RADIOFREQUENCY CARDIAC ABLATION

Modelling and simulation using COMSOL Multiphysics

OBJECTIVES

- Solving biomedical transport problems using COMSOL Multiphysics
- Simulating radiofrequency ablation for treating cardiac arrhythmias

WHAT IS ARYTHMIA

- Irregular beating of the heart
- Causes decreased blood flow and oxygen supply to the brain and body

RADIOFREQUENCY ABLATION(RFA)

- Ablation is a process of removing body tissues
- RFA -
  - Destroys tumors that cannot be removed surgically
  - Through controlled heating
  - Minimally invasive

PROBLEM FORMULATION

- A cylindrical electrode is introduced into the middle of the selected myocardial tissue.
- Tissue properties are homogenous.
- Joule heat generation by resistive heating.
- Tissue temperature must go more then 50°C.

GOVERNING EQUATIONS

- Penne's bioheat transfer equation:

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (-k \cdot \nabla T) = \rho_b C_b v_b (T_b - T) + Q$$

Here, $\rho_b C_b v_b (T_b - T)$ is the blood perfusion term.

Where,

ρ_b = Blood Density

C_b = Specific Heat capacity of Blood

v_b = Blood perfusion Rate

T_b = Arterial Blood Temperature

T = Local tissue temperature

- $Q = \sigma |\nabla V|^2$ is from the electrode

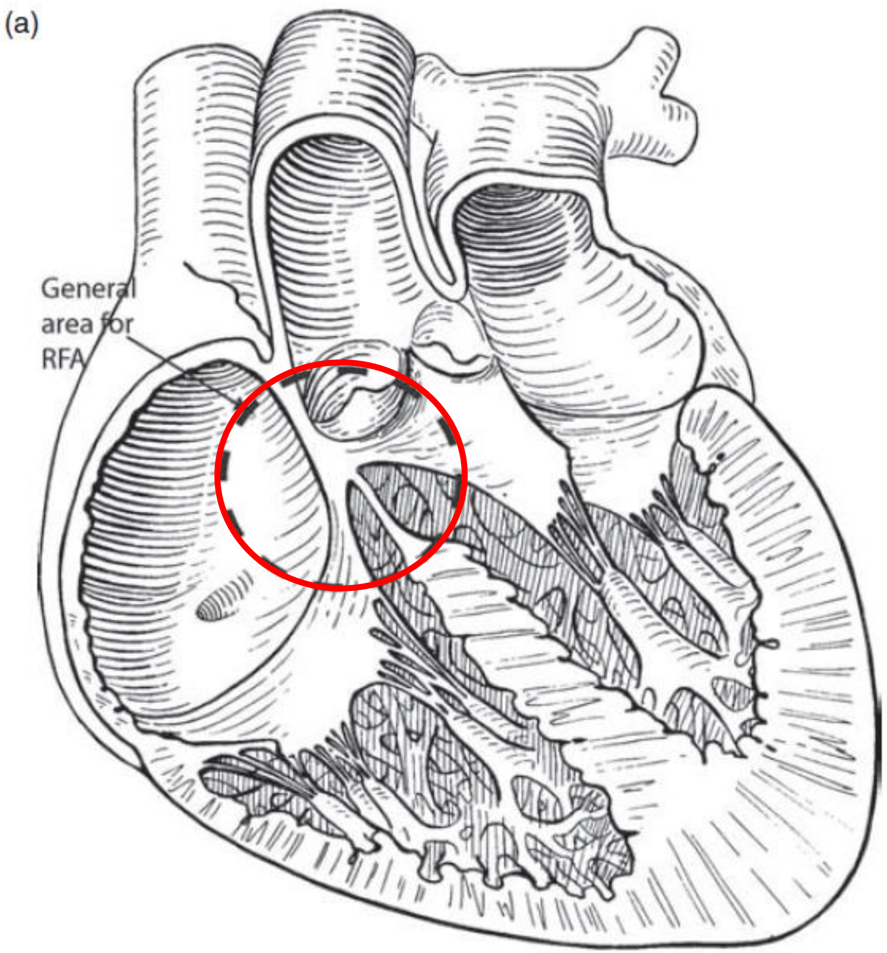
Where,

σ = Electrical conductivity

V = Electrical potential

GEOMETRY

A



B

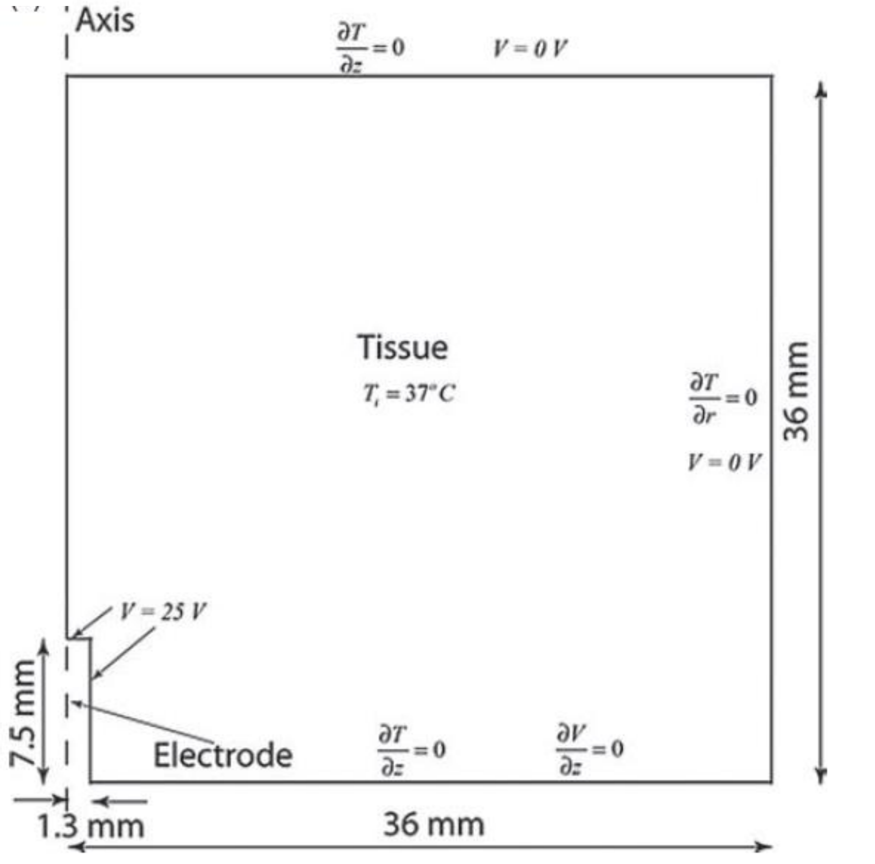
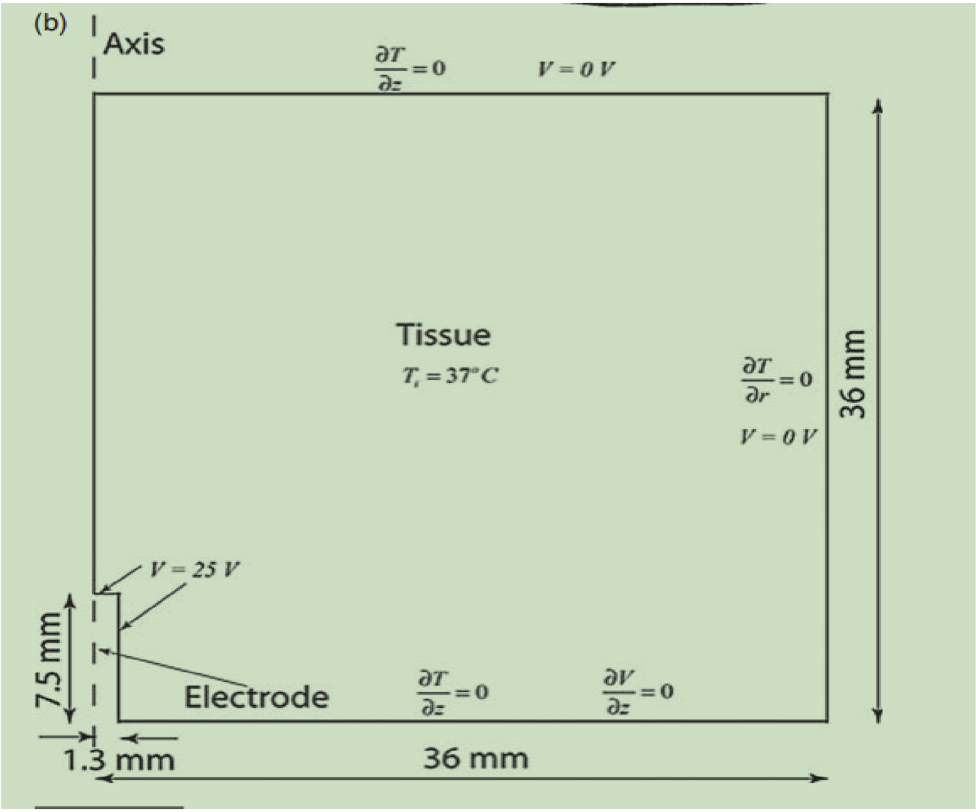


Figure 6.14

BOUNDARY CONDITIONS

- Axisymmetric
- Left surface is the axis
- Initial Temperature- 37°C
- Electrode is excluded in the geometry
- Electric potential to the surface of electrode is implemented as a boundary condition
- Heat fluxes at all surface are zero



INPUT PARAMETERS

Parameter	Value
Thermal conductivity of the tissue, k	$0.4925+0.001\,195T$ $Wm^{-1}K^{-1}$
Specific heat of the tissue, C_p	3200 $Jkg^{-1}K^{-1}$
Density of the tissue, ρ	1200 kgm^{-3}
Duration of heating, t	60 s
Blood perfusion coefficient, $\rho_b C_{p,b} \dot{V}_b^V$	2000 $Wm^{-3}K^{-1}$
Electrical conductivity, σ	0.222 $S\,m^{-1}$
Arterial blood temperature, T_a	37 °C
Initial tissue temperature, T_i	37 °C
Electric potential at the electrode surface, V	25 V

DEFINITION OF EXPRESSION

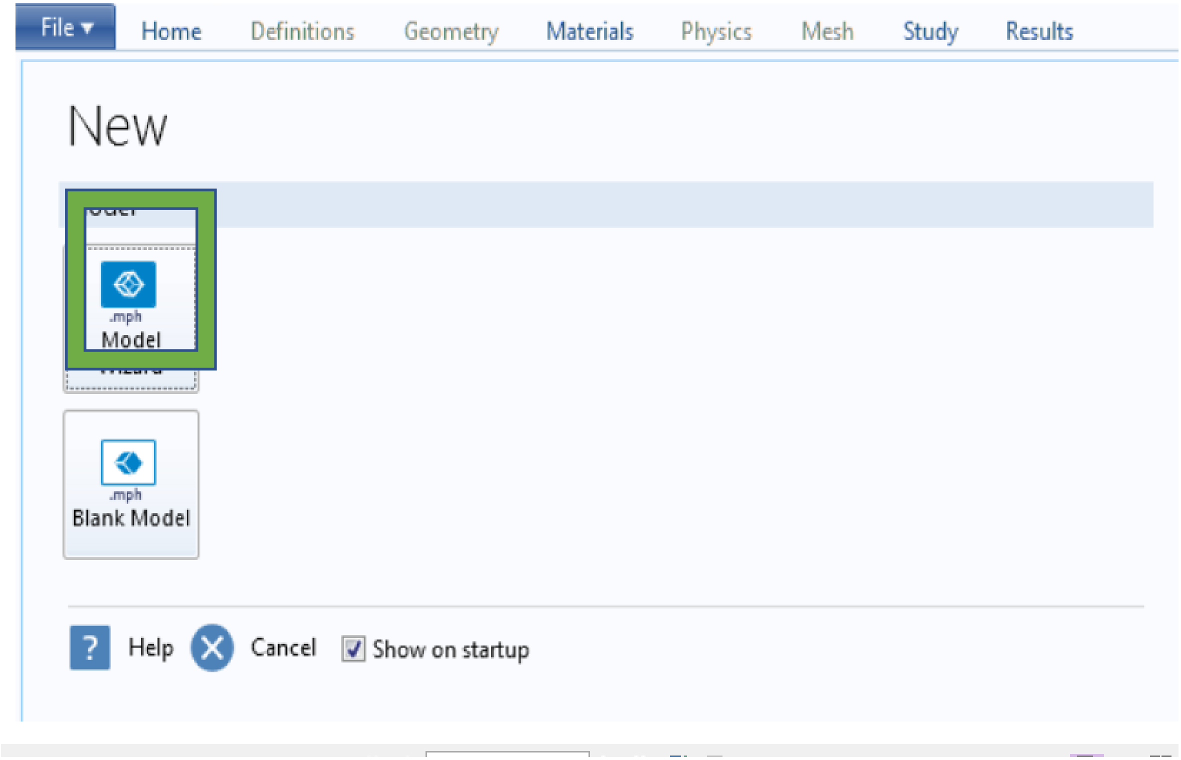
- Two most significant expression:
- k – thermal conductivity of tissue: 0.4225+0.001195*T
- Q_blood – Blood perfusion heat
- Q_dc – heat source term due to radiofrequency (not used in Comsol Multiphysics v5.4/v5.5)

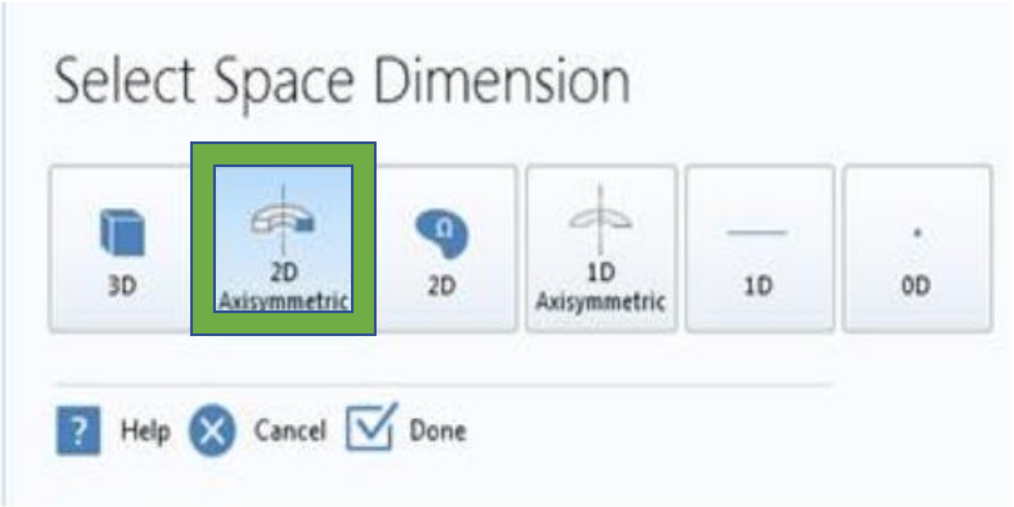
- Operational time: 60s

SIMULATION STEPS

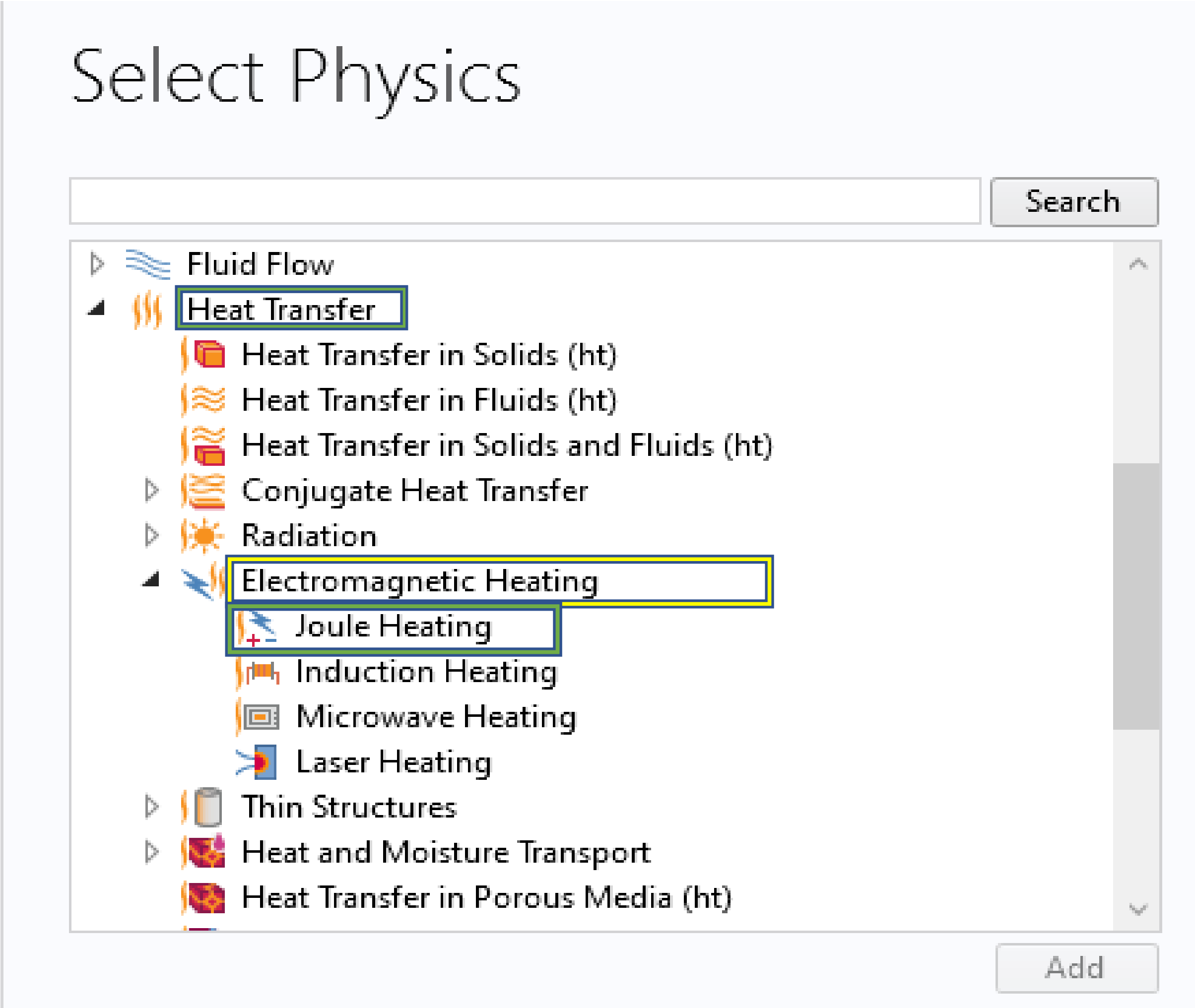
- Problem type specification:

Model wizard → space dimension → 2D Axisymmetric

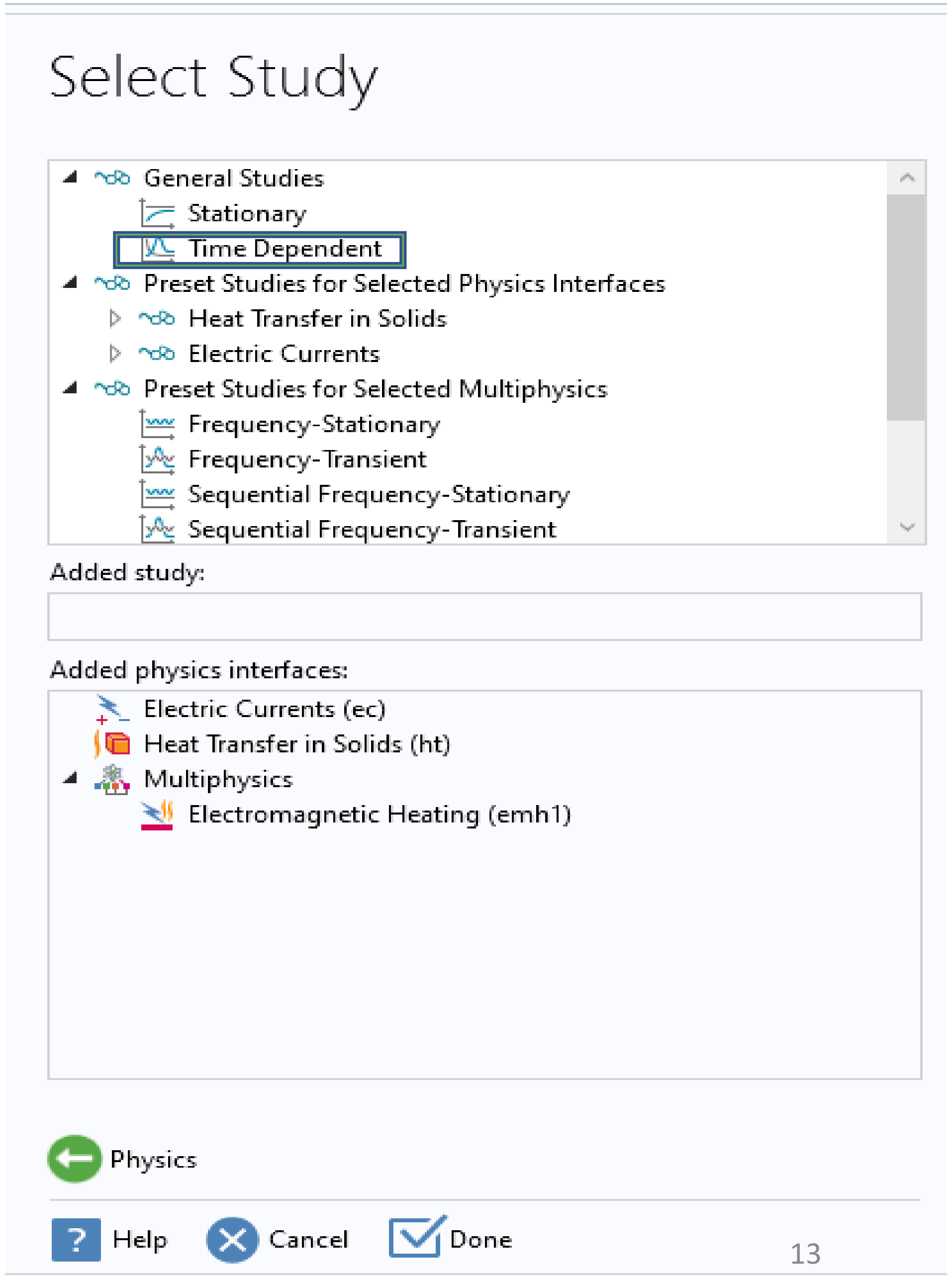




- Under **Select Physics** → **Heat transfer** → **Electromagnetic** → **Joule- heating**



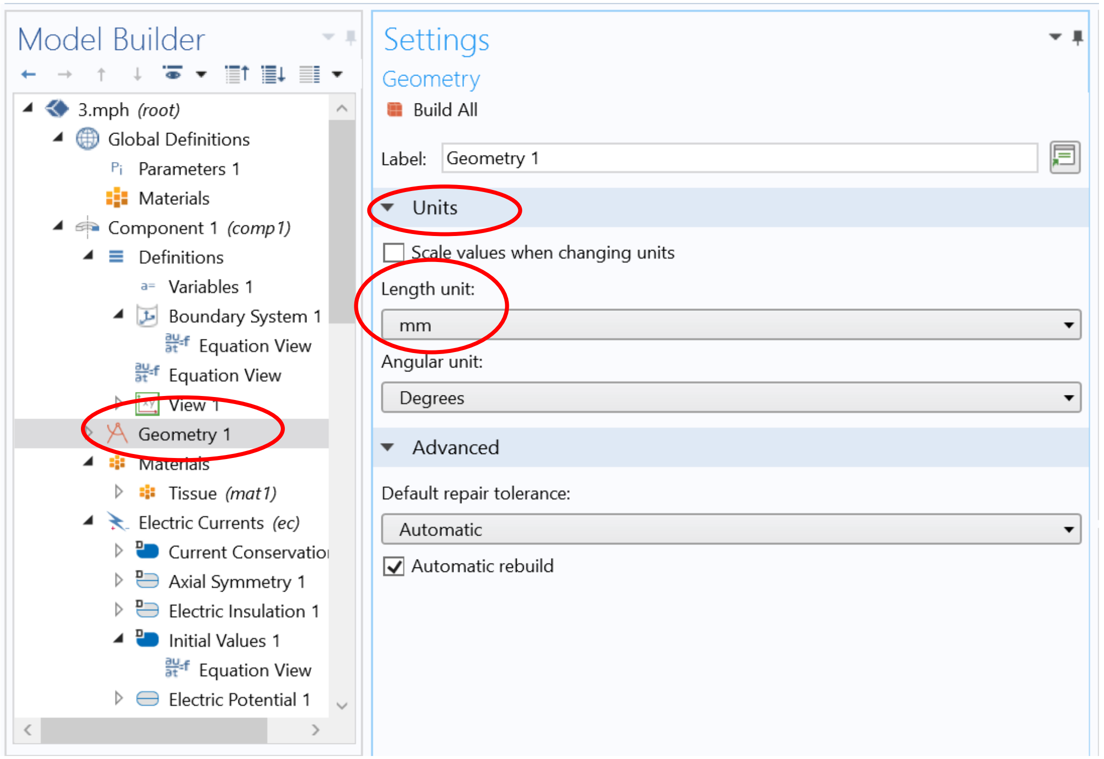
- Under **Select Study** → **time dependent**



GEOMETRY CREATION

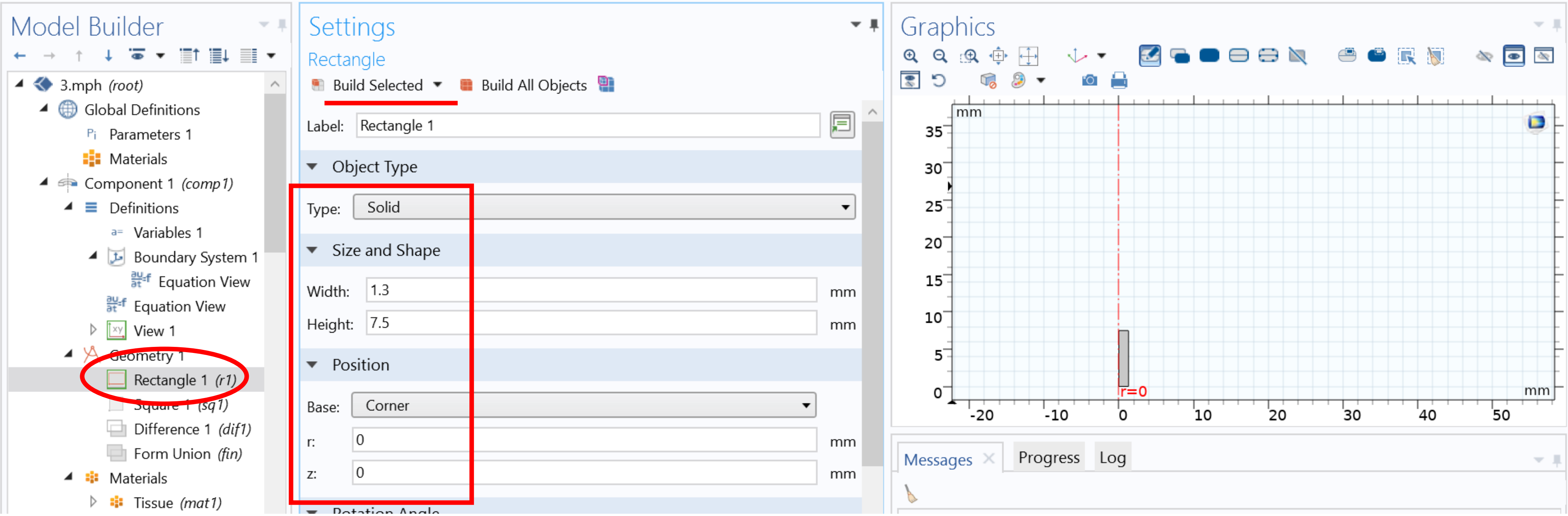
- Under **Model Builder:**

Geometry ⇨ Units



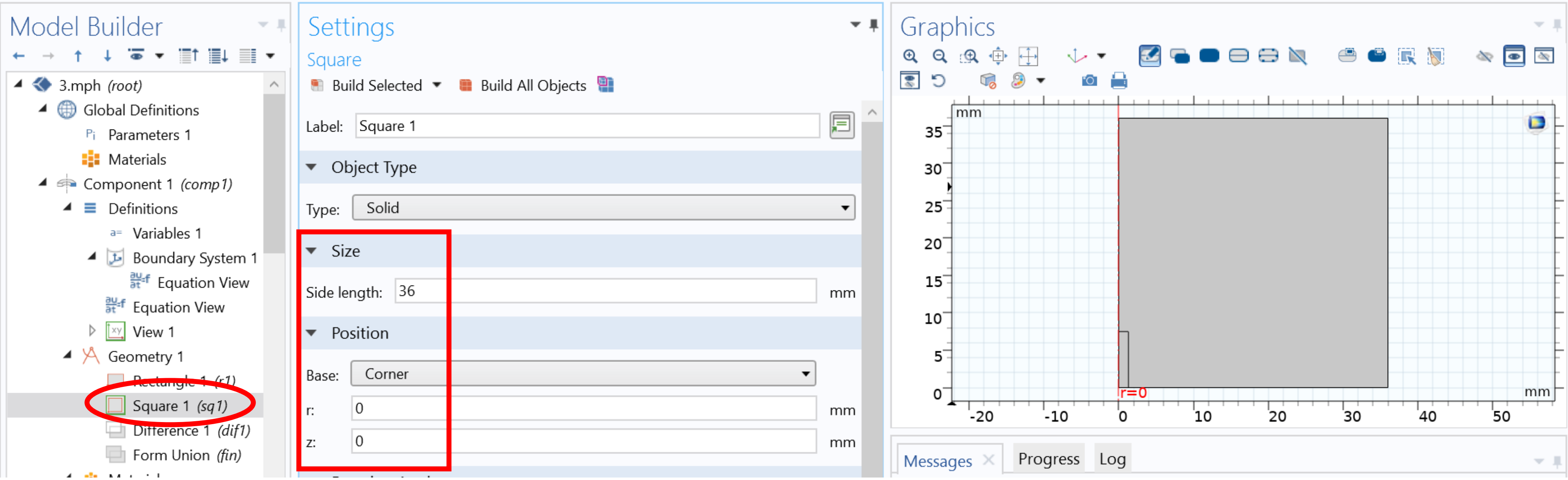
GEOMETRY CREATION

- **Geometry** → **"Rectangle"**



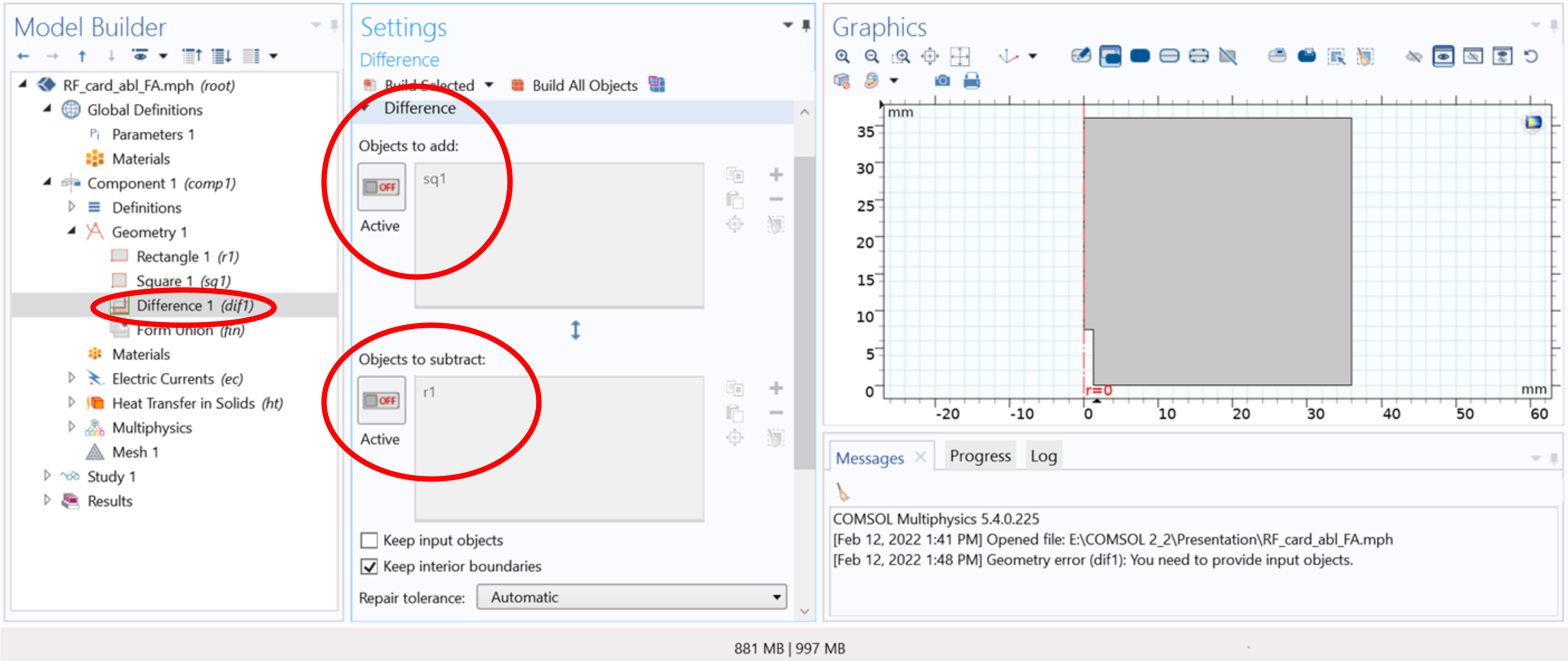
GEOMETRY CREATION

- **Geometry** → “Square”



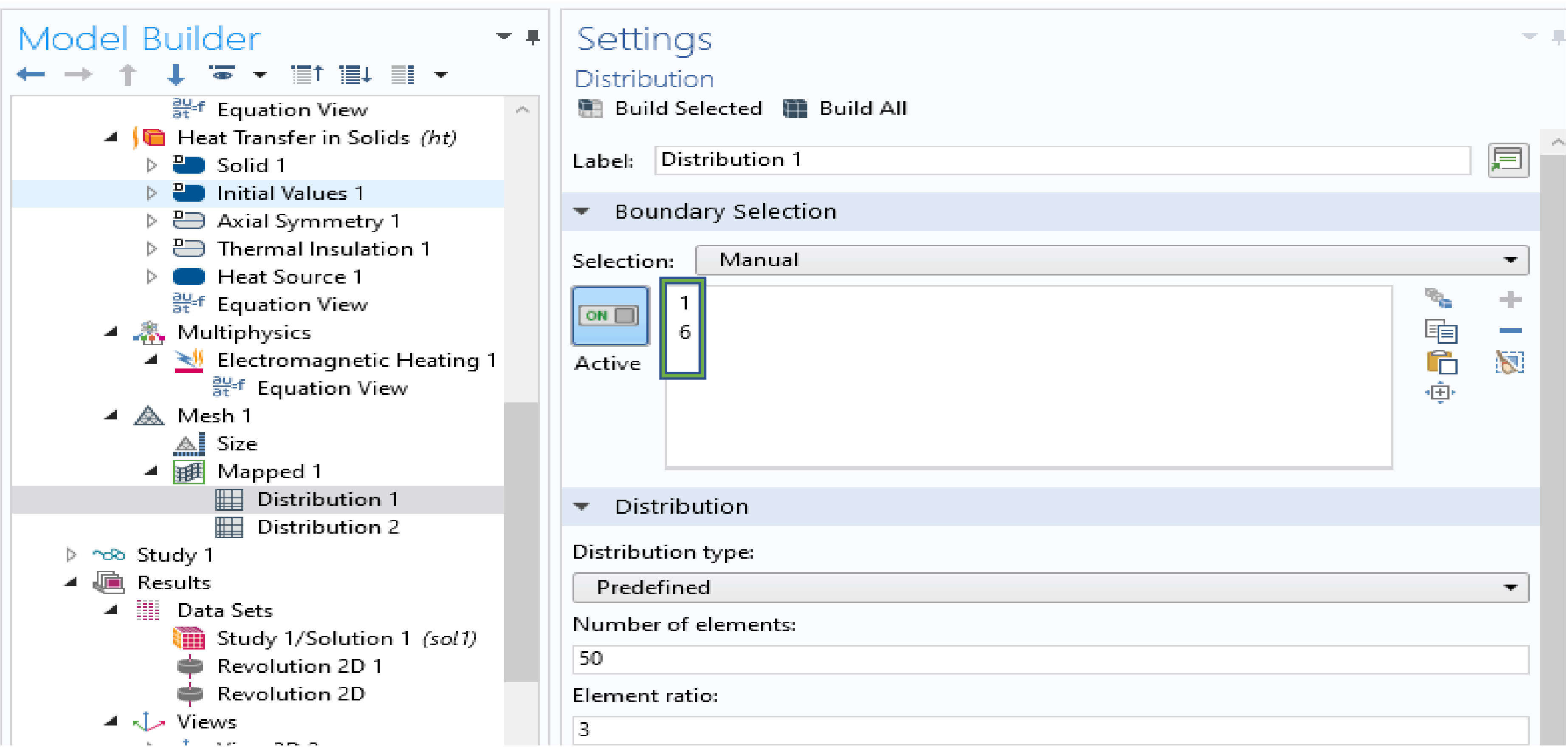
GEOMETRY CREATION

- **Geometry** → Booleans and Partitions → Difference

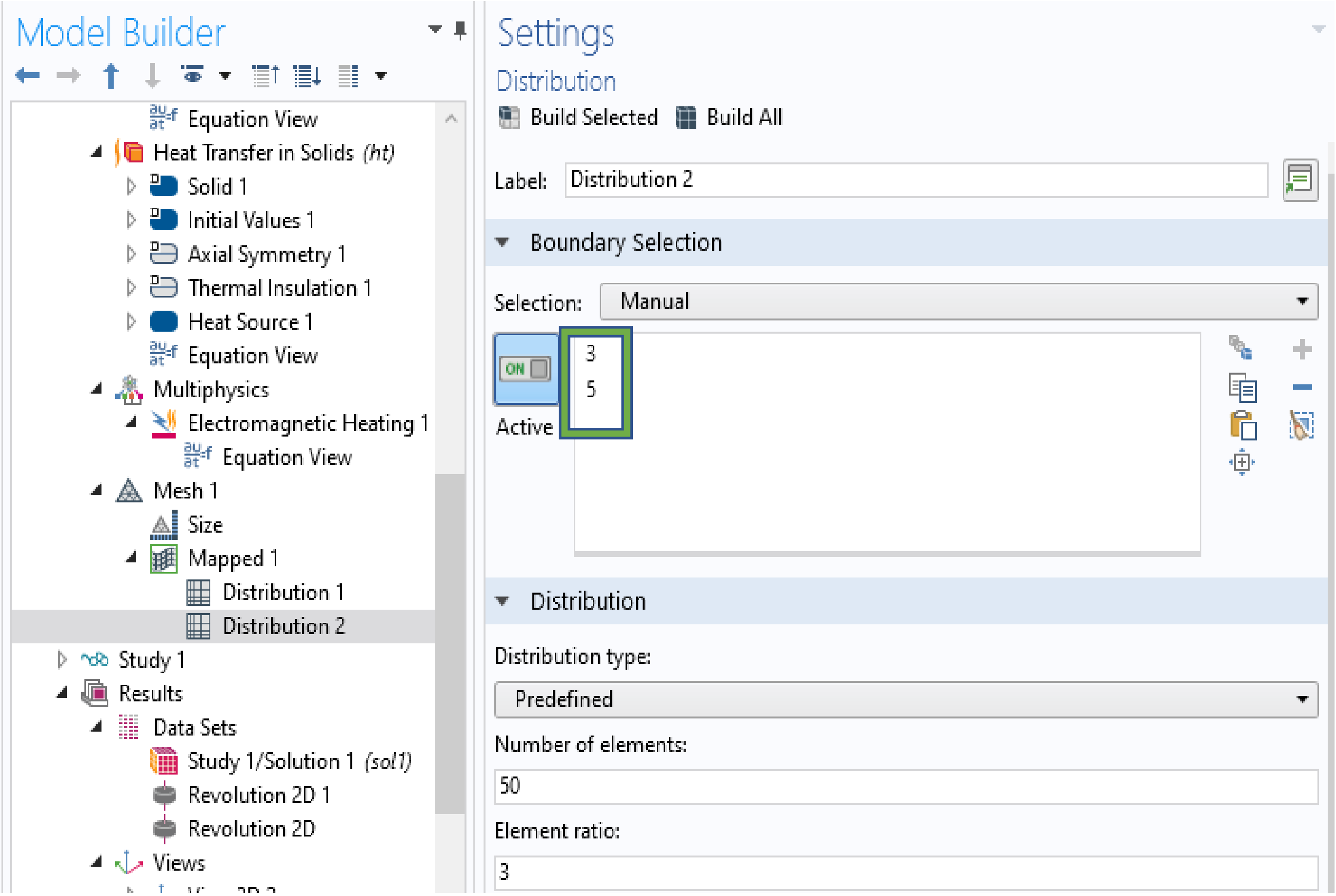


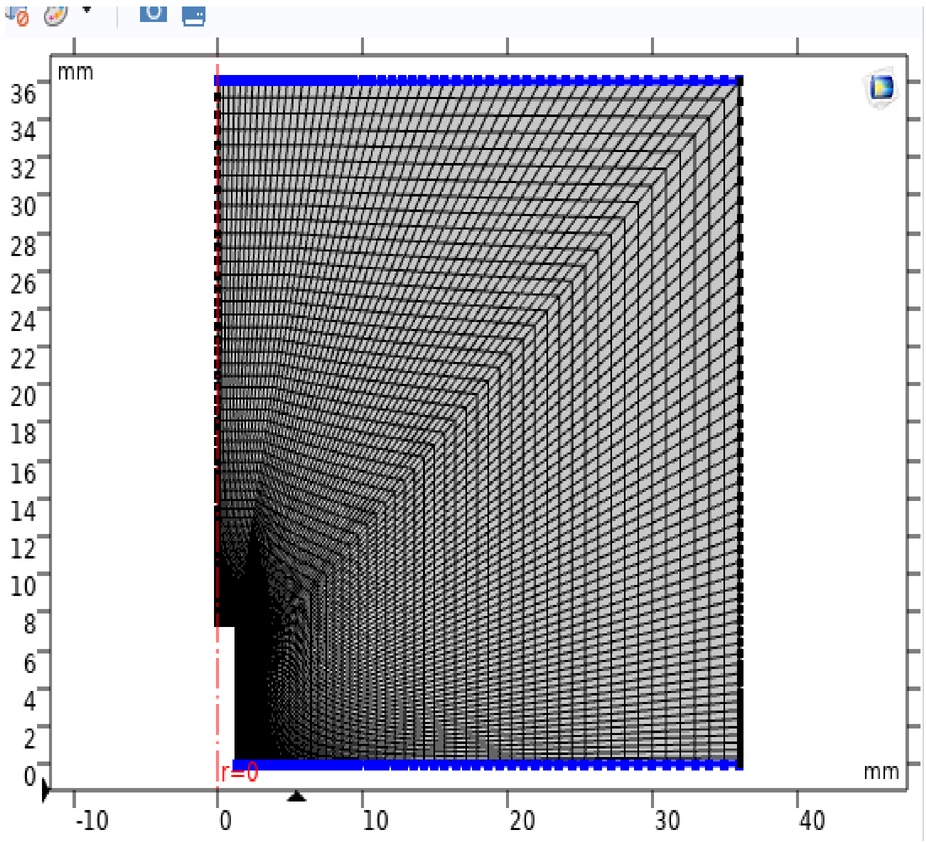
MESHING

- **Mesh → Mapped → Distribution**



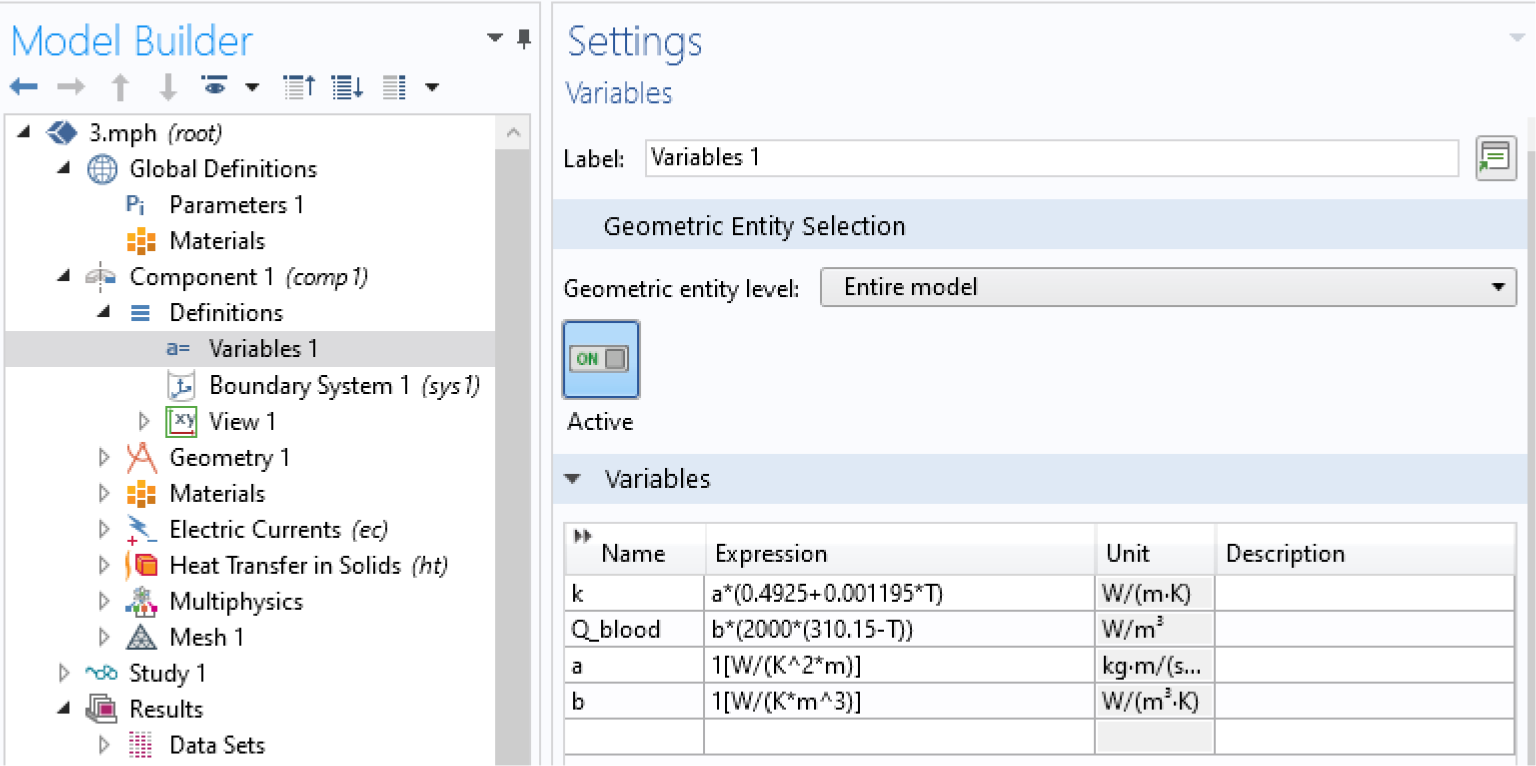
MESHING


Model Builder
Equation View
Heat Transfer in Solids (ht)
Solid 1
Initial Values 1
Axial Symmetry 1
Thermal Insulation 1
Heat Source 1
Equation View
Multiphysics
Electromagnetic Heating 1
Equation View
Mesh 1
Size
Mapped 1
Distribution 1
Distribution 2
Study 1
Results
Data Sets
Study 1/Solution 1 (sol1)
Revolution 2D 1
Revolution 2D
Views
Settings
Distribution
Build Selected
Build All
Label:
Distribution 2
Boundary Selection
Selection:
Manual
ON
Active
3
5
Distribution
Distribution type:
Predefined
Number of elements:
50
Element ratio:
3


mm
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
r=0
mm
-10
0
10
20
30
40

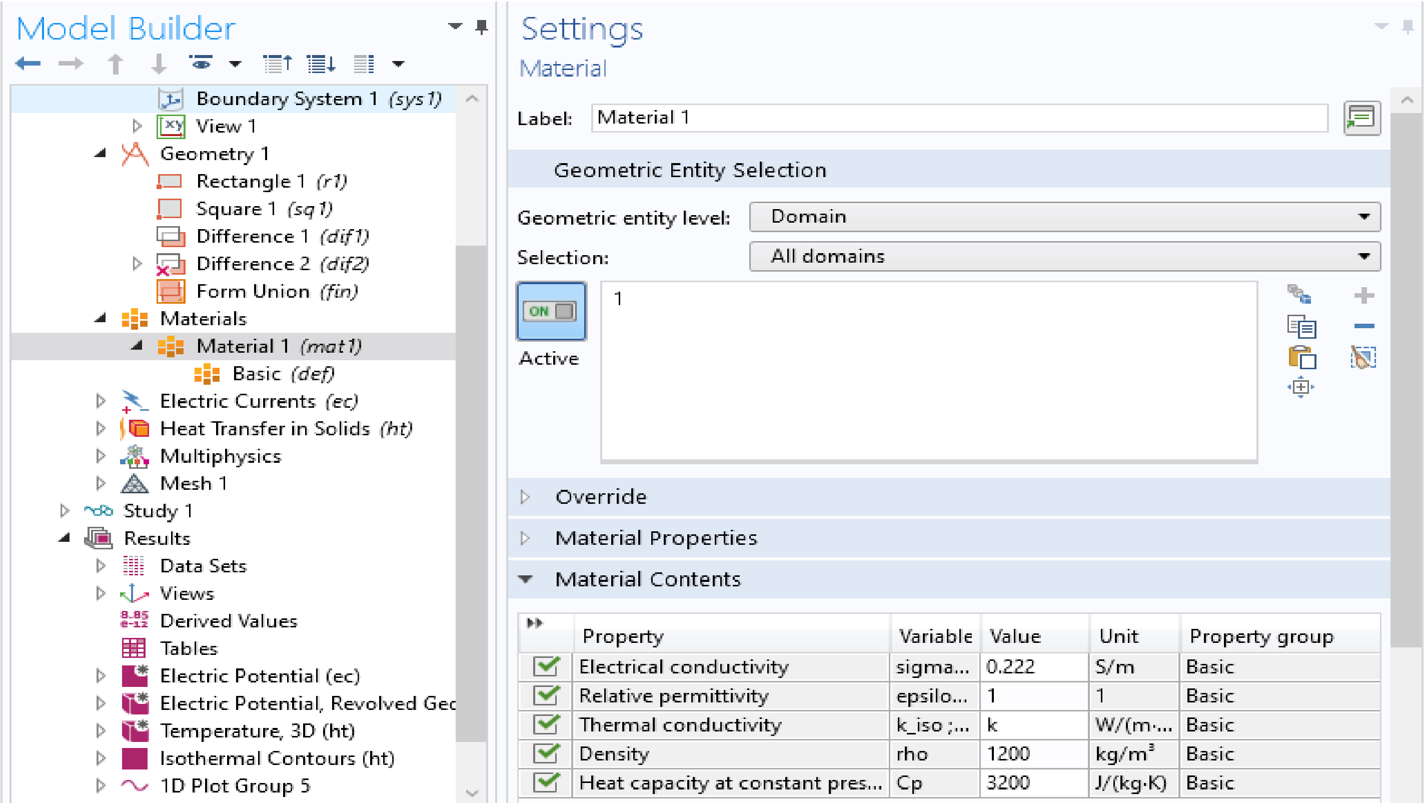
VARIABLE DECLARATION

- K and Q_blood are set as variables.



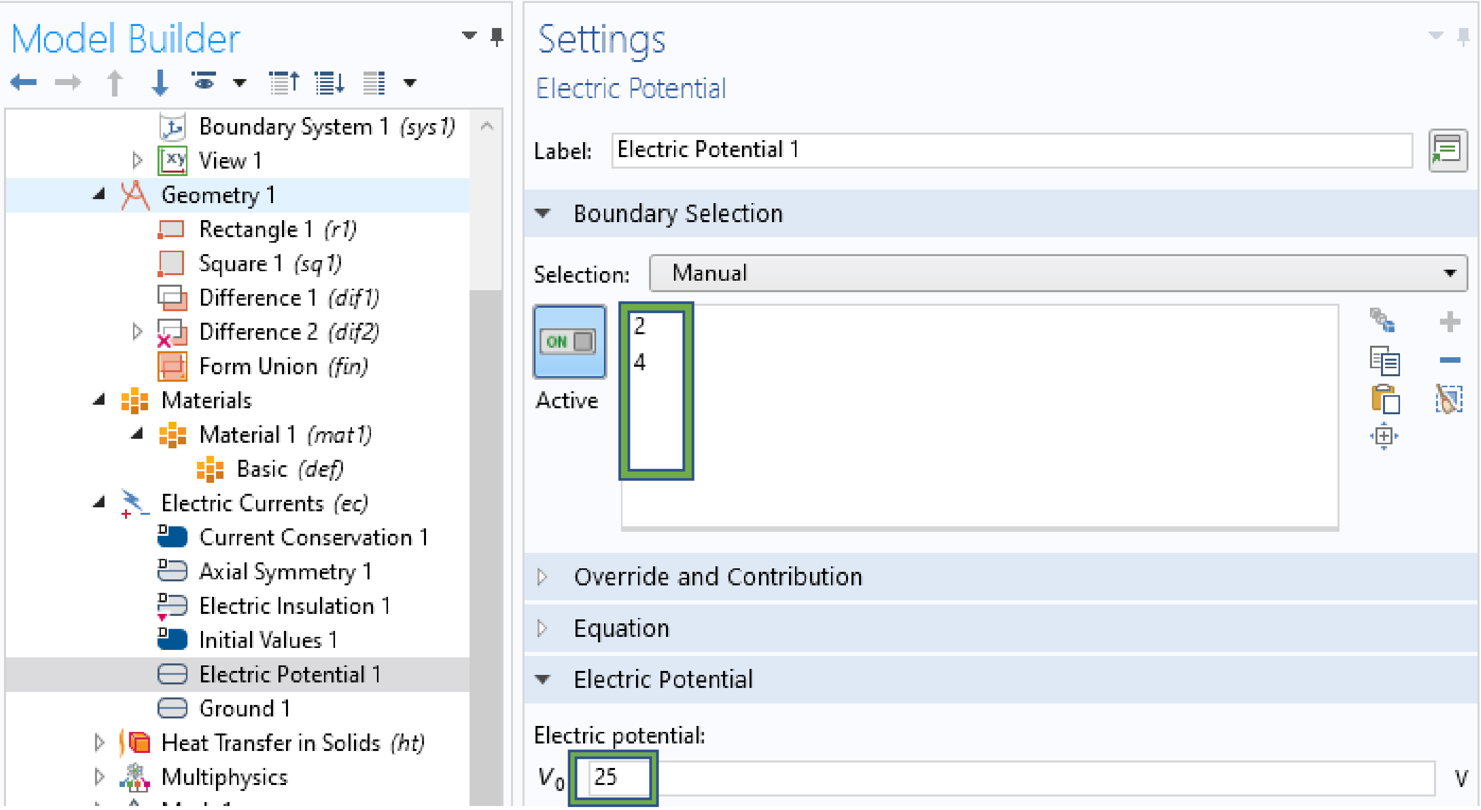
MATERIALS PROPERTY

Basic properties of tissue are defined under **Materials**

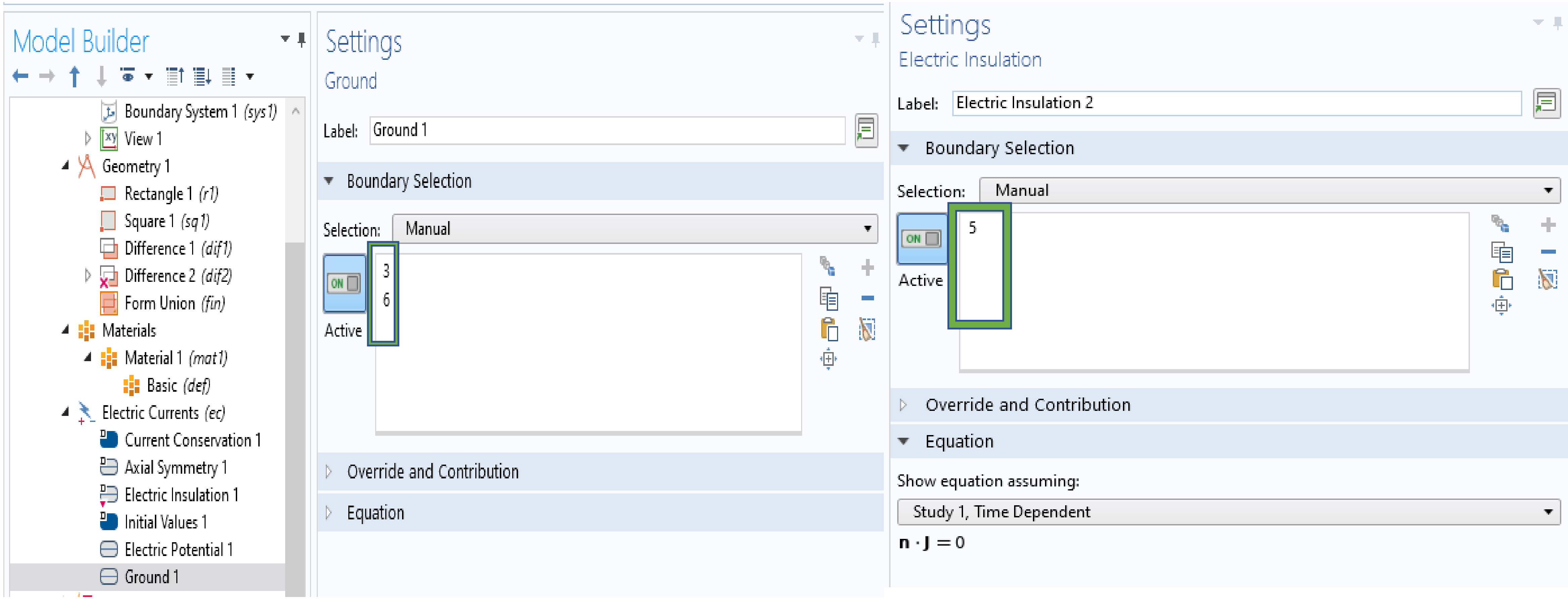


BOUNDARY CONDITIONS

- Boundary conditions are given of Electric Potential, Electric insulation and Ground under **Electric current**

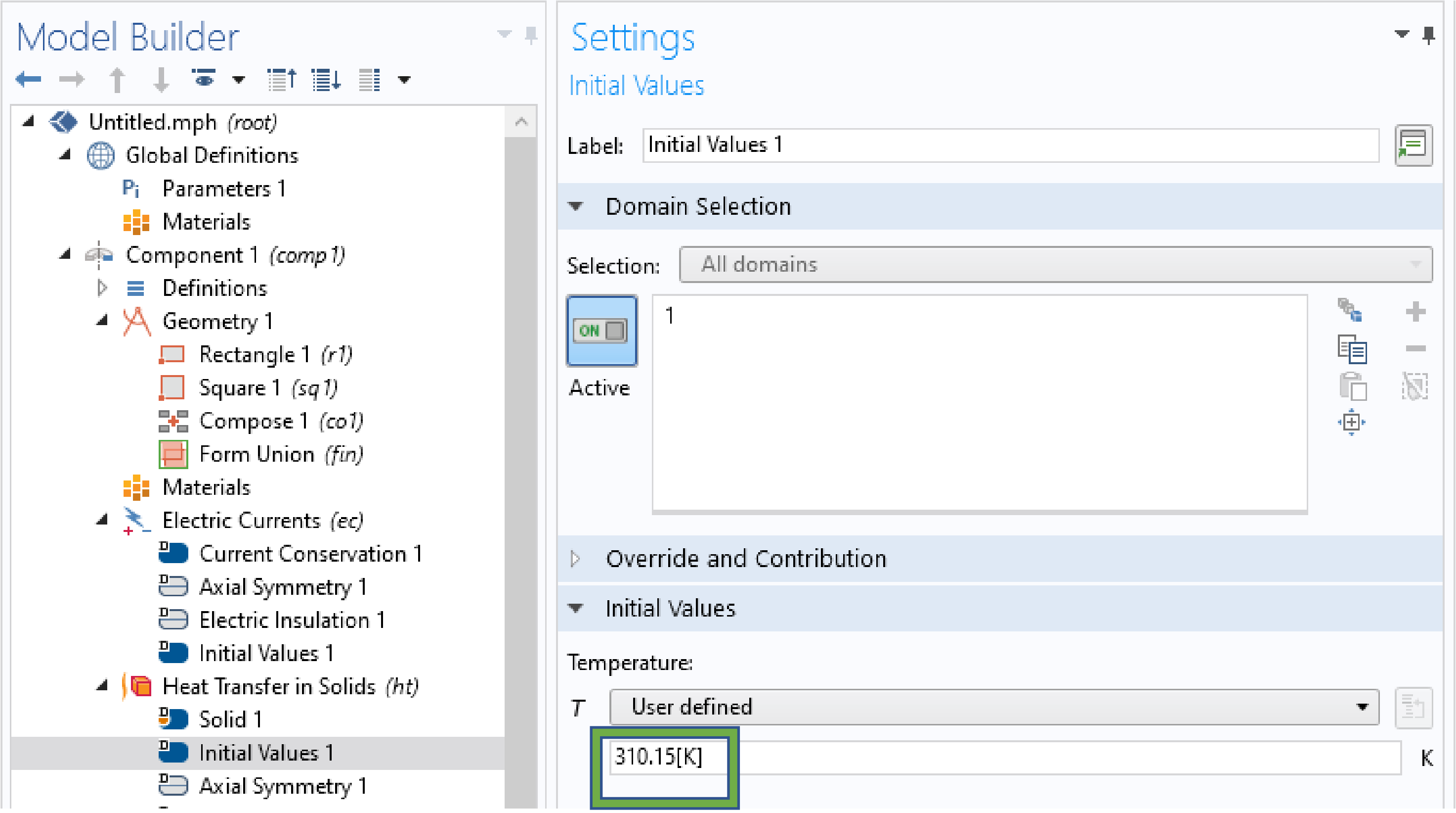


BOUNDARY CONDITIONS



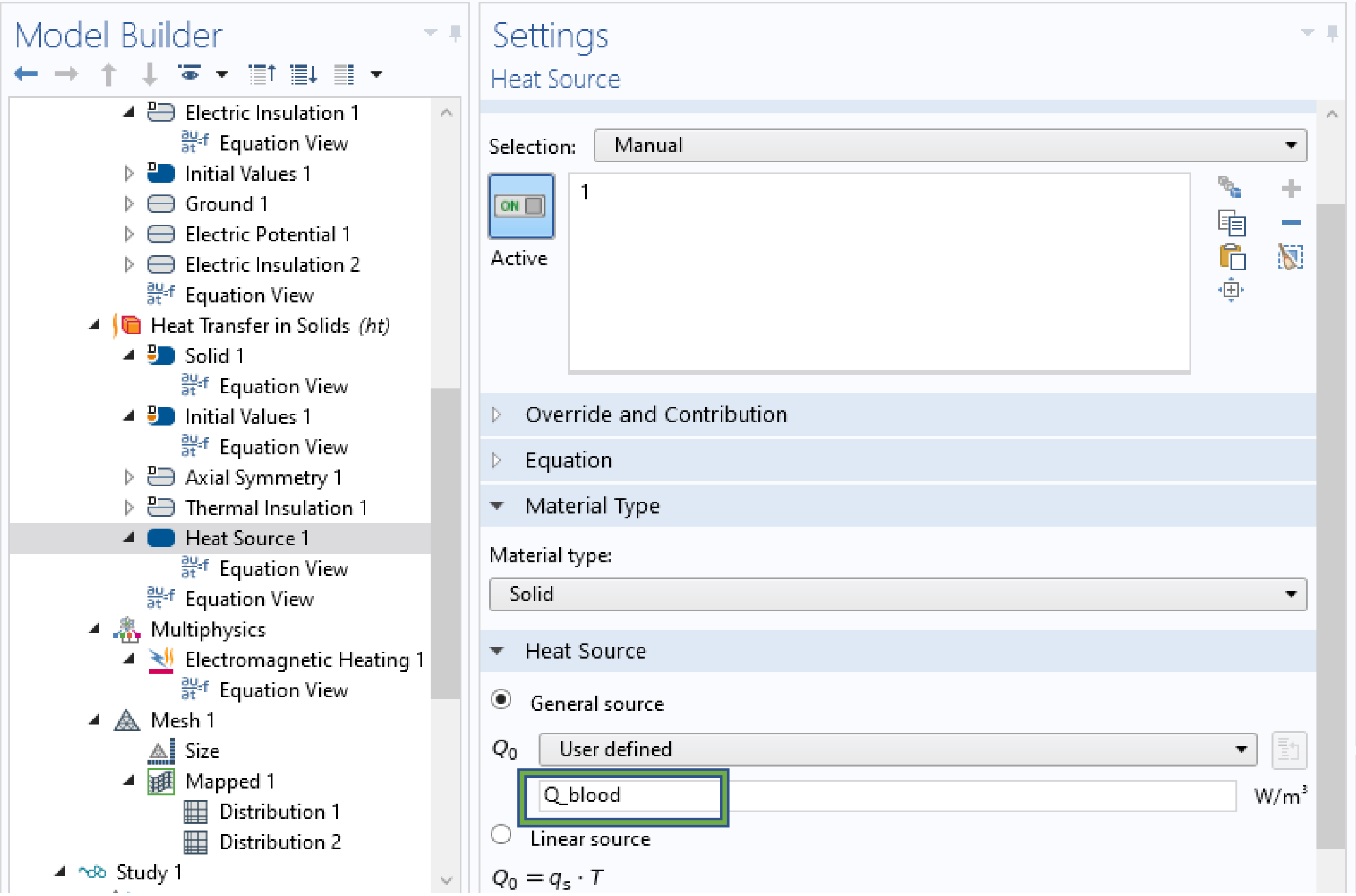
INITIAL VALUE

- 310.15 K is set as initial temperature



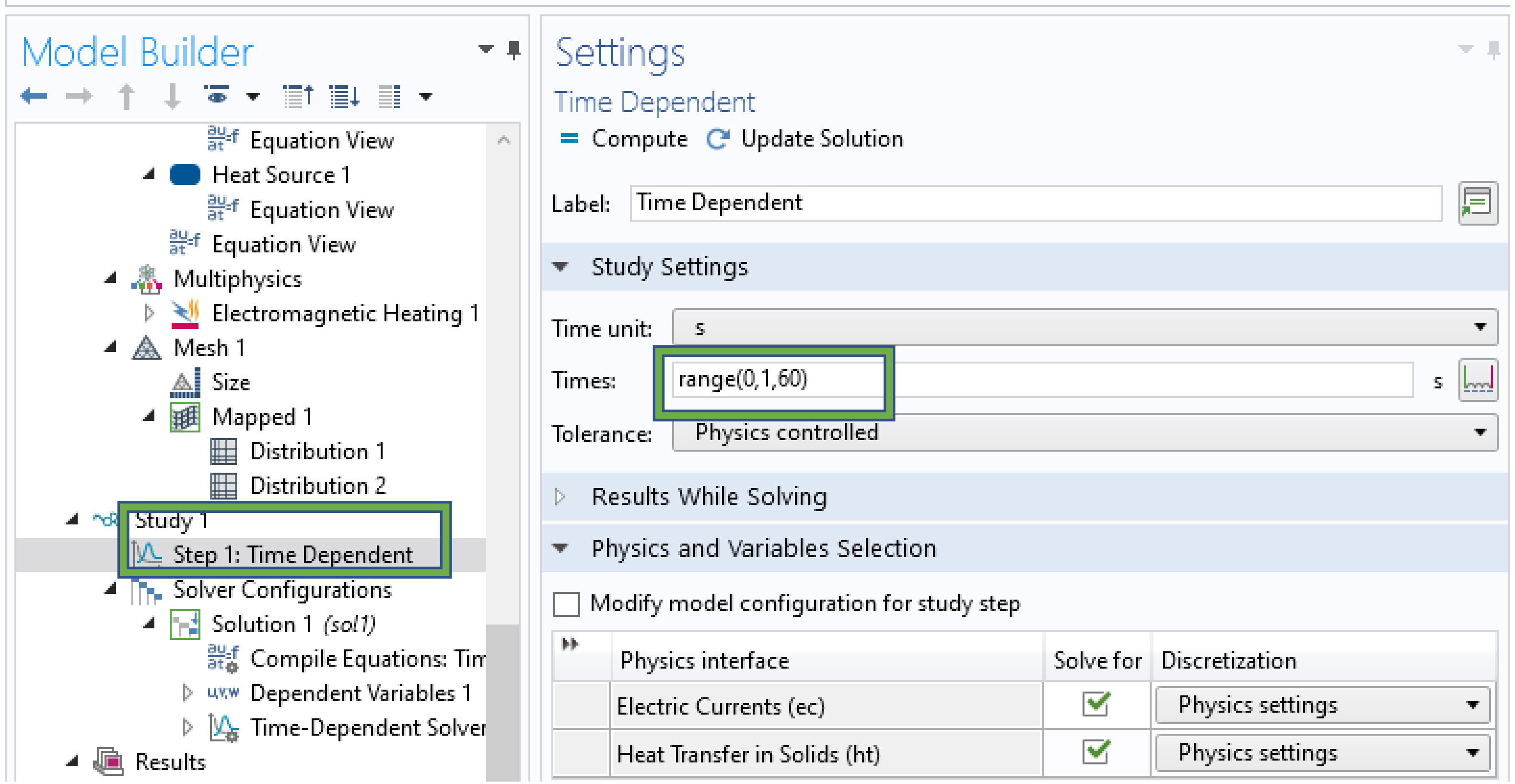
BOUNDARY CONDITION

- Heat source is defined under **Heat Transfer in solid**



STUDY

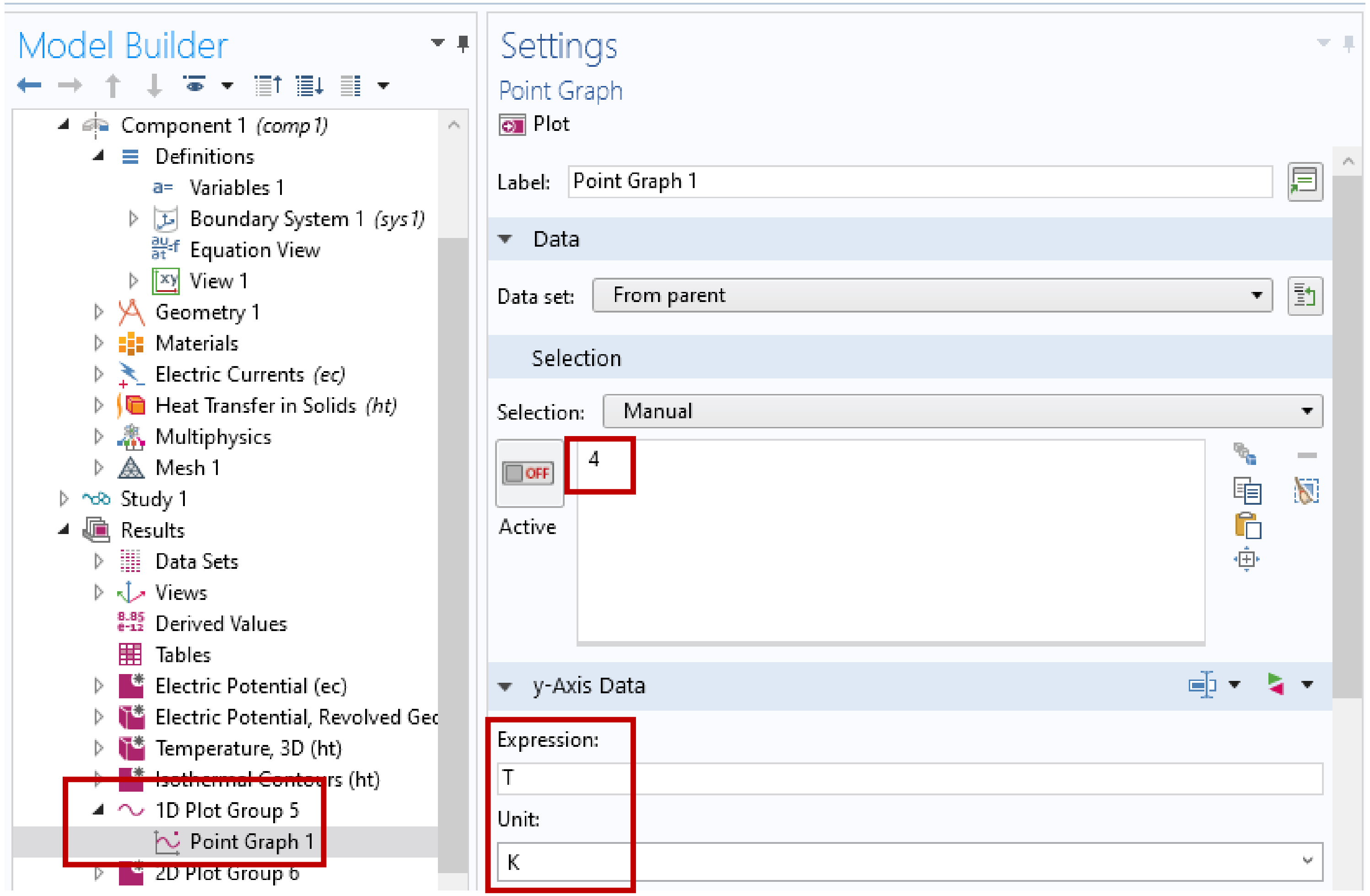
- Time Dependent → Change range → Compute



POST PROCESSING

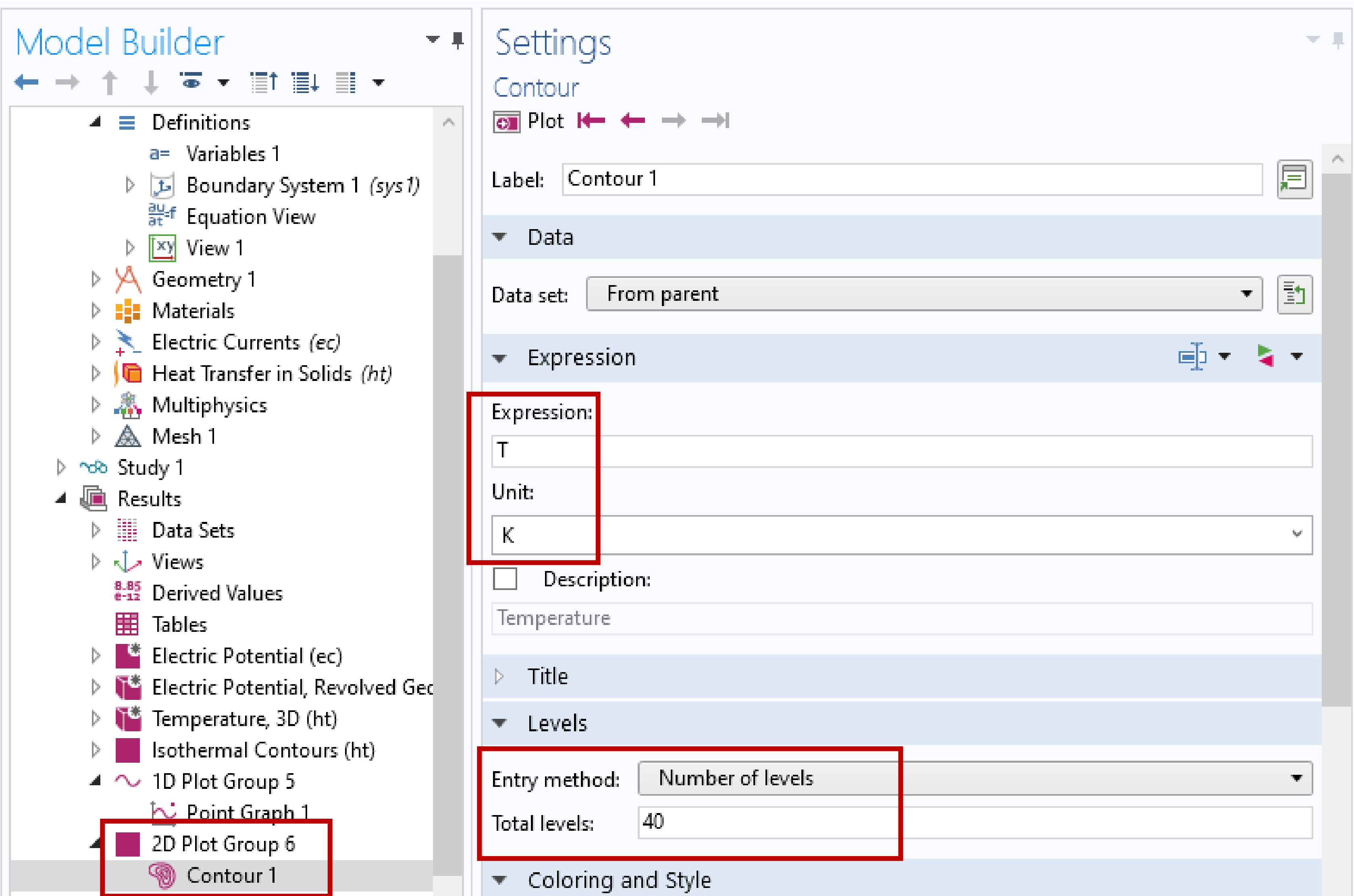
TEMPERATURE VS TIME PLOT

- 1D Plot>Domain plot parameters>Point (4 selected)
- Y Axis – Temperature (K)
- X Axis – Time (s)



POST PROCESSING

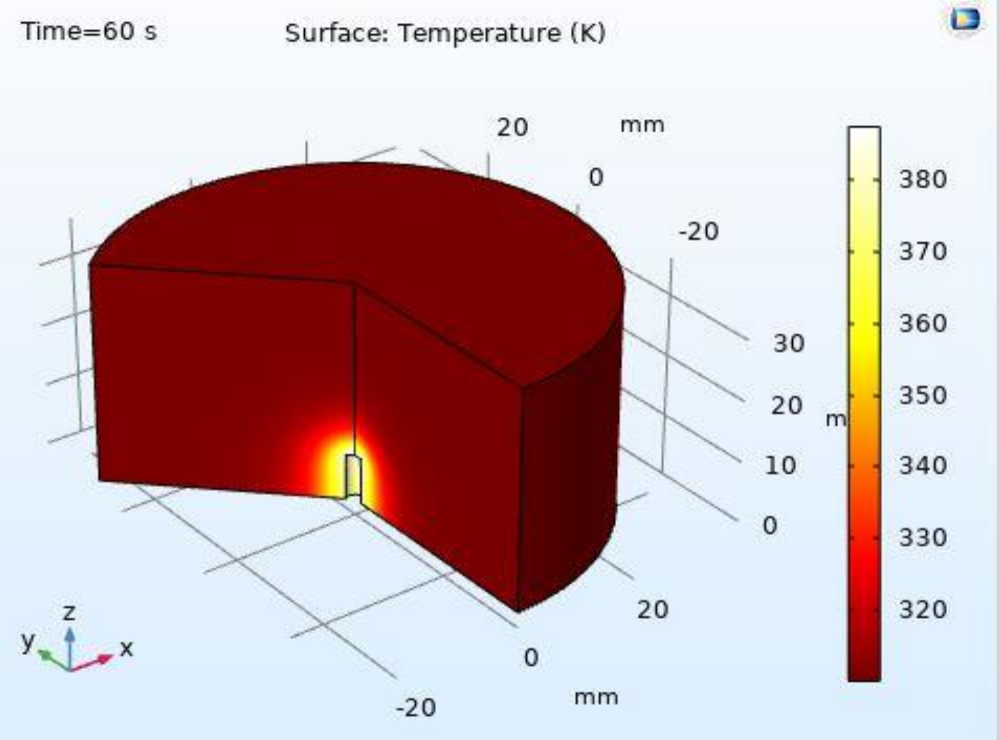
ISOTHERMAL CONTOURS



PHILOSOPHY OF THE SIMULATION

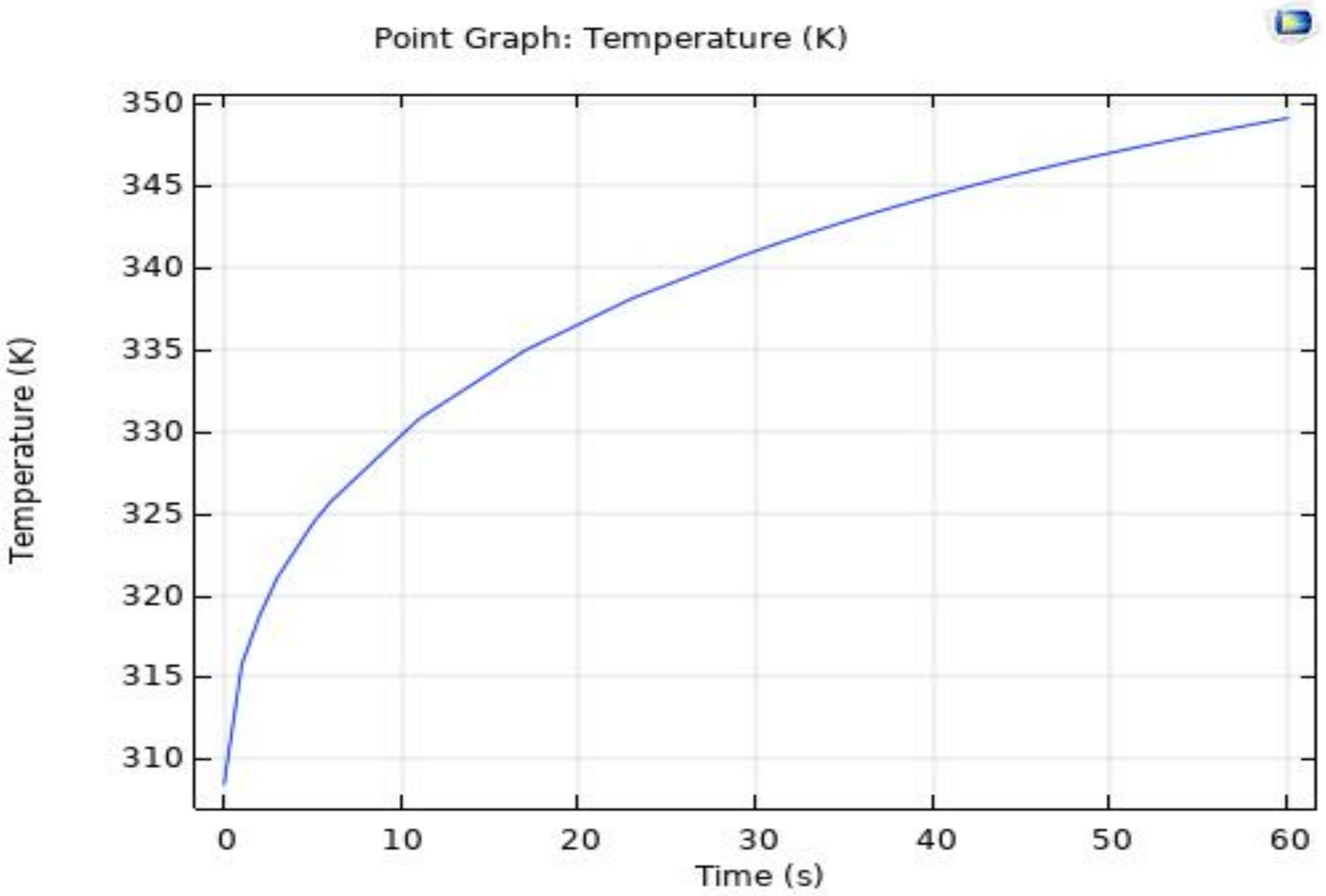
- To observe the variation of the temperature of the tissue
- Range: 37°C to more than 50°C
- Observe when the desired myocardial injury takes place
- Maintain the temperatures in the tissue below 100°C to avoid unwanted phenomena
- The temperature is controlled by Voltage regulation of the electrode

SO LET'S STUDY THE OBSERVATIONS



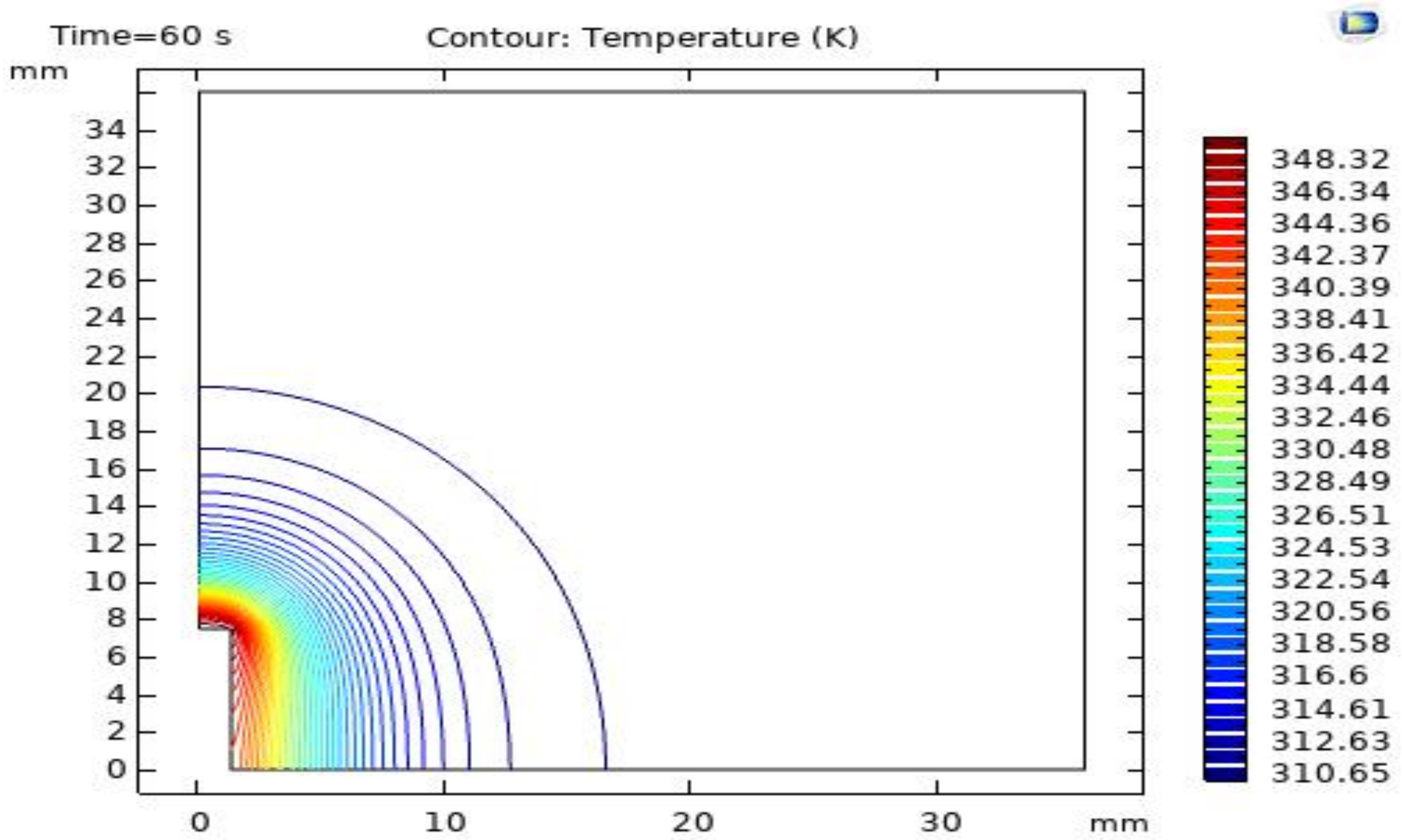
V=25V
Initial temperature = 310.15k

TEMPERATURE VS TIME GRAPH



Temperature varies from 305K to 350K.

TEMPERATURE CONTOUR



- Accurate Range
  310K-348.3K
- Ablation scale
  3-4 mm

ADDITIONAL SIMULATION

Objective: Adaptive Mesh Refinement

- Mesh is adapted automatically to a finer mesh while the solution runs
- Feature supported only for steady state solution

CONVERTING TO STEADY STATE SOLUTION

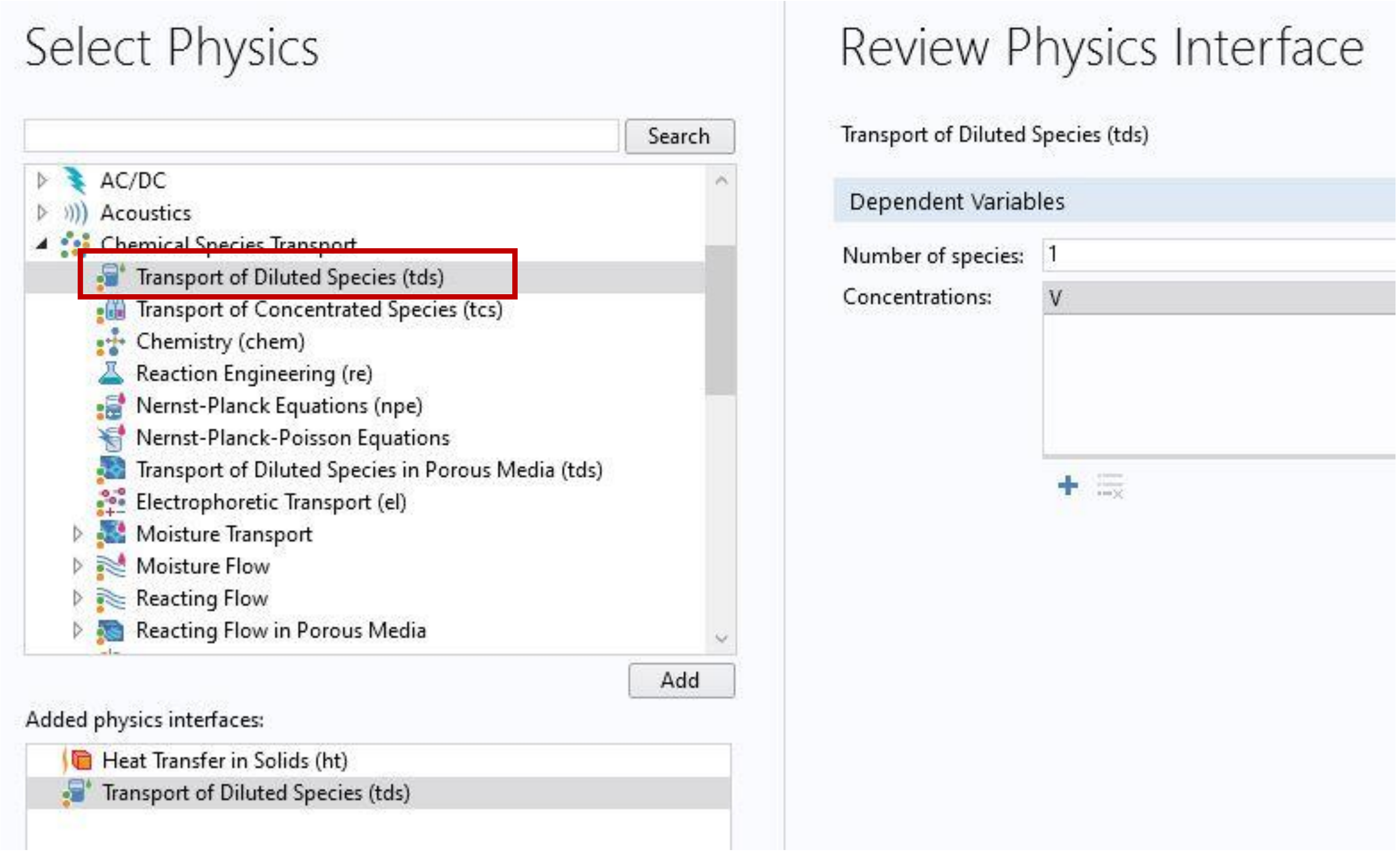
Heat Generation Equation by Joule Heating:

$$Q = \sigma \, |\nabla V|^2$$

Equivalent Heat Generation from steady state diffusion concentration:

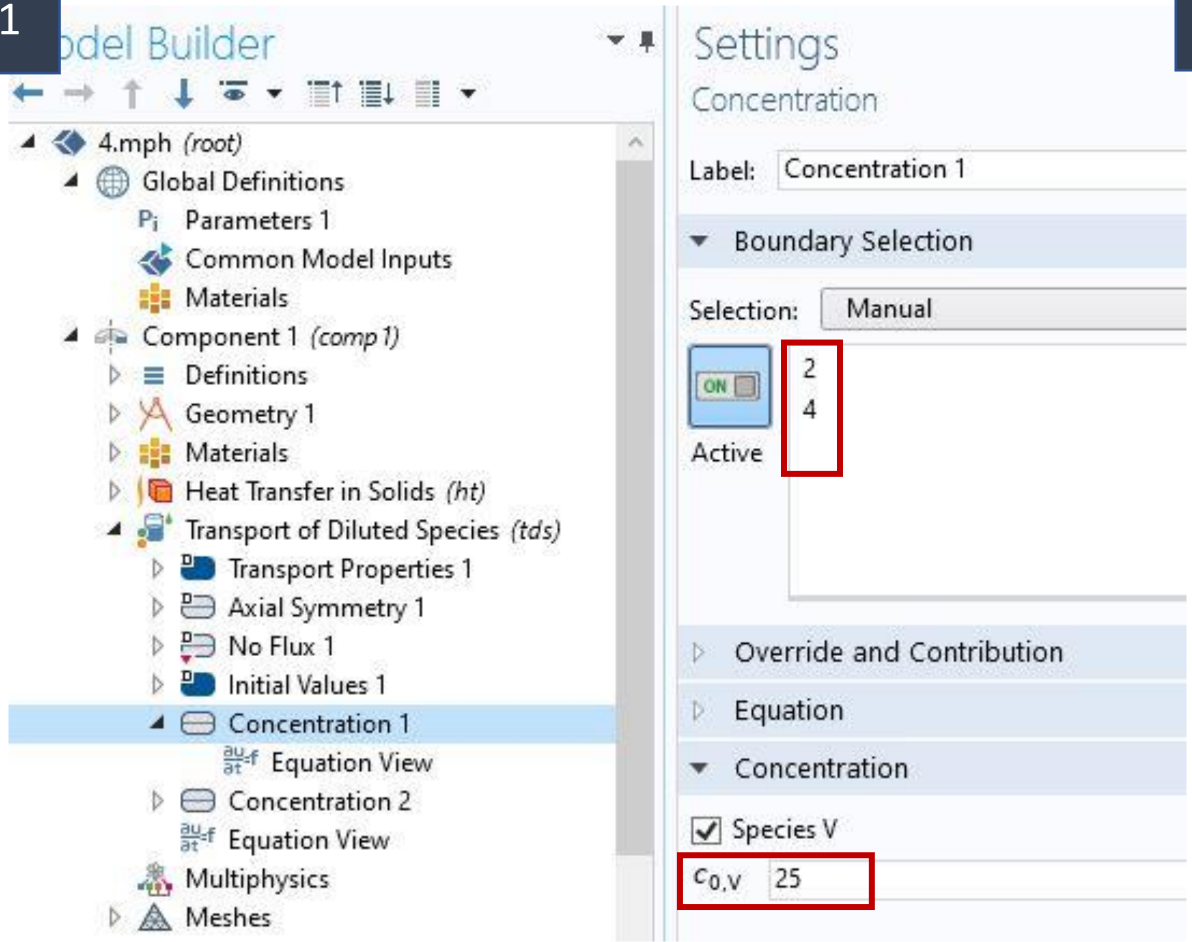
Q_dc	0.222*Vr*Vr+0.222*Vz*Vz

SIMULATION STEP VARIATION

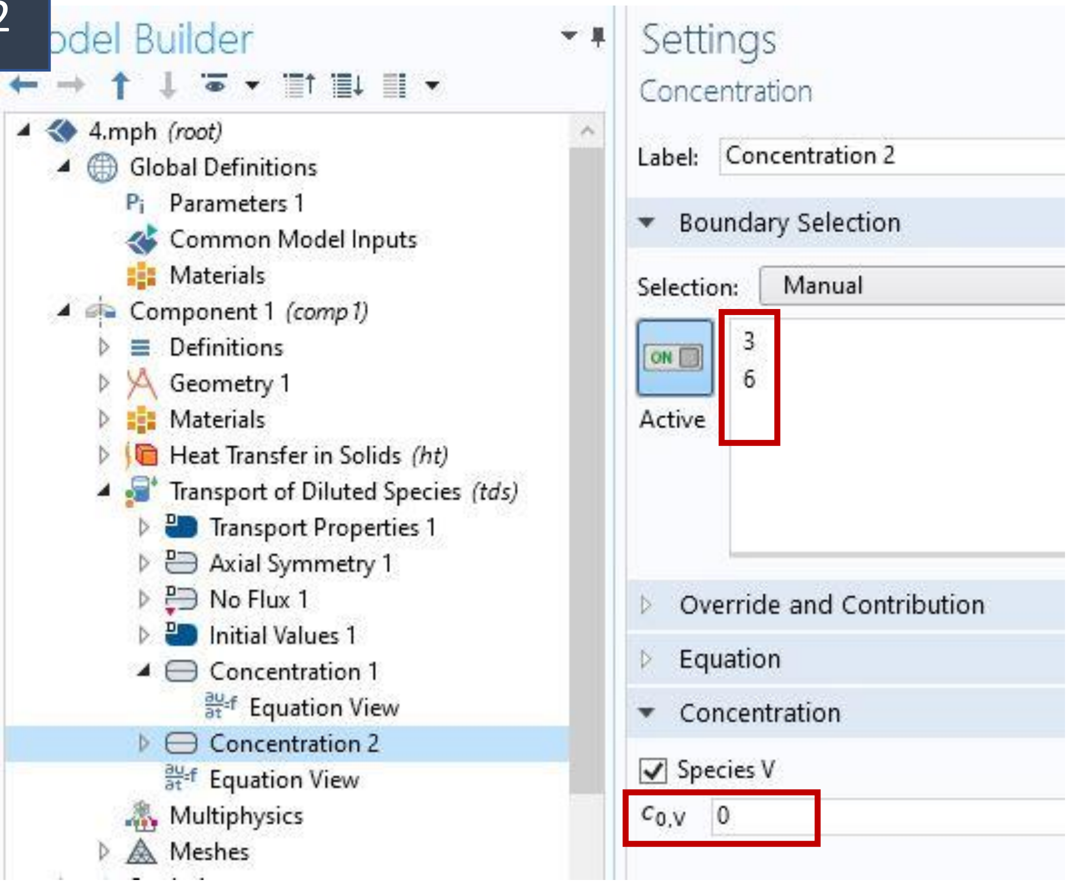


BOUNDARY CONDITIONS

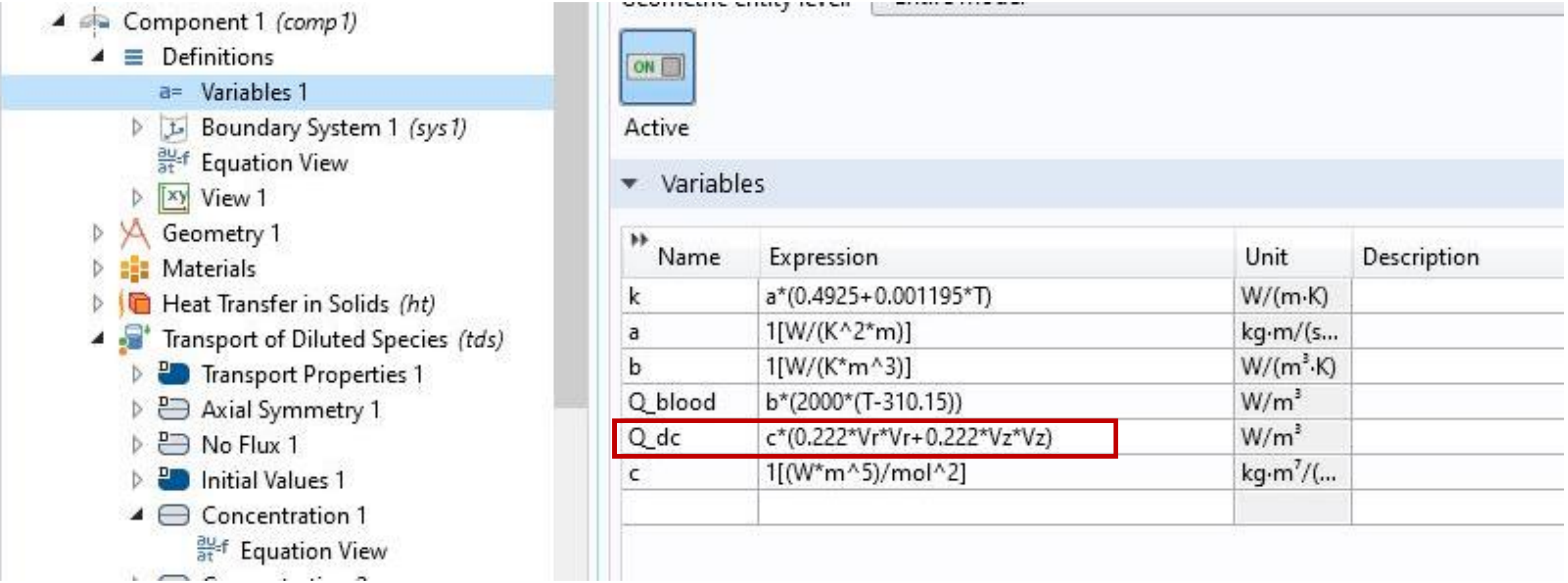
1



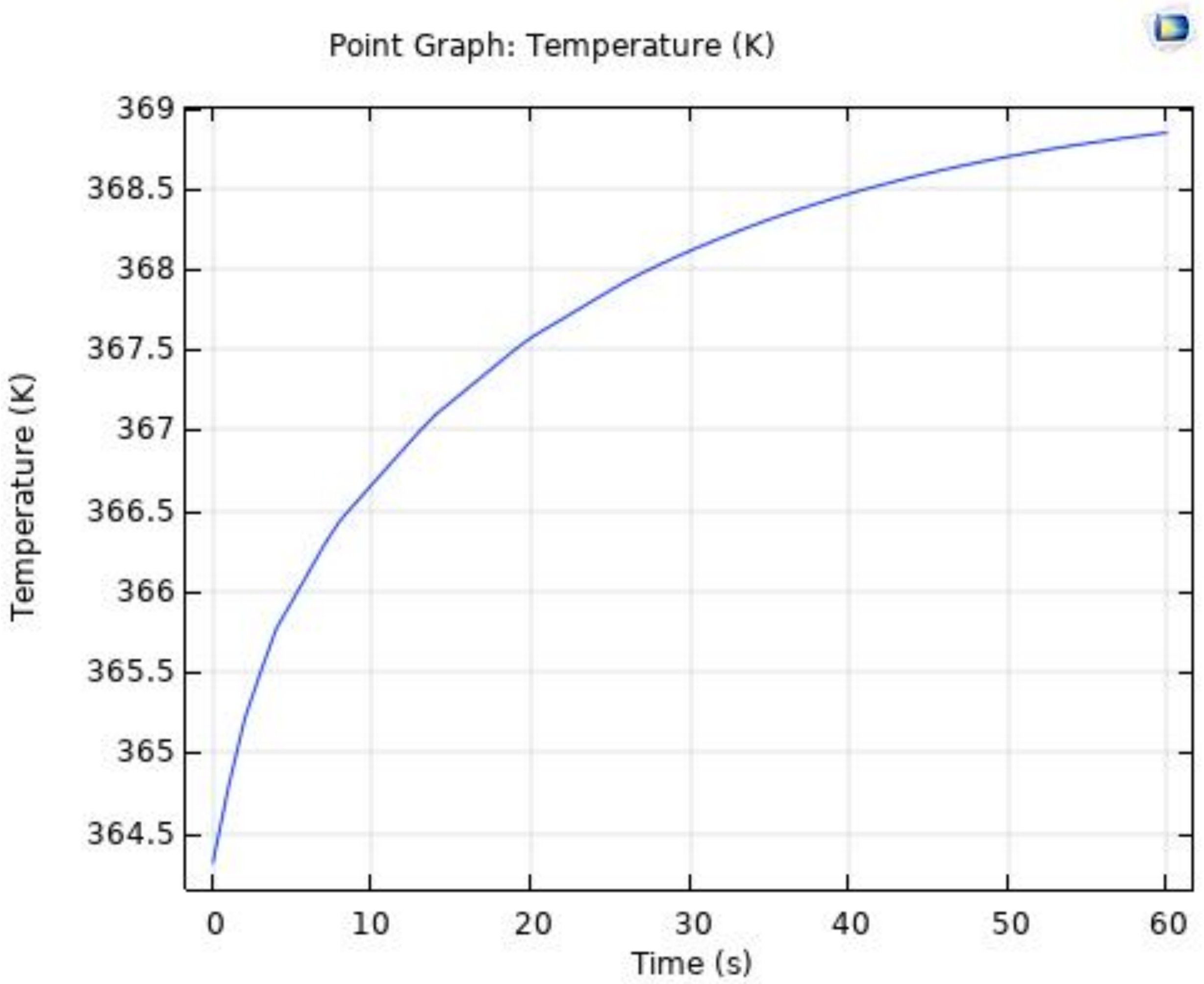
2



INPUT ALTERNATE EQUATION

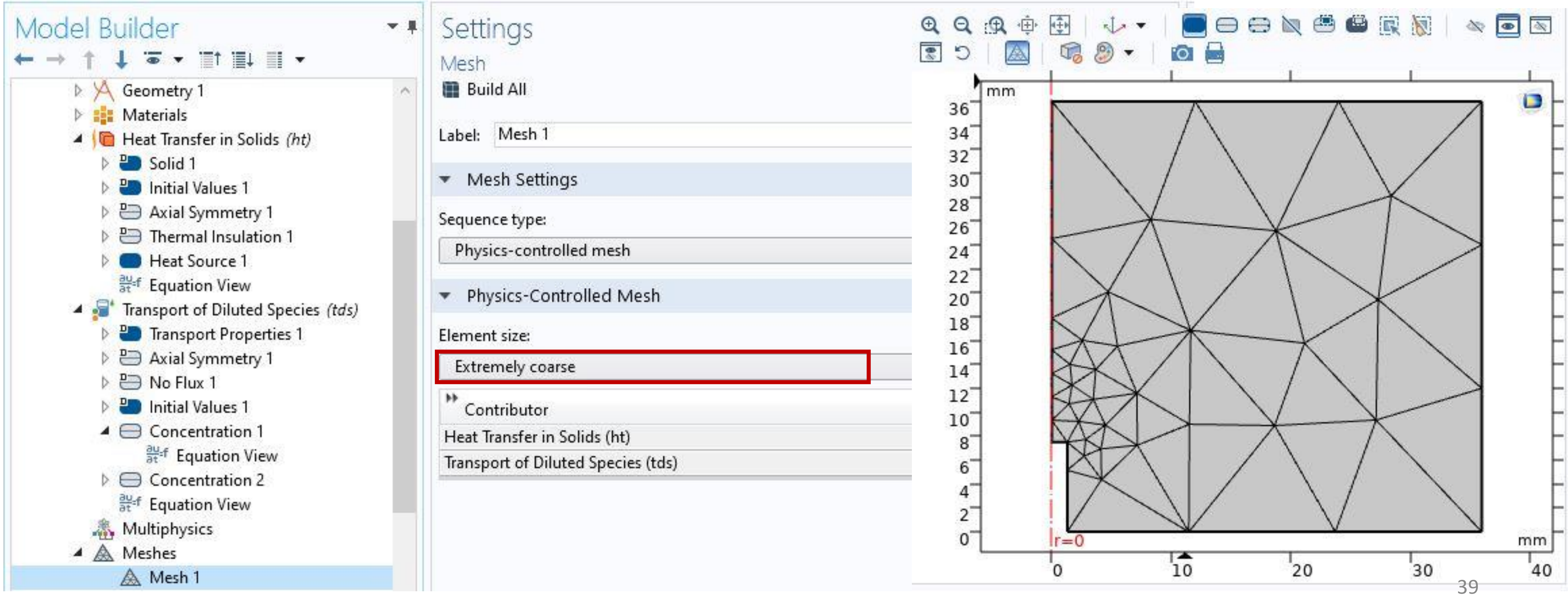


TIME DEPENDENT SOLUTION

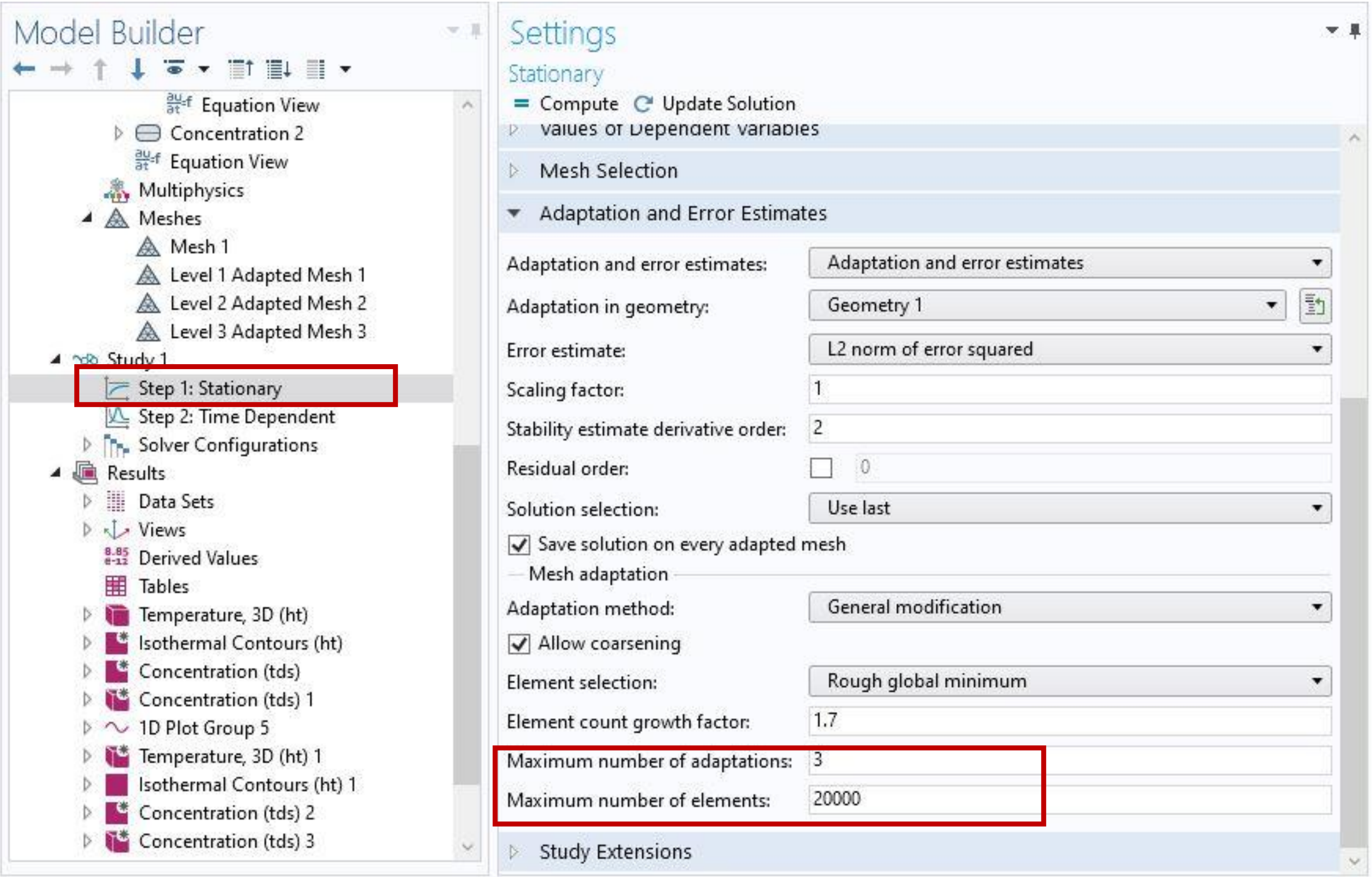


STATIONARY SOLUTION

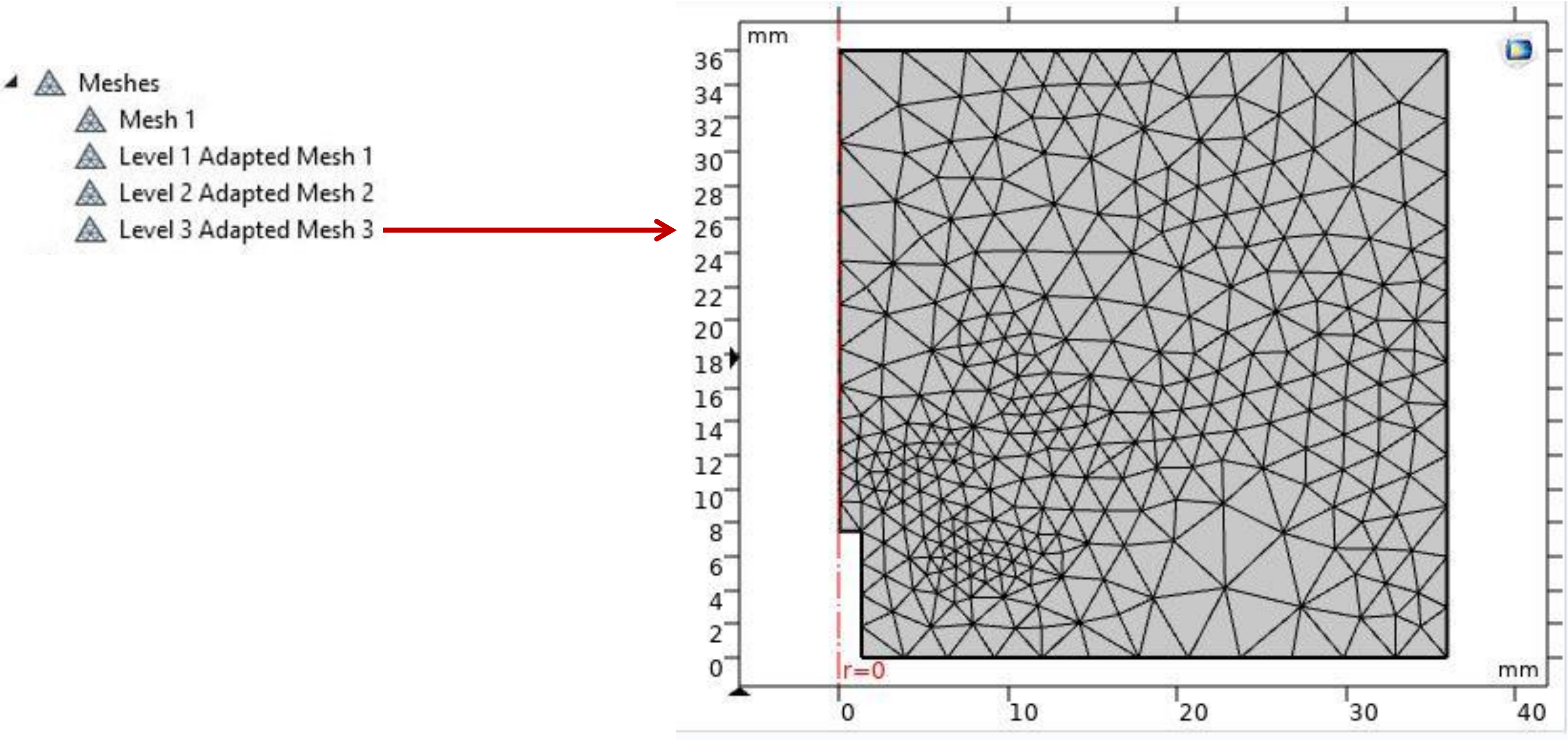
Mesh is initially set at ‘Extremely Coarse’ when solution is started:



ADAPTIVE MESH SETTINGS

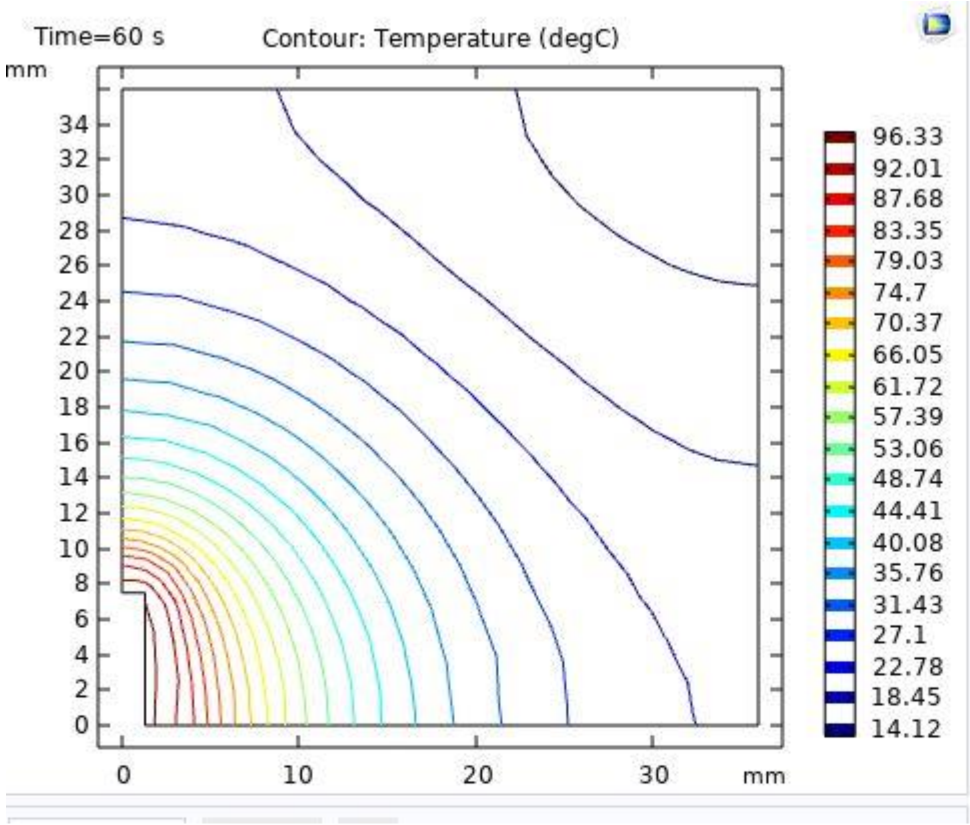


FINAL ADAPTED MESH AFTER SOLUTION

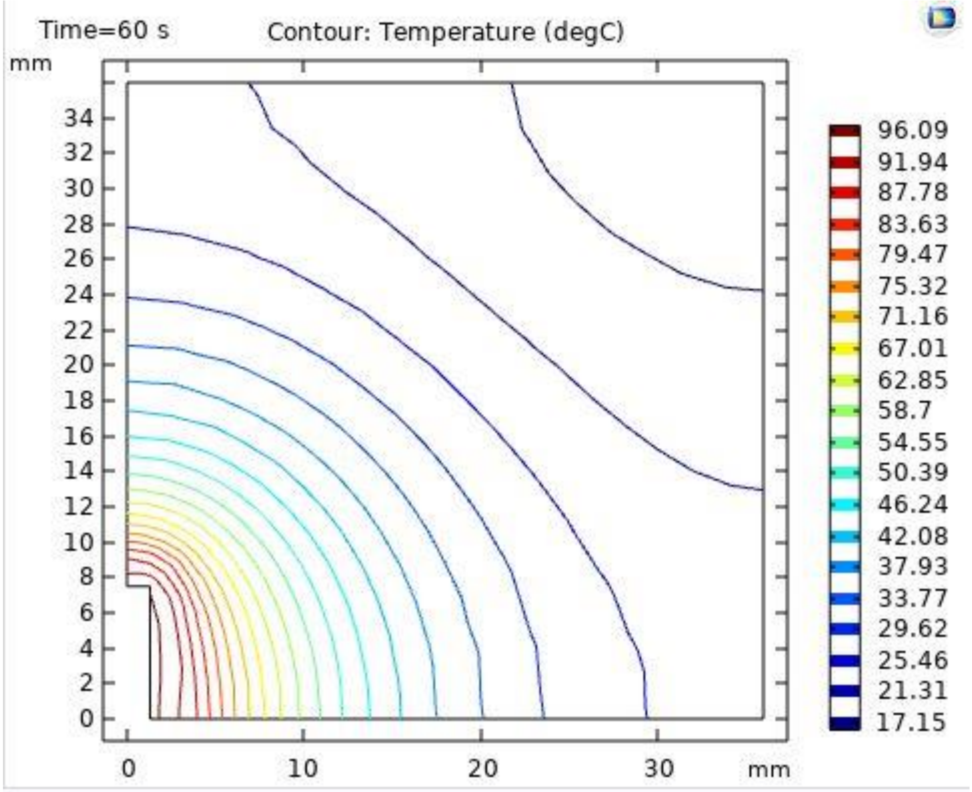


RESULT VARIATION

At extremely coarse mesh:



At final adaptive mesh:



TEAM MEMBERS AND CONTRIBUTION

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Post Processing & Result Analysis	Simulation of 2nd Method & Analysis	Theory, Simulation of 1st Method (Geometry)	Simulation of 1st Method

THANK YOU!