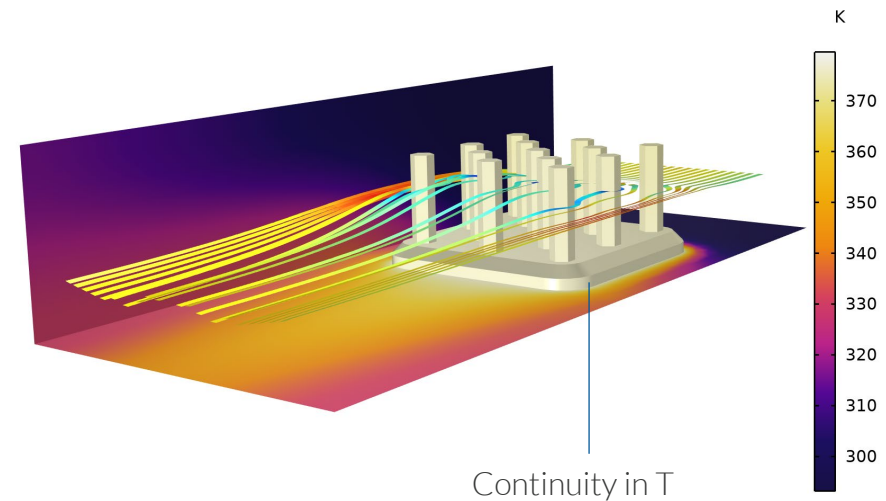
# Conjugate Heat Transfer

# Conjugate Heat Transfer with Laminar Flow

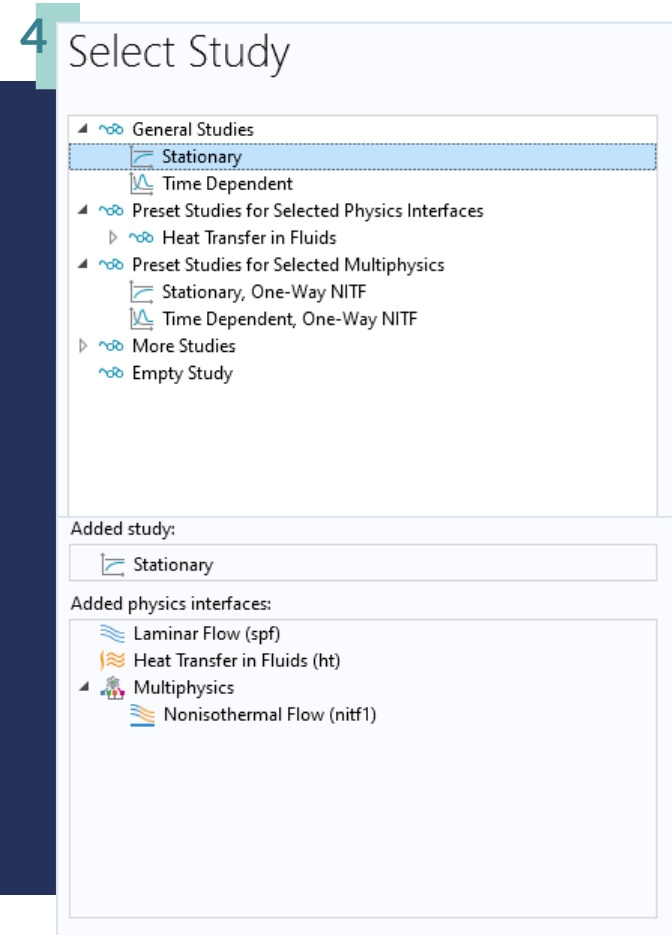
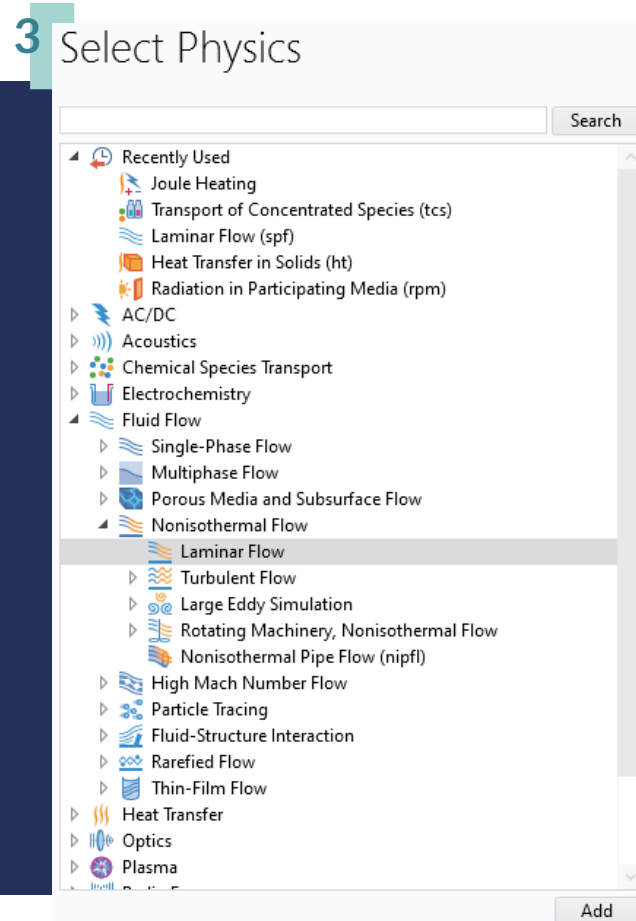
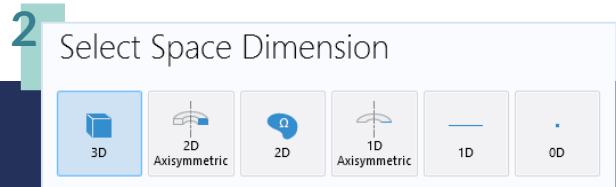
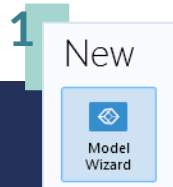
- Fluid flow, conduction, and convection in the fluid domain
- Conduction in the solid domain
- Heat transfer between fluid and solid domain:
  - No-slip condition gives continuity in heat flux and temperature at the fluid-solid interface



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







## THE FIRST STEP

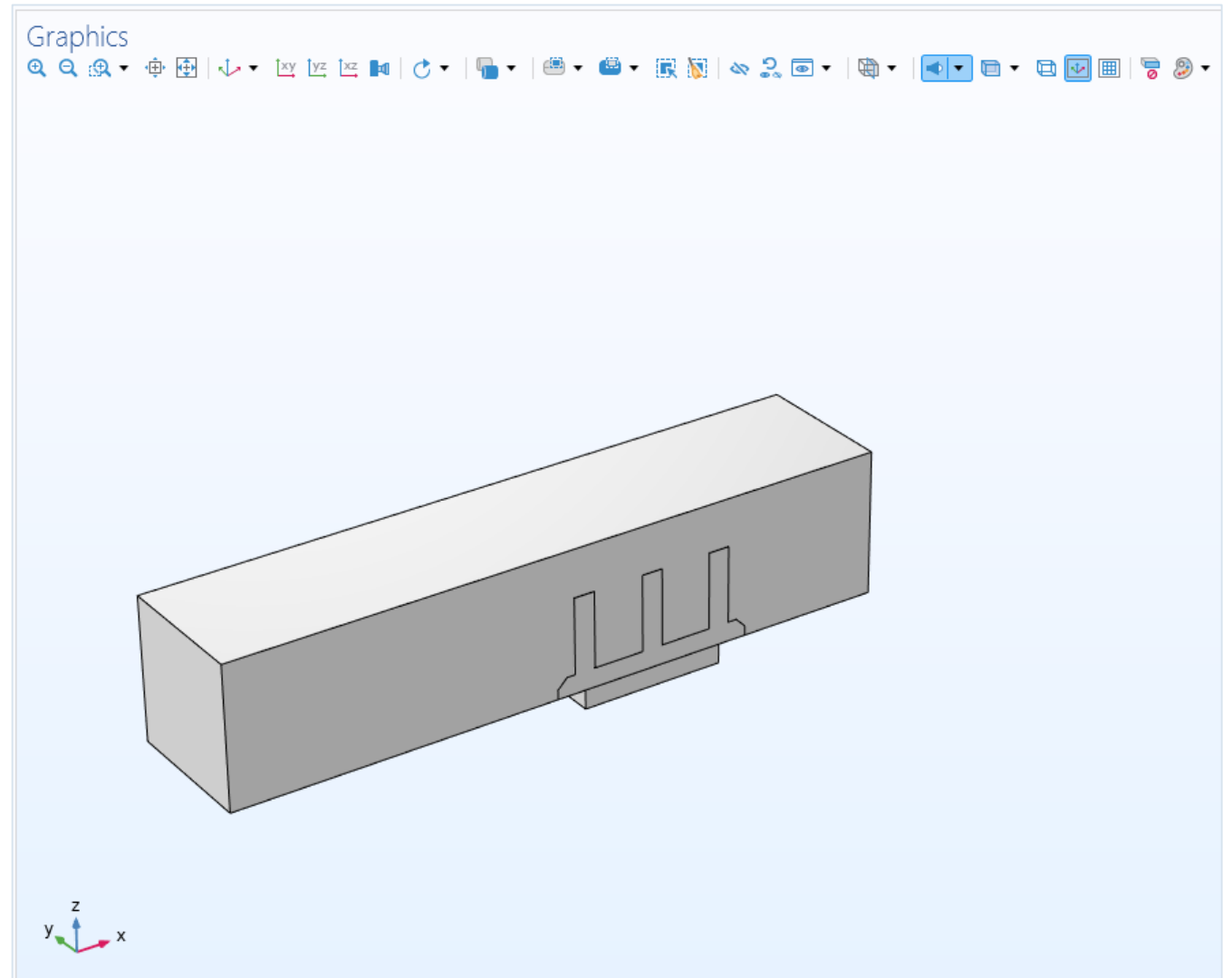
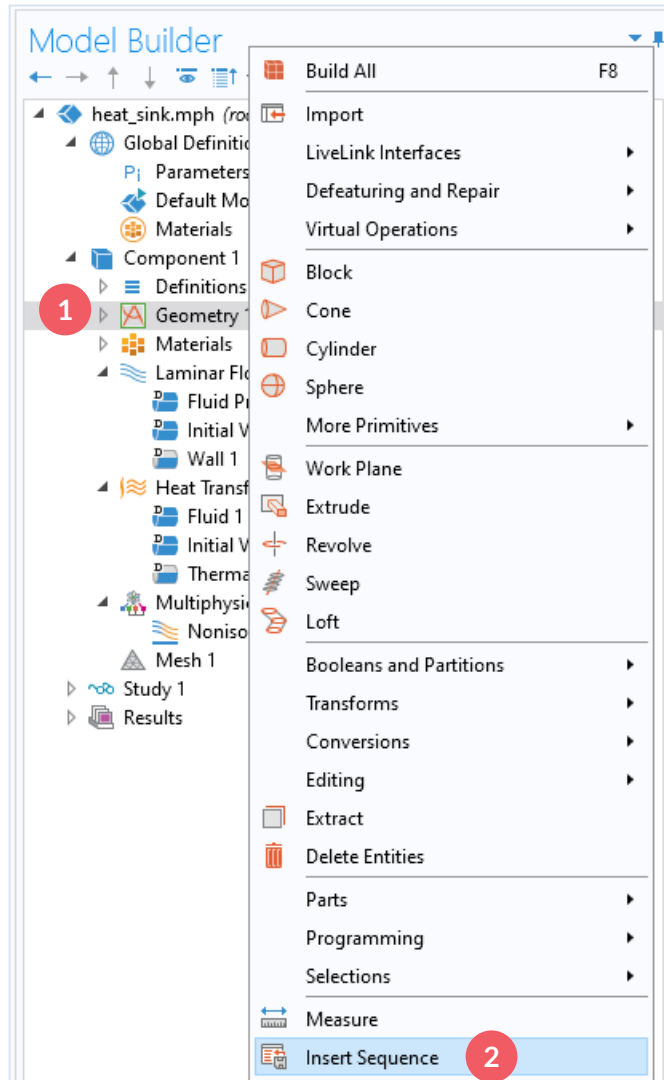
# The Model Wizard

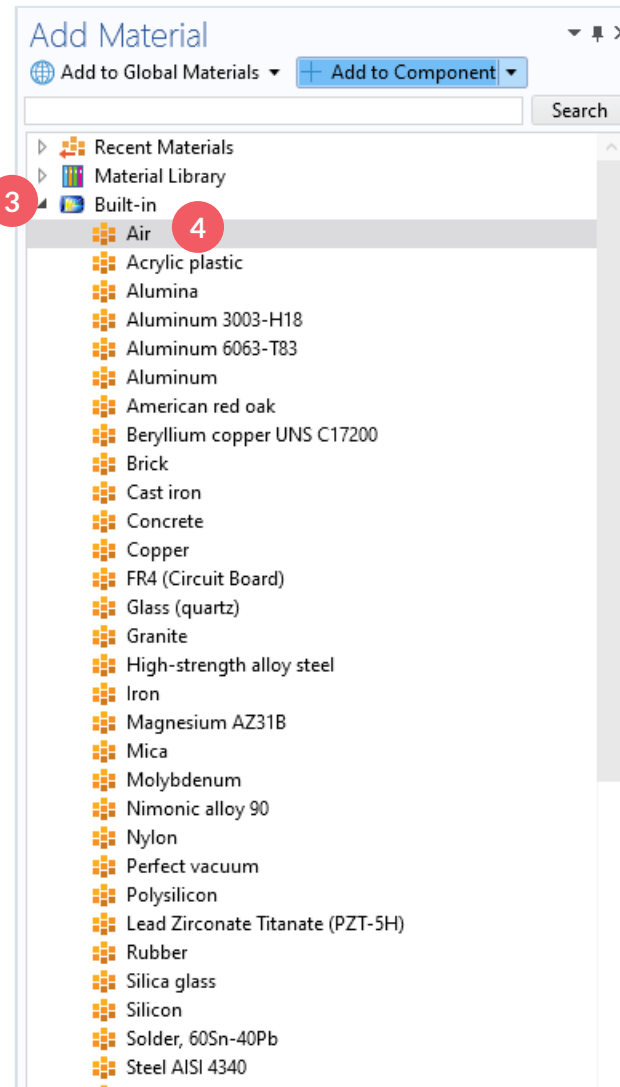
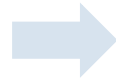
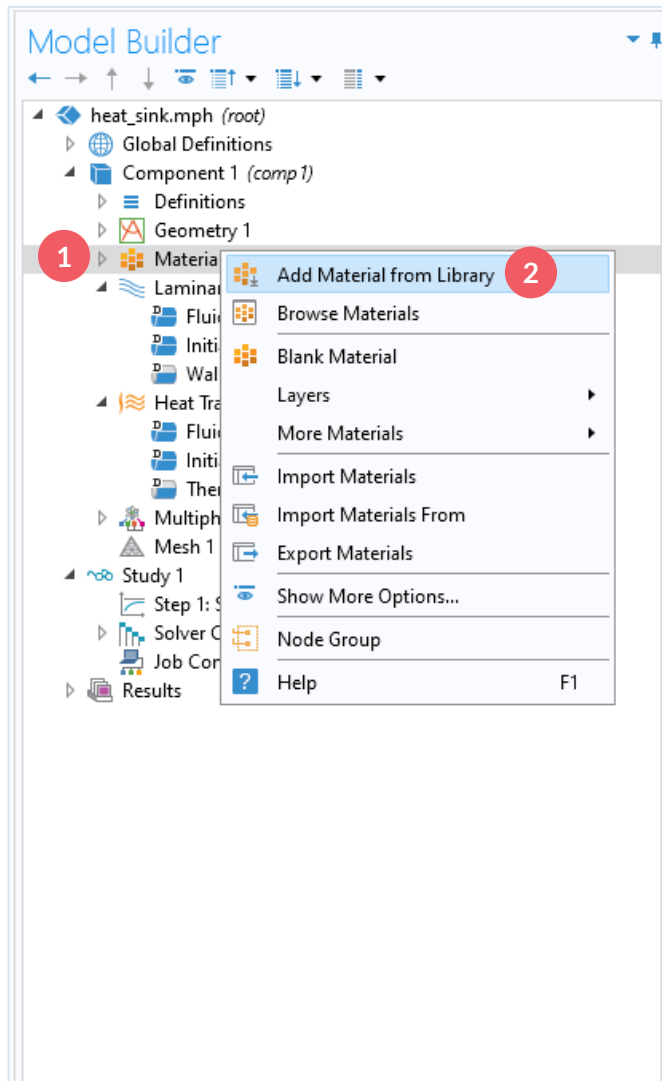
When creating a new model, the Model Wizard assists with selecting:

- 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





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

**Aluminum -> Add to Component**

**Silica Glass -> Add to Component**

Model Builder

- heat\_sink.mph (root)
  - Global Definitions
    - Parameters 1
    - Default Model Inputs
    - Materials
  - Component 1 (comp1)
    - Definitions
    - Geometry 1
    - Materials
      - Air (mat2)
      - Aluminum (mat1)** 1
      - Silica glass (mat3)
    - Laminar Flow (spf)
      - Fluid Properties 1
      - Initial Values 1
      - Wall 1
    - Heat Transfer in Fluids (ht)
      - Fluid 1
      - Initial Values 1
      - Thermal Insulation 1
    - Multiphysics
      - Nonisothermal Flow 1 (nitf1)
    - Mesh 1
  - Study 1
  - Results



Settings

Material

Label: Aluminum

Name: mat1

Geometric Entity Selection

Geometric entity level: Domain

Selection: Aluminum 2

2

Override

Material Properties

Material Contents

| Property  | Variable   | Value       | U  |
|---|------------|-------------|----|
| <input checked="" type="checkbox"/> Heat capacity at constant pres... | Cp         | 900[J/(k... | J/ |
| <input checked="" type="checkbox"/> Thermal conductivity              | k_iso ;... | 238[W/(...  | W  |
| <input checked="" type="checkbox"/> Density                           | rho        | 2700[kg...  | kg |
| Relative permeability   | mur_i...   | 1           | 1  |
| Electrical conductivity   | sigma...   | 3.774e7[... | S  |
| Relative permittivity   | epsilo...  | 1           | 1  |
| Coefficient of thermal expansi...                                     | alpha_...  | 23e-6[1/... | 1/ |
| Young's modulus   | E          | 70e9[Pa]    | P  |
| Poisson's ratio   | nu         | 0.33        | 1  |
| Murnaghan third-order elastic...                                      | l          | -2.5e11[... | N  |

Graphics

2

Model Builder

- heat\_sink.mph (root)
  - Global Definitions
    - Parameters 1
    - Default Model Inputs
    - Materials
  - Component 1 (comp1)
    - Definitions
    - Geometry 1
    - Materials
      - Air (mat2)
      - Aluminum (mat1)
      - Silica glass (mat3)** 1
    - Laminar Flow (spf)
      - Fluid Properties 1
      - Initial Values 1
      - Wall 1
    - Heat Transfer in Fluids (ht)
      - Fluid 1
      - Initial Values 1
      - Thermal Insulation 1
    - Multiphysics
      - Nonisothermal Flow 1 (nitf1)
    - Mesh 1
  - Study 1
  - Results



Settings

Material

Label: Silica glass

Name: mat3

Geometric Entity Selection

Geometric entity level: Domain

Selection: Silica Glass 2

3

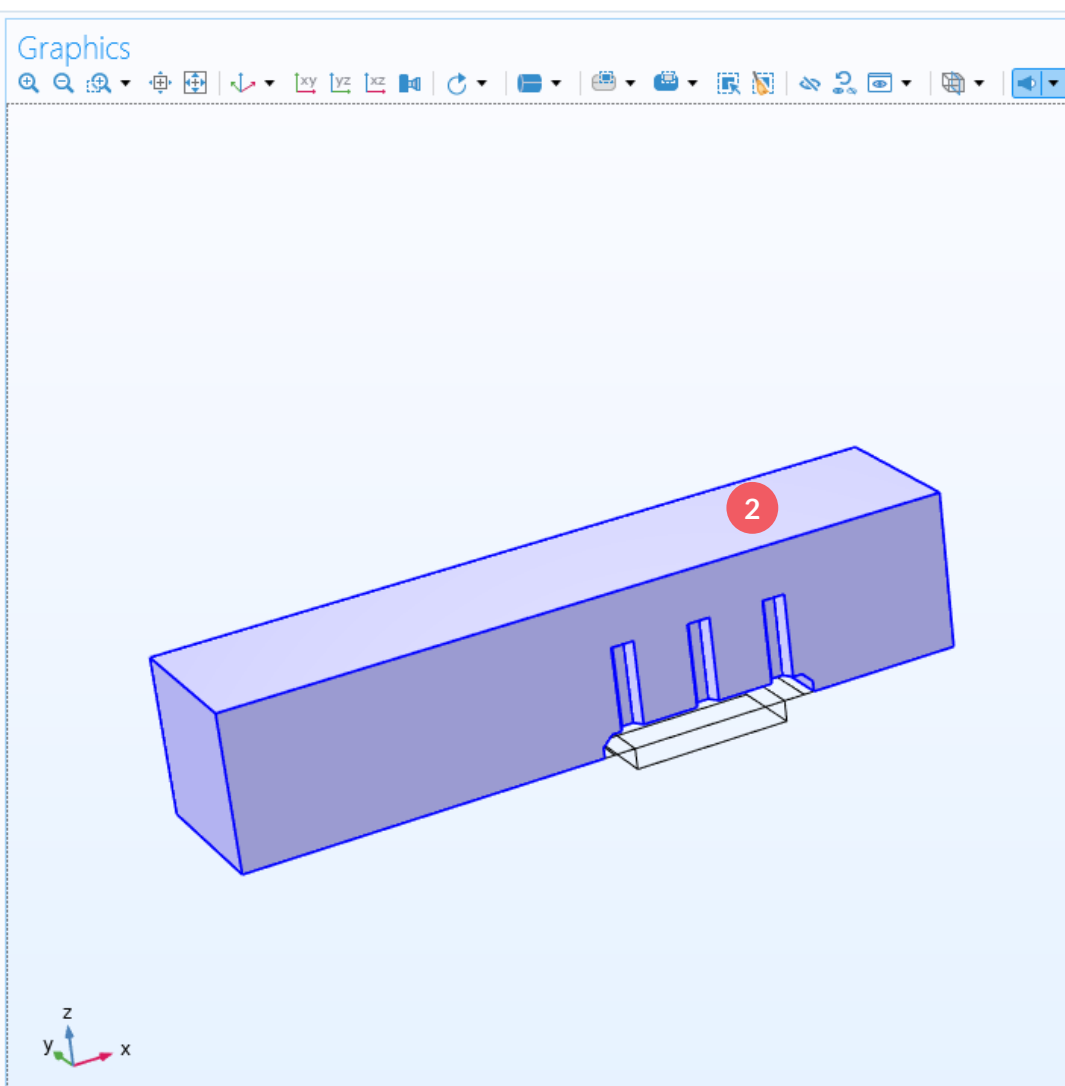
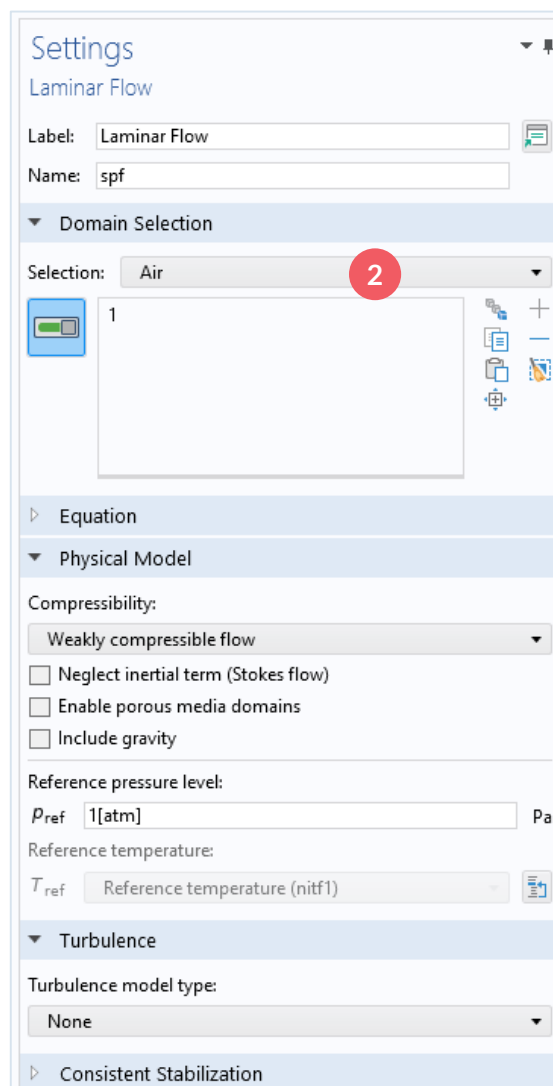
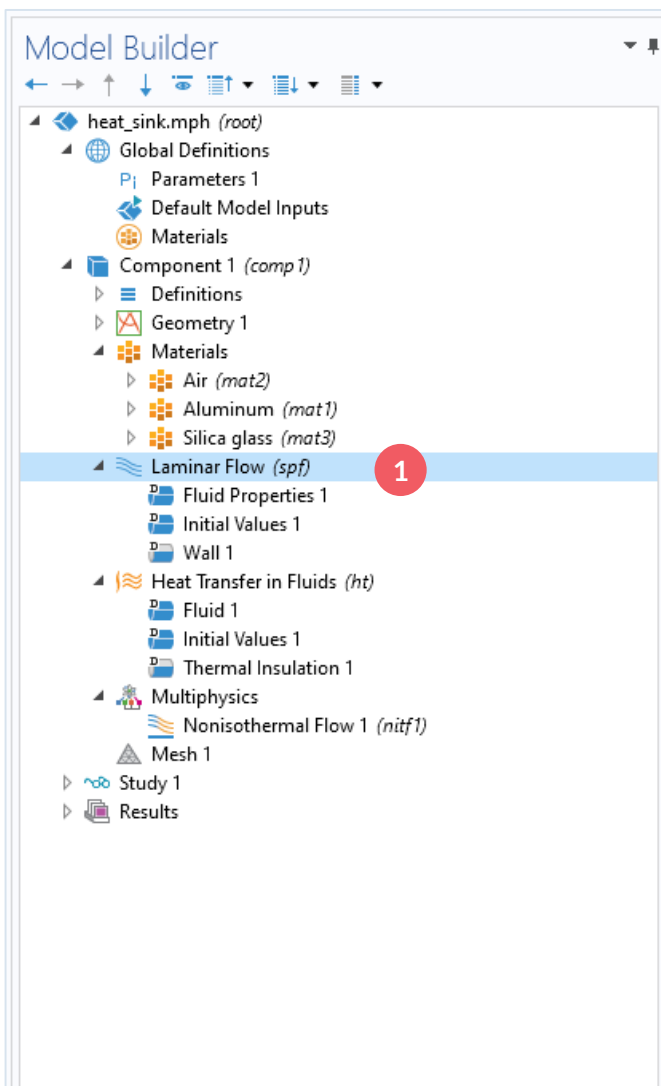
Override

Material Properties

Material Contents

| Property  | Variable   | Value       | U    |
|---|------------|-------------|------|
| <input checked="" type="checkbox"/> Heat capacity at constant pres... | Cp         | 703[J/(k... | J/ ^ |
| <input checked="" type="checkbox"/> Density                           | rho        | 2203[kg...  | kg   |
| <input checked="" type="checkbox"/> Thermal conductivity              | k_iso ;... | 1.38[W/...  | W    |
| Relative permeability   | mur_i...   | 1           | 1    |
| Electrical conductivity   | sigma...   | 1e-14[S/... | S    |
| Coefficient of thermal expansi...                                     | alpha_...  | 0.55e-6[... | 1/   |
| Relative permittivity   | epsilo...  | 3.75        | 1    |
| Young's modulus   | E          | 73.1e9[P... | P    |
| Poisson's ratio   | nu         | 0.17        | 1    |
| Refractive index real part  | n_iso ...  | 1.45        | 1    |

Graphics



Model Builder

heat\_sink.mph (root)

- Global Definitions
  - Parameters
  - Default Values
  - Materials
- Component 1
  - Definitions
    - Geometries
  - Materials
    - Air
    - Aluminum
    - Silicon
  - Laminar Flow
    - Fluid Properties
    - Initial Values
    - More
      - Wall
      - Inlet **2**
      - Outlet
      - Symmetry
      - Open Boundary
      - Boundary Stress
      - Periodic Flow Condition
      - Interior Wall
    - Pairs
    - Flow Control Devices
    - Rotating Machinery
    - Fluid Interface Features
    - More
      - Edges
      - Points
    - Generate New Turbulence Model Interface
      - Global
    - Show More Options...
    - Node Group
    - Group by Space Dimension

- Study 1
- Results


Settings

Inlet

Label: Inlet 1

Boundary Selection

Selection: Inlet **3**

77

Override and Contribution

Equation

Boundary Condition

Fully developed flow **4**

☒ Apply condition on each disjoint selection separately

Fully Developed Flow

☒ Average velocity

☐ Flow rate

☐ Average pressure

Average velocity:

$U_{av}$   $U0$  **5** m/s

Constraint Settings

Graphics

Model Builder

- heat\_sink.mph (root)
  - Global Definitions
    - Parameters
    - Default Settings
    - Materials
  - Component 1
    - Definitions
      - Geometries
      - Materials
        - Air
        - Aluminum
        - Silicon
      - Laminar Flow (1) **1**
        - Fluid Properties
        - Initial Values
        - More...
        - Wall
        - Inlet
        - Outlet **2**
        - Symmetry
        - Open Boundary
        - Boundary Stress
        - Periodic Flow Condition
        - Interior Wall
        - Pairs
        - Flow Control Devices
        - Rotating Machinery
        - Fluid Interface Features
        - More...
        - Edges
        - Points
      - Generate New Turbulence Model Interface
        - Global
        - Show More Options...
      - Node Group
      - Group by Space Dimension



Settings

Outlet

Label: Outlet 1

Boundary Selection

Selection: Outlet **3**

1

Override and Contribution

Equation

Boundary Condition

Pressure

Pressure Conditions

$p_0$  0 **4** Pa

☐ Normal flow

☒ Suppress backflow

Constraint Settings

Graphics



Model Builder

heat\_sink.mph (root)

- Global Definitions
  - Parameters
  - Default Values
  - Materials
- Component 1
  - Definitions
    - Geometries
    - Materials
      - Air
      - Aluminum
      - Silicon
  - 1 Laminar Flow
    - Fluid Properties
    - Volume Force
    - Initial Values
    - More
    - Wall
    - Inlet
    - Outlet
    - 2 Symmetry
    - Open Boundary
    - Boundary Stress
    - Periodic Flow Condition
    - Interior Wall
    - Pairs
    - Flow Control Devices
    - Rotating Machinery
    - Fluid Interface Features
  - Heat Transfer
    - Fluid
    - Initial
    - Thermal
  - Multiphysics
    - More
    - Edges
    - Points
    - Generate New Turbulence Model Interface
    - Global
    - Show More Options...
    - Node Group
    - Group by Space Dimension
- Study 1
- Results



Settings

Symmetry

Label: Symmetry 1

Boundary Selection

Selection: Symmetry 3

- 2
- 7 (not applicable)
- 24 (not applicable)

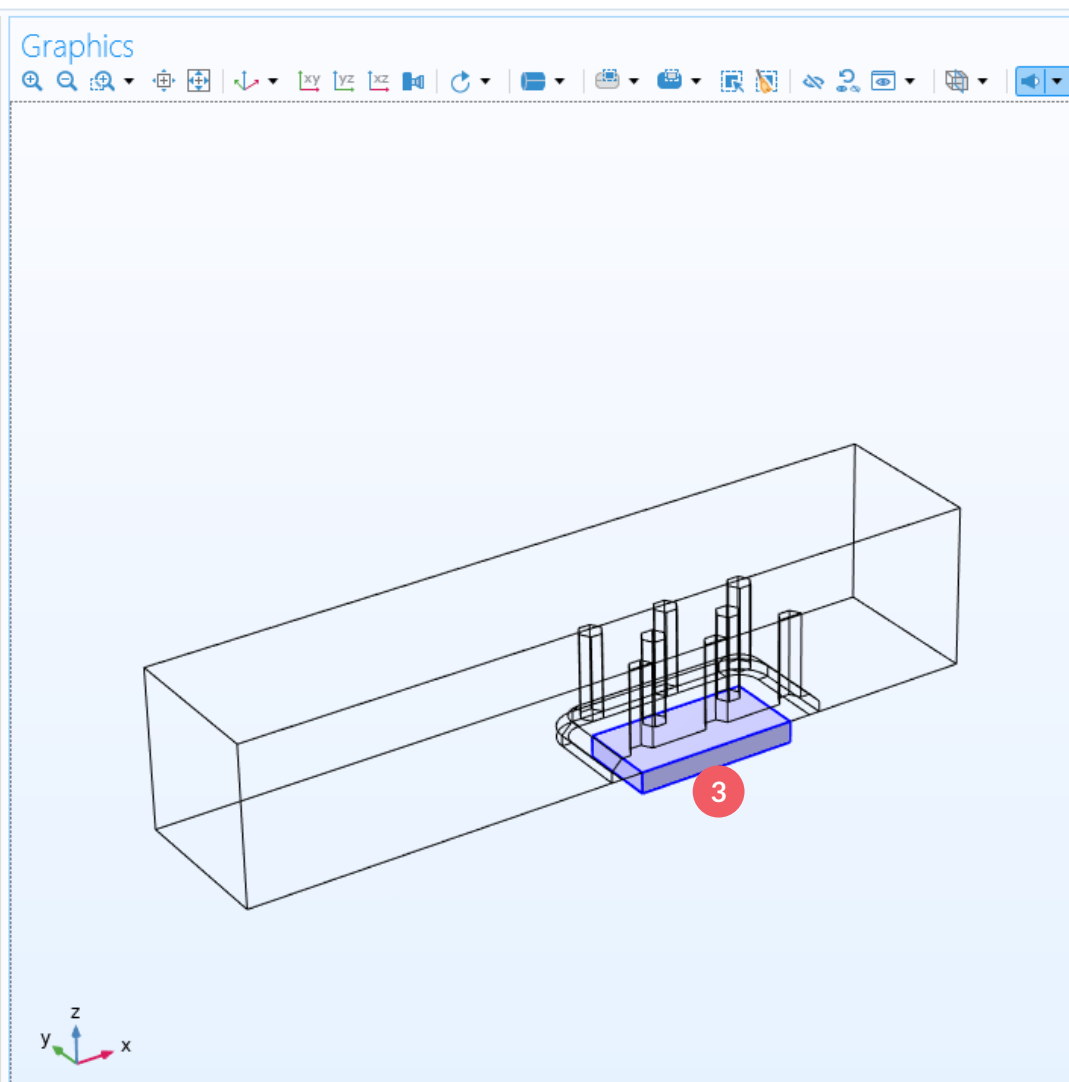
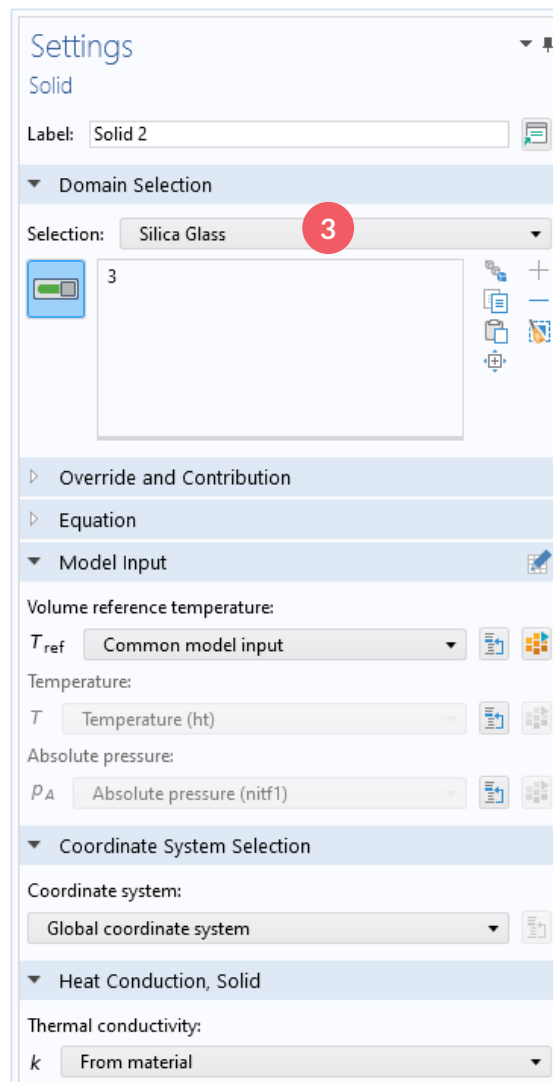
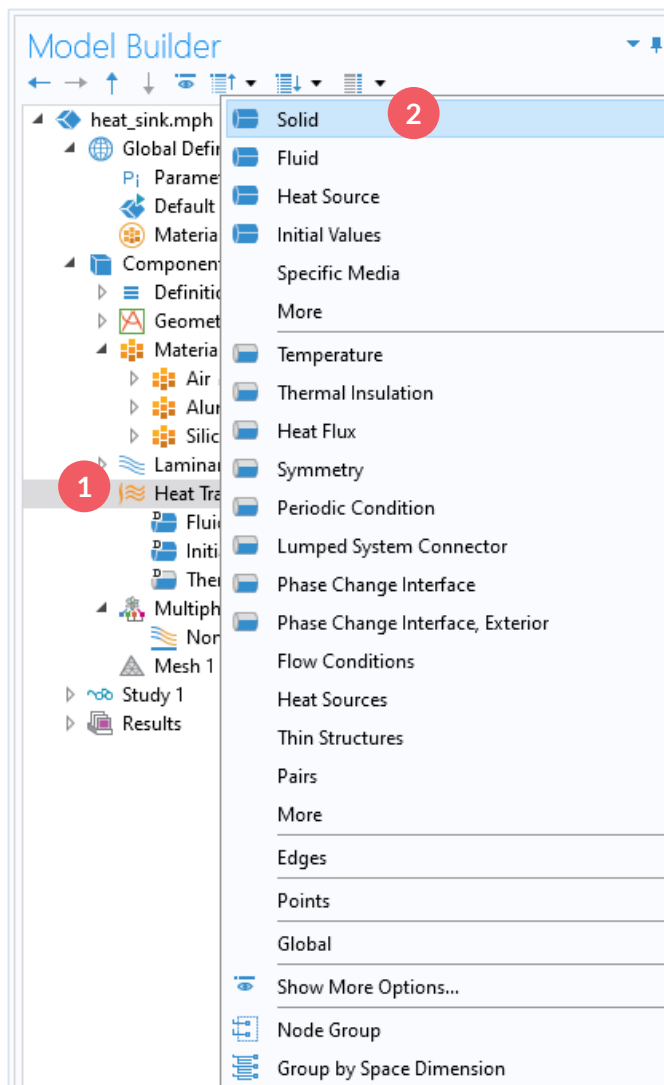
Override and Contribution

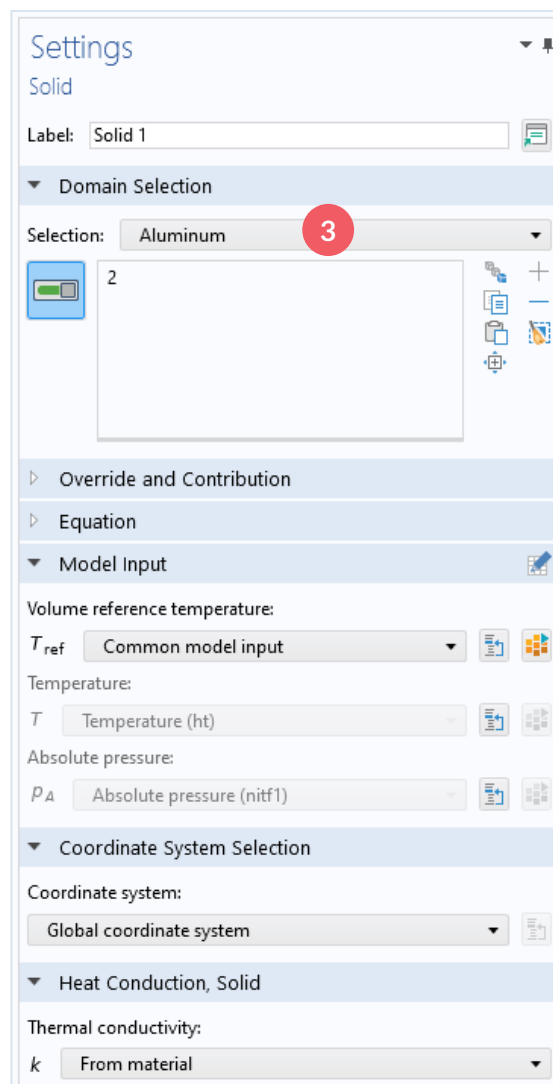
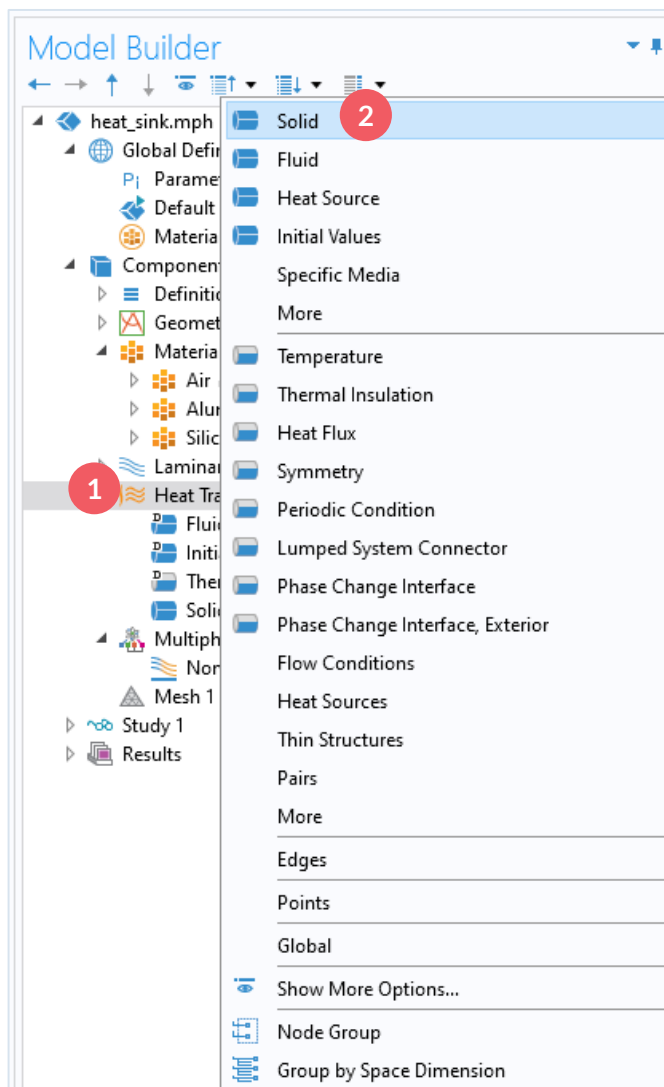
Equation

Constraint Settings

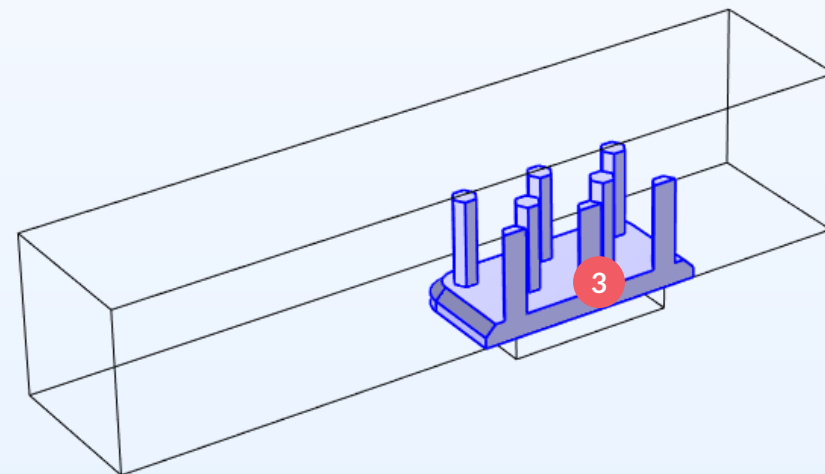
Graphics

3





Graphics



Model Builder

- heat\_sink.mph (root)
  - Global Definitions
    - Parameters 1
    - Default Model Inp
    - Materials
  - Component 1 (comp)
    - Definitions
    - Geometry 1
      - Materials
        - Air (mat2)
        - Aluminum (n
        - Silica glass (n
      - Laminar Flow (sp
      - Heat Transfer in F
      - Fluid 1
      - Initial Values 1
      - Thermal Insul
      - Solid 1
      - Solid 2

1

3

2

Flow Conditions

Heat Sources

Thin Structures

Pairs

More

Edges

Points

Global

Show More Options...

Node Group

Group by Space Dimension

Settings

Inflow

Label: Inflow 1

Boundary Selection

Selection: Inlet 4

77

Override and Contribution

Equation

Upstream Properties

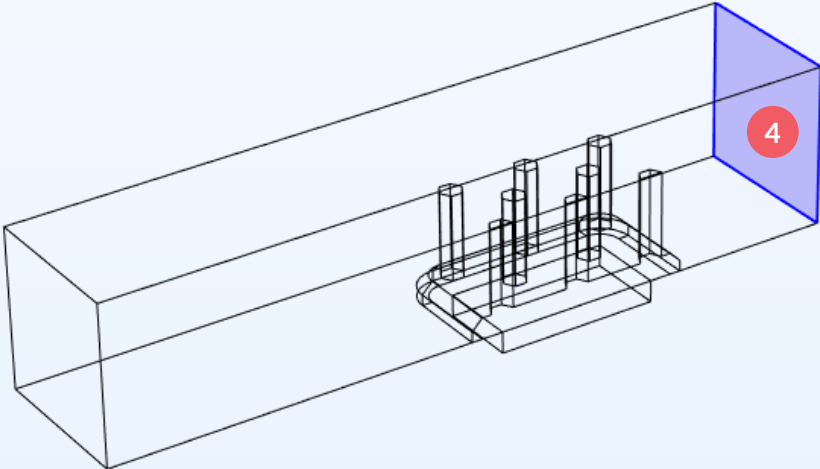
Upstream temperature:

$T_{ustr}$  User defined

293.15[K] K

☐ Specify upstream absolute pressure

Graphics



4

Model Builder

- heat\_sink.mph (root)
  - Global Definitions
    - Parameters 1
    - Default Model Input
    - Materials
  - Component 1 (comp)
    - Definitions
    - Geometry 1
      - Materials
        - Air (mat2)
        - Aluminum (mat1)
        - Silica glass (mat3)
      - Laminar Flow (spf1)
      - Heat Transfer in Fluids (ht1)
        - Fluid 1
        - Initial Values 1
        - Thermal Insulation 1
        - Solid 1
        - Solid 2

1

- Inflow
- Outflow 3
- Open Boundary

- Study 1
- Results

- Solid
- Fluid
- Heat Source
- Initial Values
- Specific Media
- More
- Temperature
- Thermal Insulation
- Heat Flux
- Symmetry
- Periodic Condition
- Lumped System Connector
- Phase Change Interface
- Phase Change Interface, Exterior
- Flow Conditions 2
- Heat Sources
- Thin Structures
- Pairs
- More
- Edges
- Points
- Global
- Show More Options...
- Node Group
- Group by Space Dimension



Settings

Outflow

Label: Outflow 1

Boundary Selection

Selection: Outlet 4

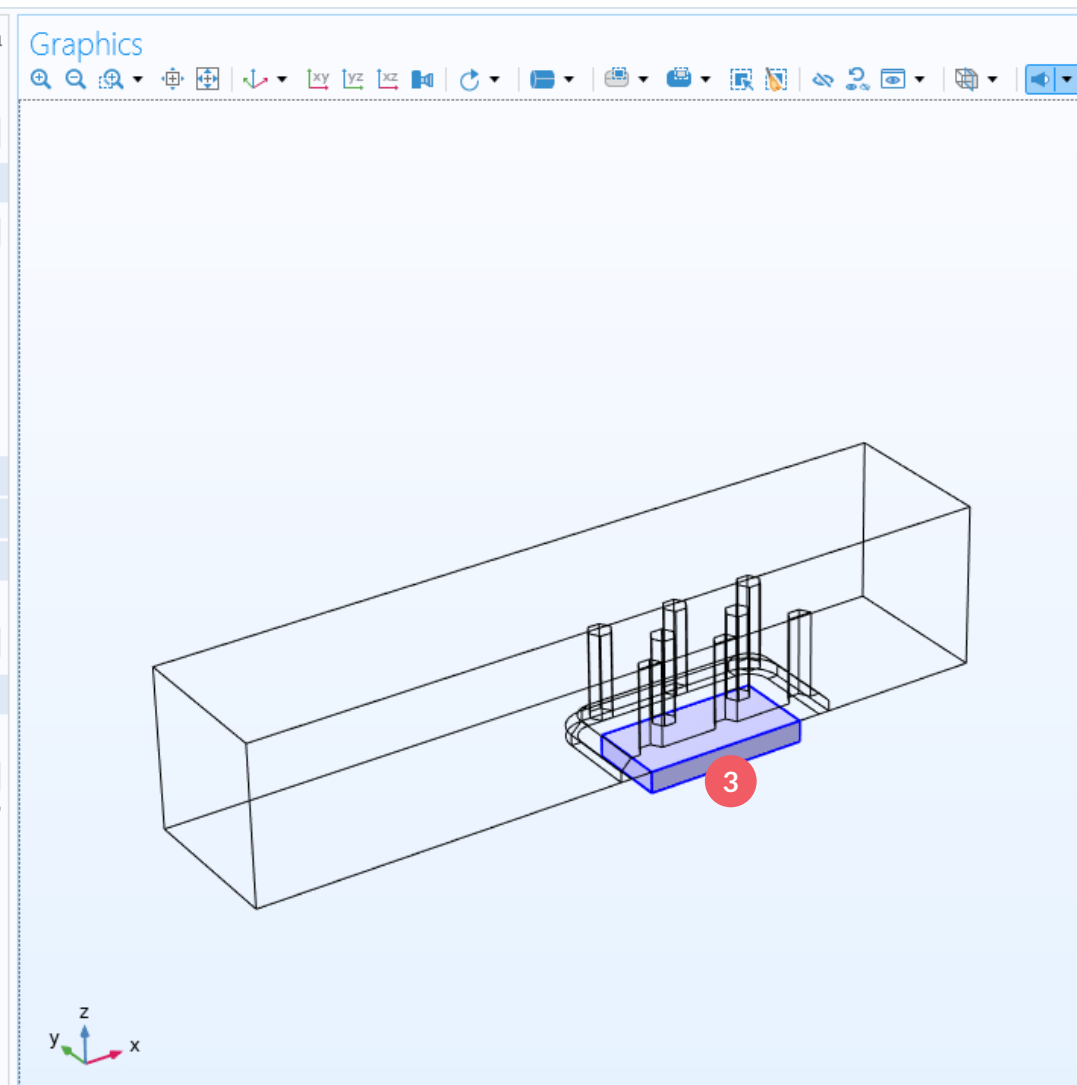
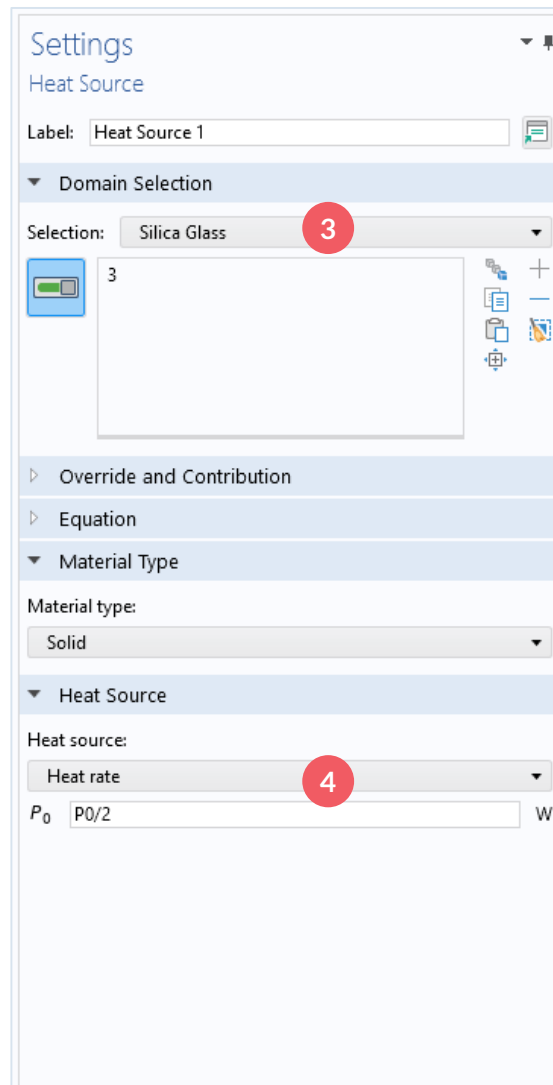
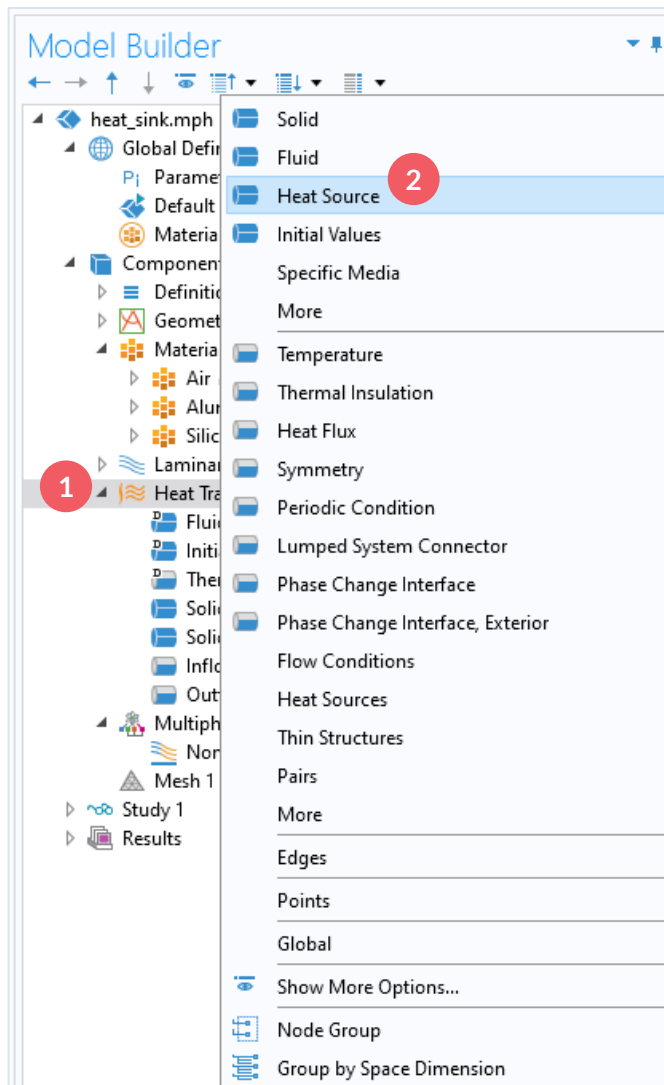
1

Override and Contribution

Equation

Graphics

4



Model Builder

- heat\_sink.mph
  - Global Definition
    - Parameters
    - Default
    - Material
  - Component
    - Definitions
      - Geometries
    - Materials
      - Air
      - Aluminum
      - Silicon
    - Laminates
    - Heat Transfer
      - Heat Transfer
      - Fluid
      - Initial Values
      - Thermal Insulation
      - Heat Flux **2**
      - Symmetry
      - Periodic Condition
      - Lumped System Connector
      - Phase Change Interface
      - Phase Change Interface, Exterior
      - Flow Conditions
      - Heat Sources
      - Thin Structures
      - Pairs
      - More
      - Edges
      - Points
      - Global
      - Show More Options...
      - Node Group
      - Group by Space Dimension



Settings

Heat Flux

Label: Heat Flux 1

Boundary Selection

Selection: Exterior Walls **3**

3  
4  
5  
6 (not applicable)  
9 (not applicable)  
10 (not applicable)

Override and Contribution

Equation

Material Type

Material type: Nonsolid

Heat Flux

Flux type: Convective heat flux **4**

Heat transfer coefficient: User defined

Heat transfer coefficient:  $h$  5 **5** W/(m<sup>2</sup>·K)

External temperature:  $T_{\text{ext}}$  User defined 293.15[K] K

Graphics

3

Model Builder

- heat\_sink.mph
  - Global Definition
    - Parameters
    - Default Values
    - Materials
  - Component 1
    - Definitions
      - Geometries
    - Materials
      - Air
      - Aluminum
      - Silicon
    - Laminar Flow
      - Heat Transfer
        - 1
        - Fluid Flow
          - Initial Values
          - Thermal Insulation
          - Heat Flux
          - 2
          - Symmetry
          - Periodic Condition
          - Lumped System Connector
          - Phase Change Interface
          - Phase Change Interface, Exterior
        - Flow Conditions
        - Heat Sources
        - Thin Structures
      - Multiphysics
        - Nonlinear
    - Mesh 1
    - Study 1
    - Results



Settings

Symmetry

Label: Symmetry 1

Boundary Selection

Selection: Symmetry 3

2  
7  
24

Override and Contribution

Equation

Graphics

3



**Model Builder**

- heat\_sink.mph (root)
  - Global Definitions
    - Parameters 1
    - Default Model Inputs
    - Materials
  - Component 1 (comp1)
    - Definitions
    - Geometry 1
      - Materials
        - Air (mat2)
        - Aluminum (mat1)
        - Silica glass (mat3)
      - Laminar Flow (spf)
      - Heat Transfer in Fluids (ht) **1**
      - Fluid 1
      - Initial Values 1
      - Thermal Insulation 1
      - Solid 1
      - Solid 2
      - Inflow 1
- Boundary Heat Source
- Deposited Beam Power
- Surface-to-Ambient Radiation **3**
  - Nonisothermal Flow 1 (nitf1)
  - Mesh 1
  - Study 1
  - Results

**Heat Sources** **2**

- Solid
- Fluid
- Heat Source
- Initial Values
- Specific Media
- More
- Temperature
- Thermal Insulation
- Heat Flux
- Symmetry
- Periodic Condition
- Lumped System Contr
- Phase Change Interfa
- Phase Change Interfa
- Flow Conditions
- Heat Sources **2**
- Thin Structures
- Pairs
- More
- Edges
- Points
- Global
- Show More Options...
- Node Group
- Group by Space Dime



**Settings**

Surface-to-Ambient Radiation

Label: Surface-to-Ambient Radiation 1

**Boundary Selection**

Selection: Exterior Walls **4**

|    |
|----|
| 70 |
| 71 |
| 72 |
| 73 |
| 75 |
| 76 |

Override and Contribution

Equation

**Model Input**

Radiation Settings

**Surface-to-Ambient Radiation**

Surface emissivity:

$\epsilon$  User defined **5**

0.9 1

Ambient temperature:

$T_{amb}$  User defined

293.15[K] K

**Graphics**

4

**Model Builder**

- heat\_sink.mph (root)
  - Global Definitions
    - Parameters 1 {default}
    - Default Model Inputs {cminpt}
    - Materials
  - Component 1 (comp1) {comp1}
    - Definitions
    - Geometry 1 {geom1}
    - Materials
    - Laminar Flow (spf) {spf}
    - Heat Transfer in Fluids (ht) {ht}
    - Multiphysics
    - Mesh 1 {mesh1}** 1
  - Study 1 {std1}
    - Step 1: Stationary {stat}
    - Solver Configurations
    - Job Configurations
    - Results

**Settings**

Mesh

Build All

Label: Mesh 1

Sequence Type

Physics-controlled mesh

Physics-Controlled Mesh

Element size:

Coarser 2

| Contributor                          | Use                                 |
|--------------------------------------|-------------------------------------|
| Laminar Flow (spf) {spf}             | <input checked="" type="checkbox"/> |
| Heat Transfer in Fluids (ht) {ht}    | <input checked="" type="checkbox"/> |
| Nonisothermal Flow 1 (nitf1) {nitf1} | <input checked="" type="checkbox"/> |



**Model Builder**

- heat\_sink.mph (root)
  - Global Definitions
    - Parameters 1 {default}
    - Default Model Inputs {cminpt}
    - Materials
  - Component 1 (comp1) {comp1}
    - Definitions
    - Geometry 1 {geom1}
    - Materials
    - Laminar Flow (spf) {spf}
    - Heat Transfer in Fluids (ht) {ht}
    - Multiphysics
    - Mesh 1 {mesh1}
  - Study 1 {std1} 3
    - Step 1: Stationary {stat}**
    - Solver Configurations
    - Job Configurations
    - Results

**Settings**

Stationary

Compute 4

Label: Stationary

Study Settings

Results While Solving

Physics and Variables Selection

☐ Modify model configuration for study step

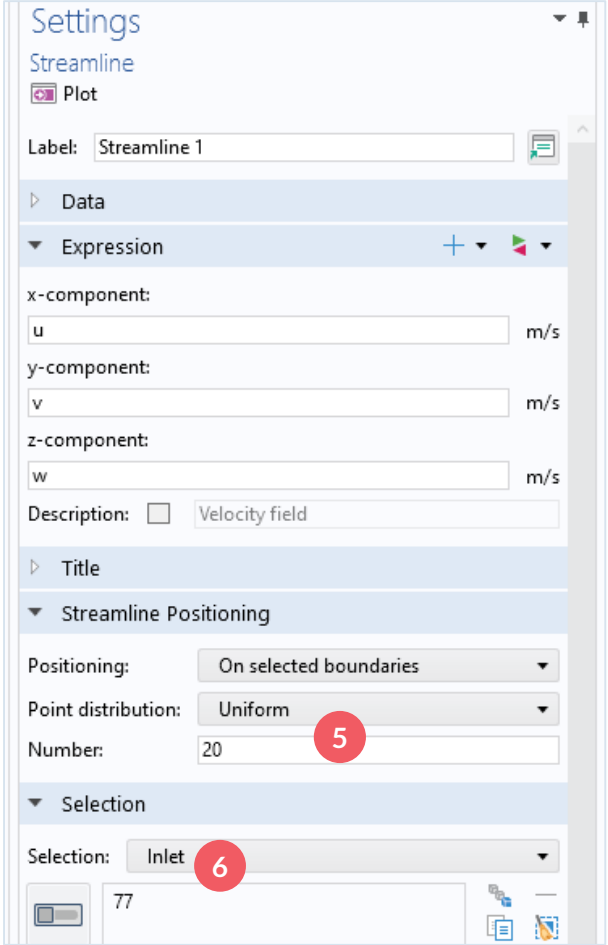
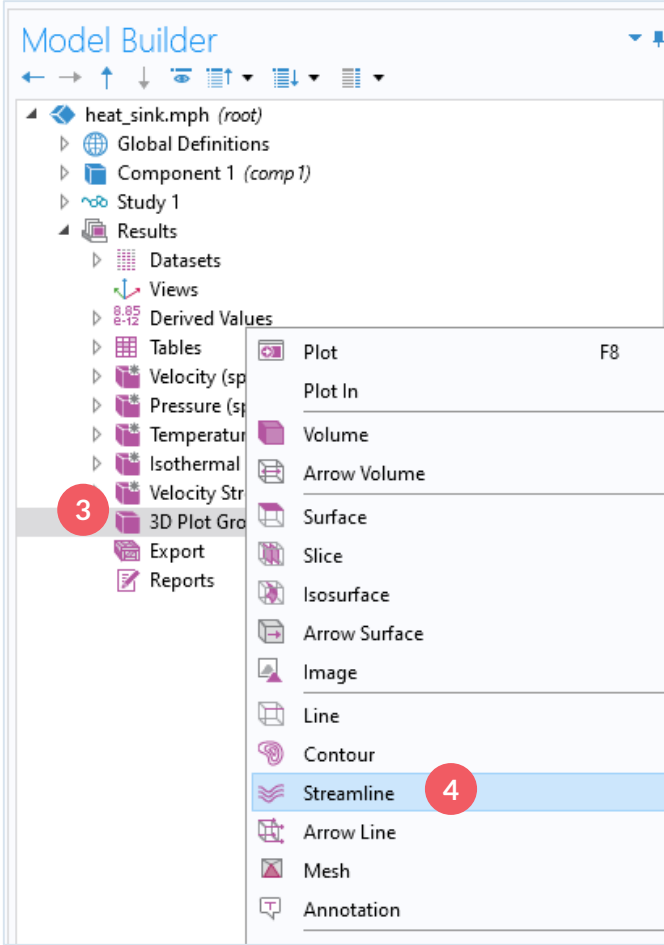
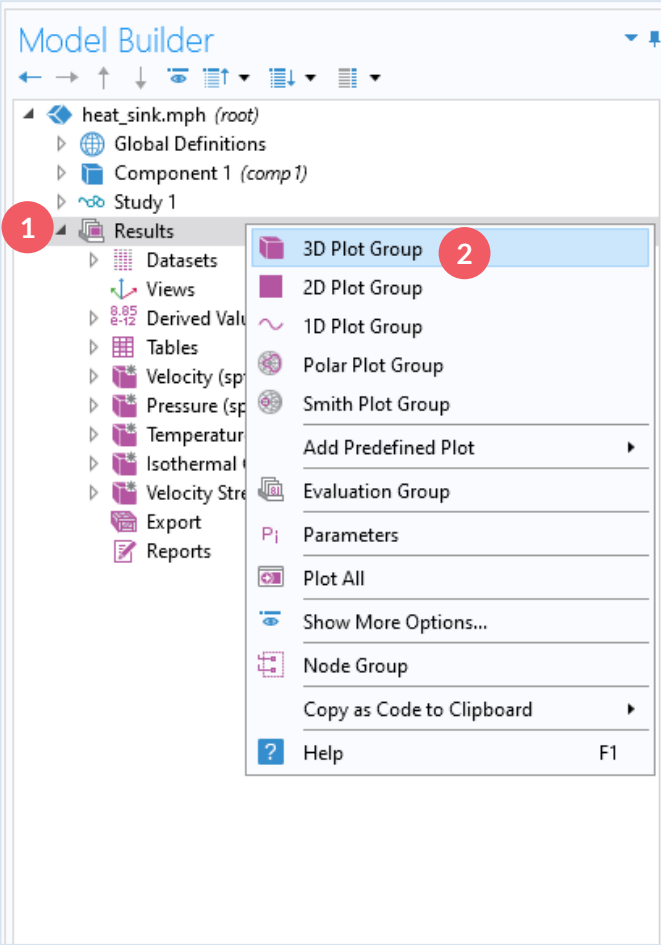
|    | Physics interface                    | Solve for                           | Equation |
|----|--------------------------------------|-------------------------------------|----------|
| ▶▶ | Laminar Flow (spf) {spf}             | <input checked="" type="checkbox"/> | Auto     |
| ▶▶ | Heat Transfer in Fluids (ht...) {ht} | <input checked="" type="checkbox"/> | Auto     |

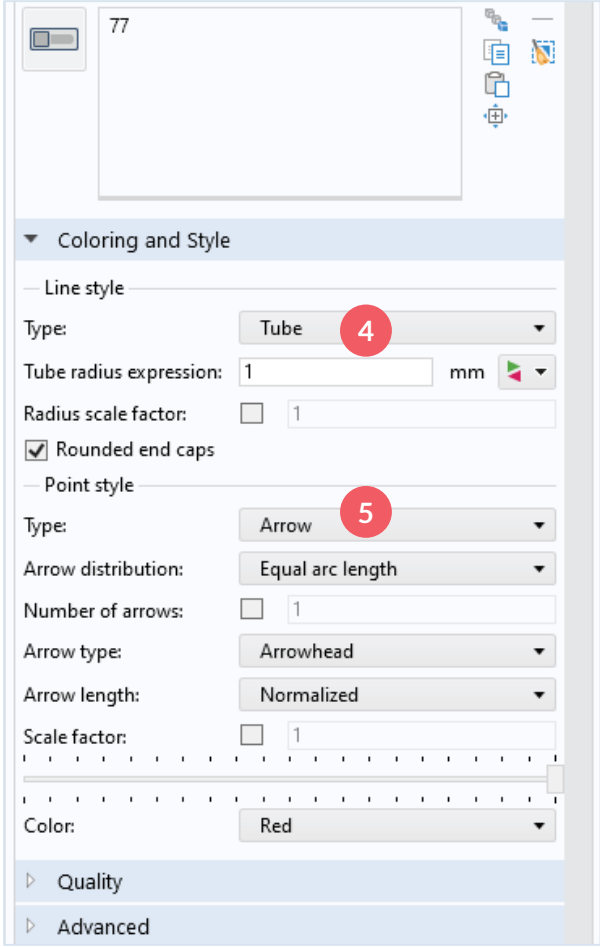
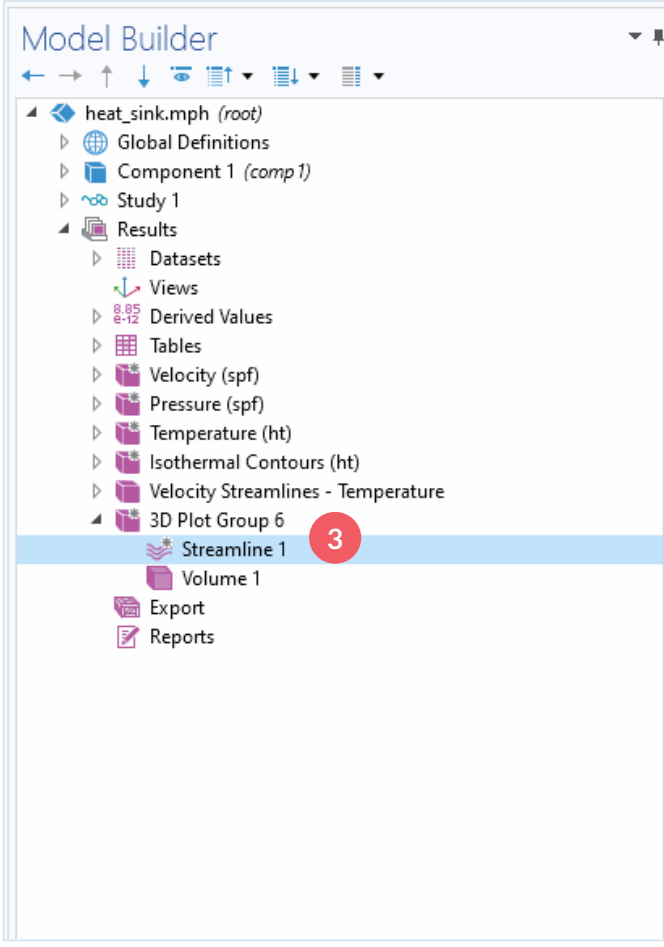
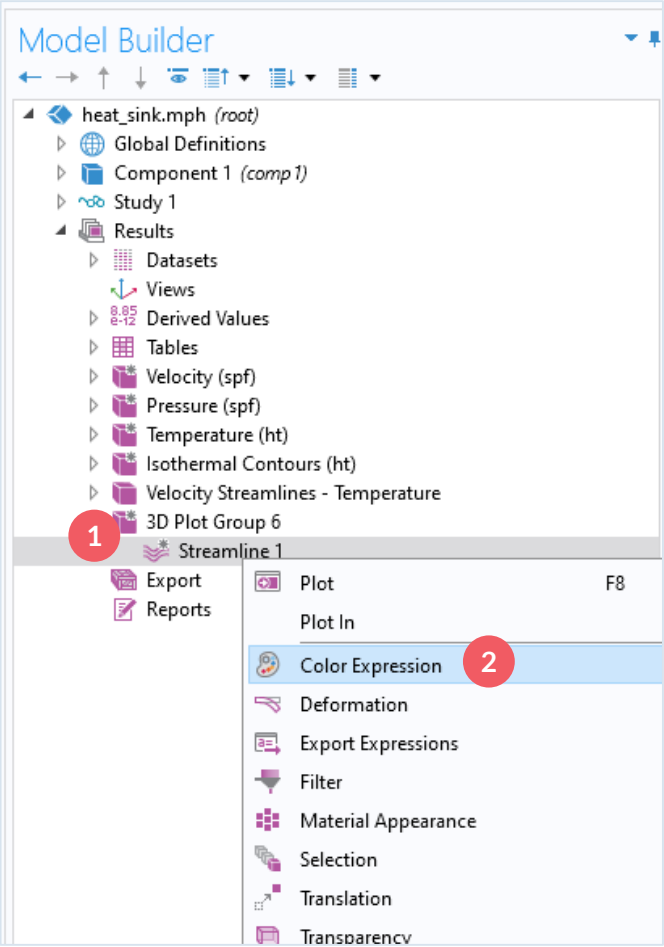
Values of Dependent Variables

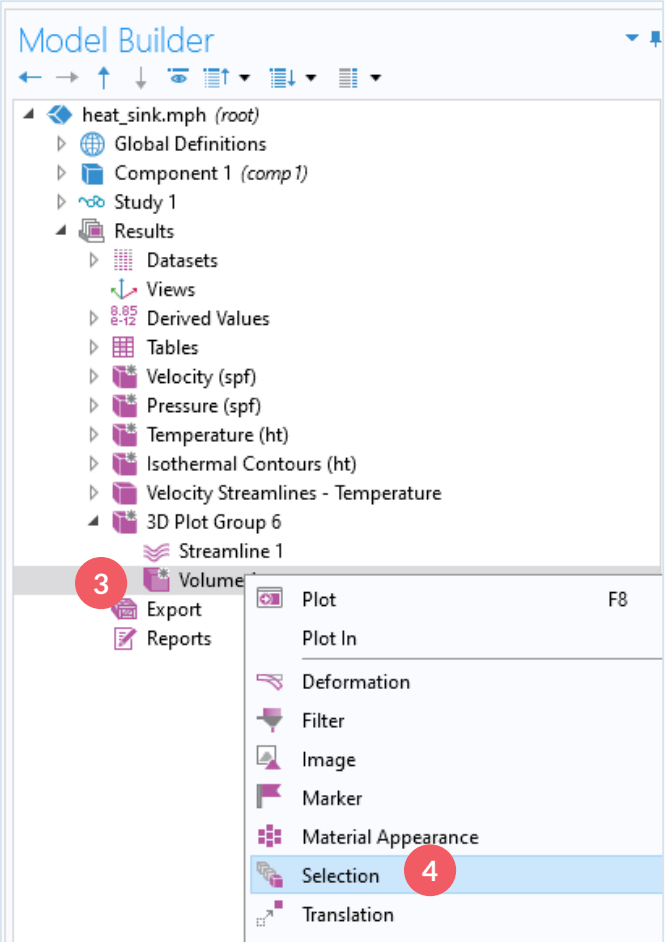
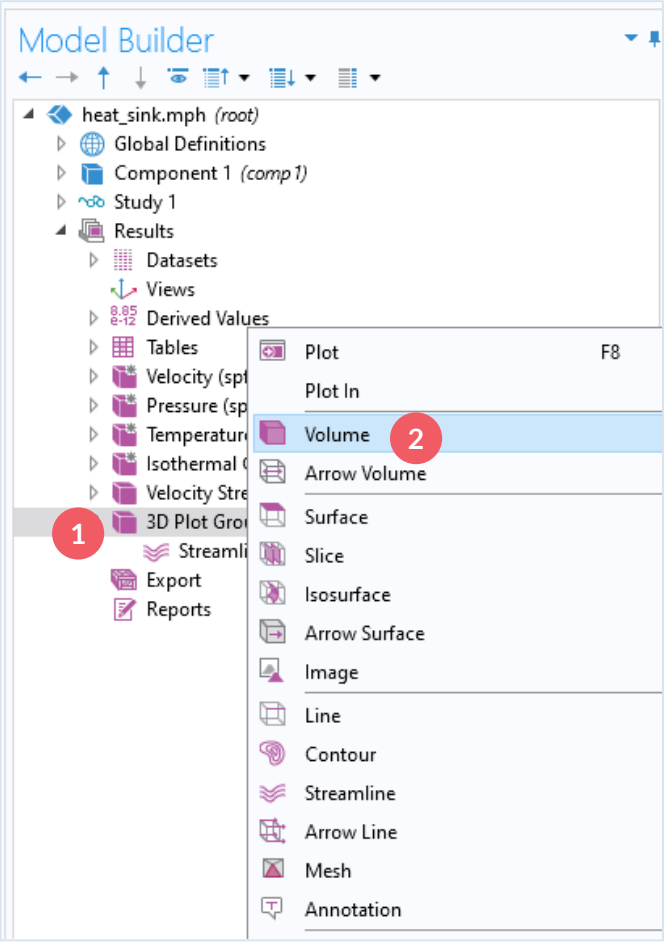
Mesh Selection

Adaptation and Error Estimates

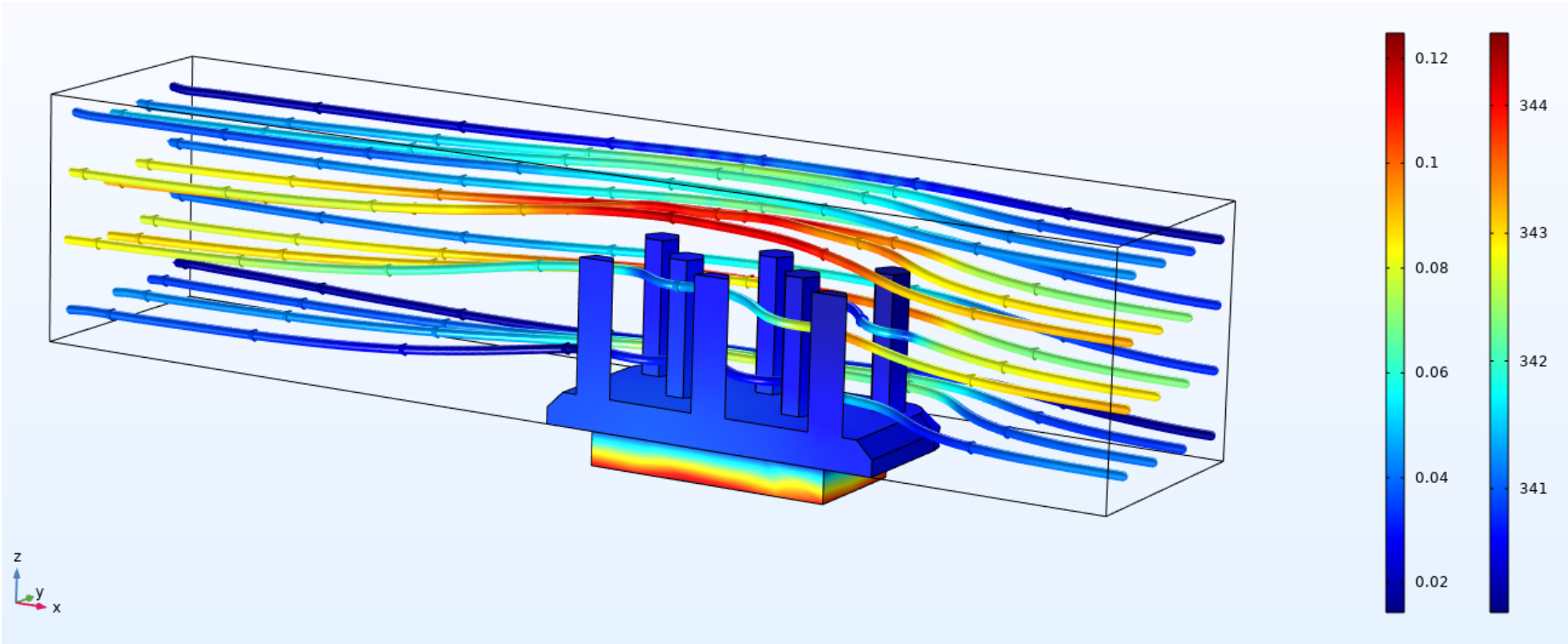
Study Extensions





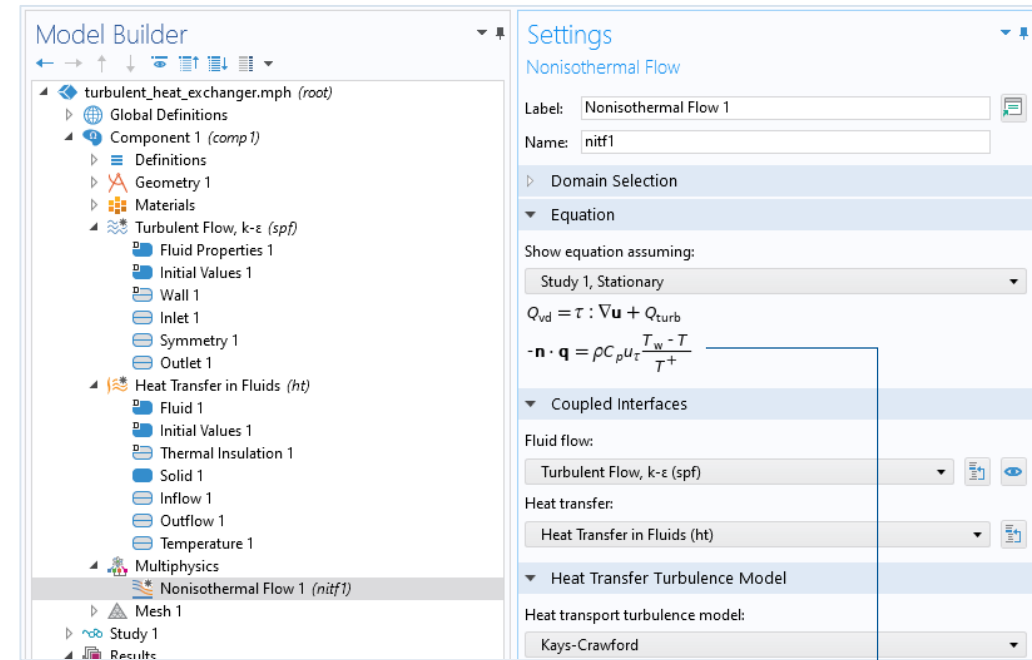


Plot variable "T" in domains 2 and 3

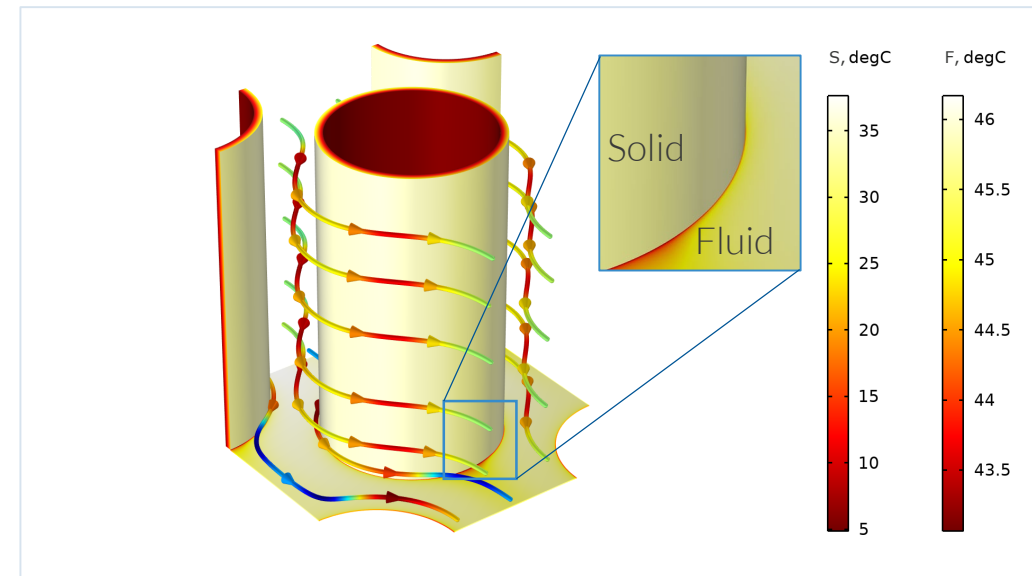


# Conjugate Heat Transfer with Turbulent Flow

- 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 ( $T_w - T$ ).



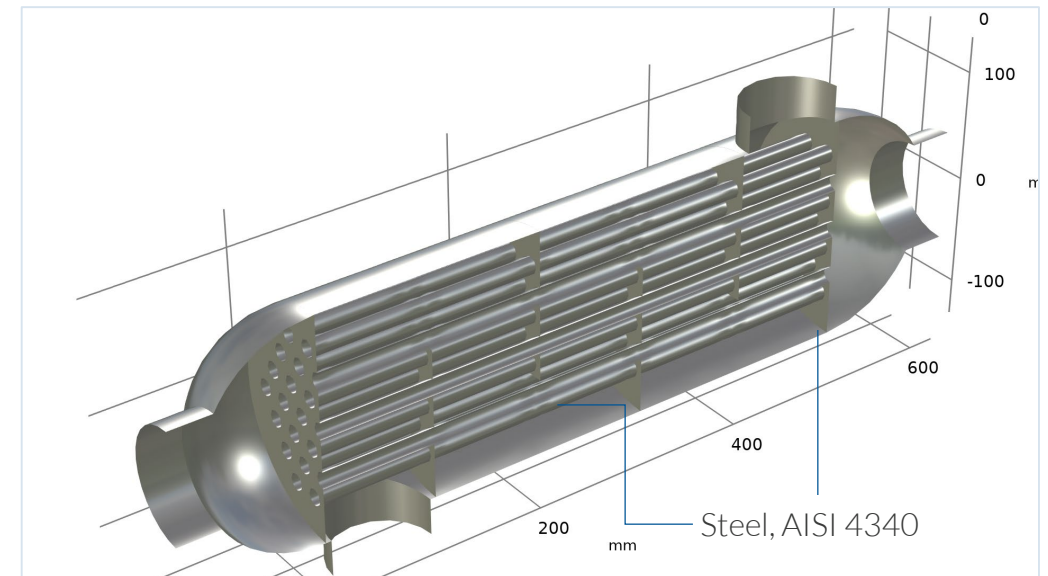
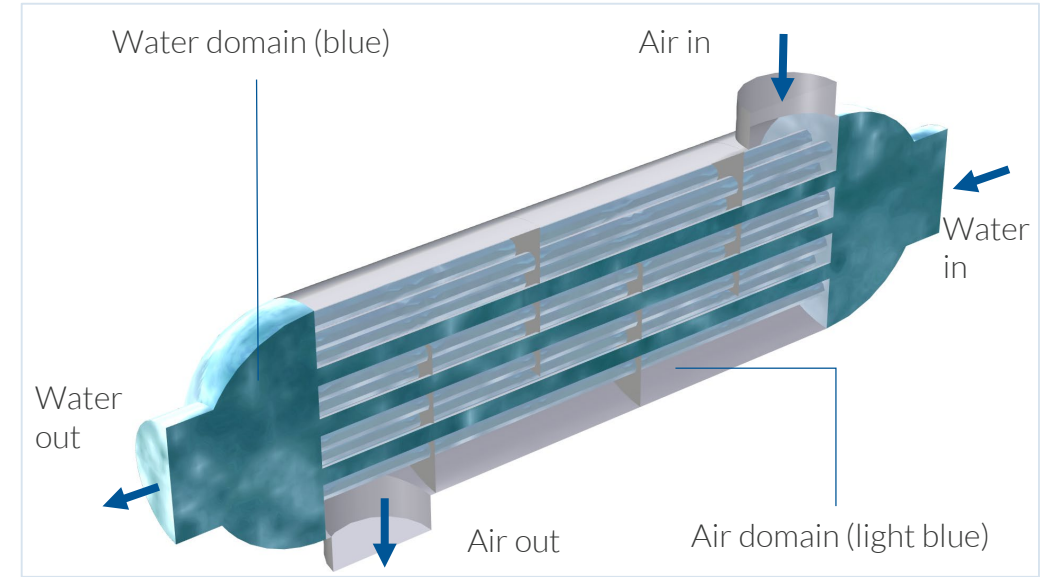
# Demo

Shell & Tube Heat Exchanger



## Problem Definition

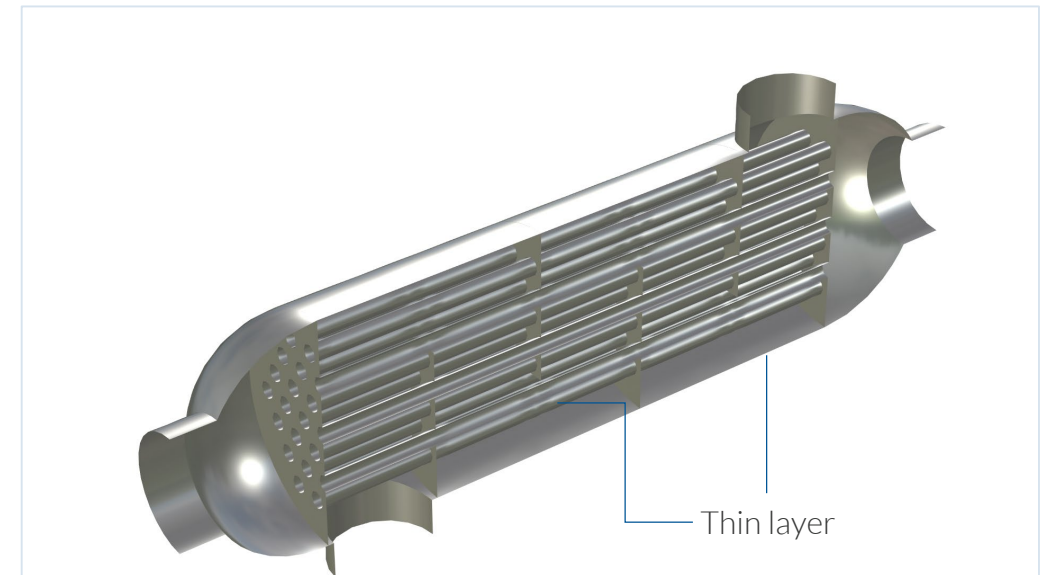
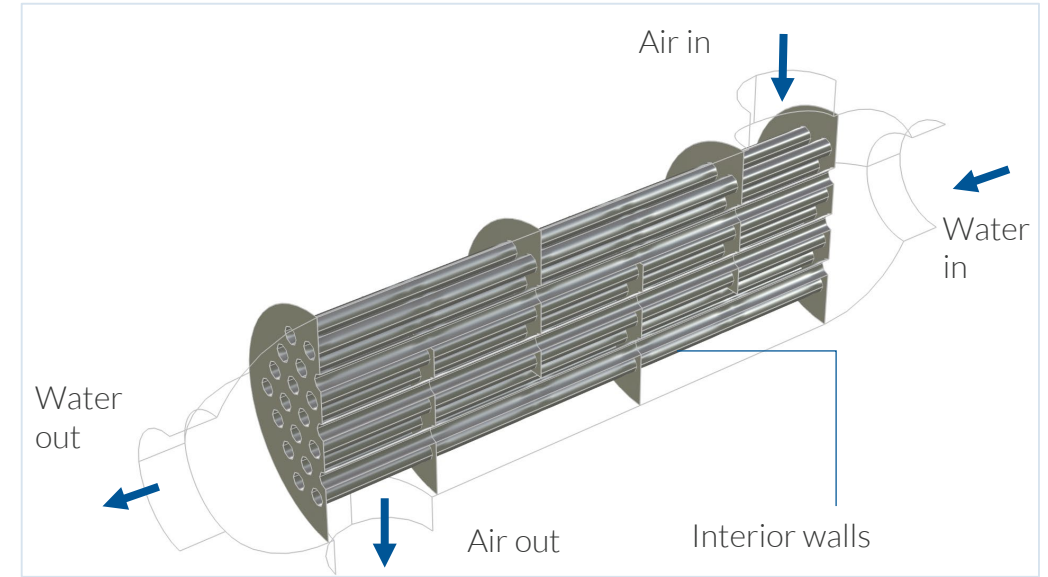
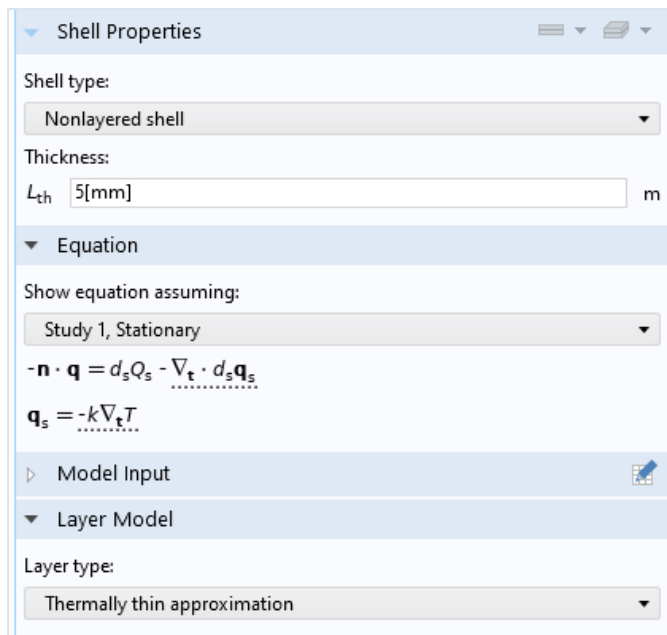
- Conjugate heat transfer with turbulent flow where the solid domain is represented by shells
- Separated water and air domains
- Shells
  - Interior walls for flow separate the water and air domains
  - Thin layer for heat transfer defined on all shells
- Wall functions and heat transfer coefficients 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:

▼ Expression

Expression:  
ht.Tu

Unit:  
degC

☐ Description:  
Temperature

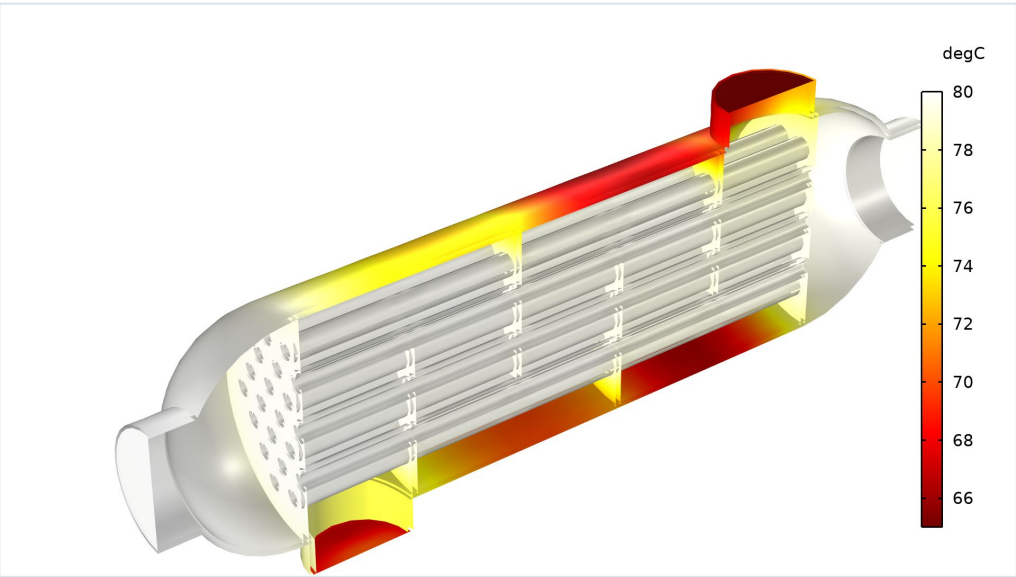
▼ Expression

Expression:  
ht.Td

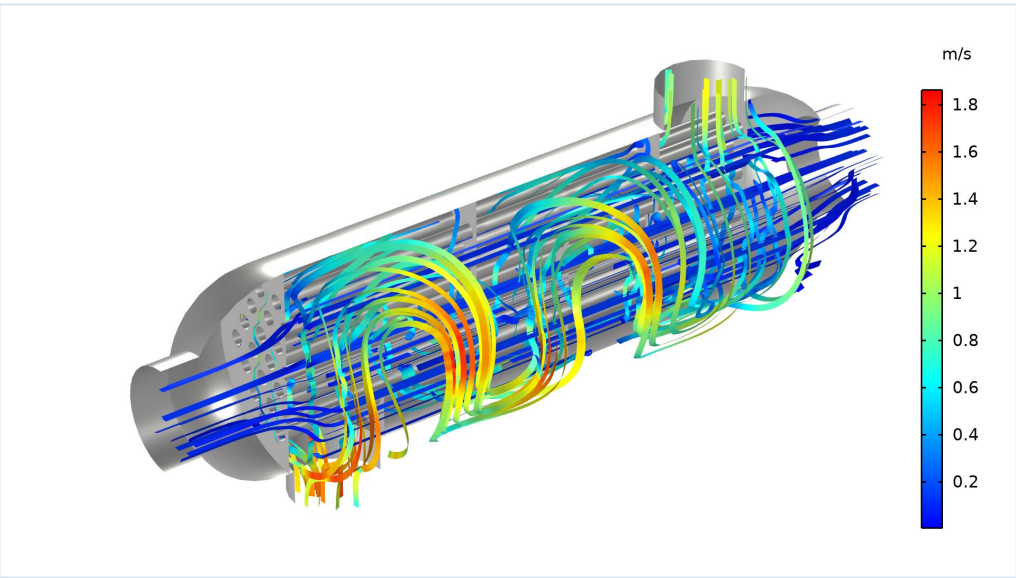
Unit:  
degC

☐ Description:  
Temperature

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.