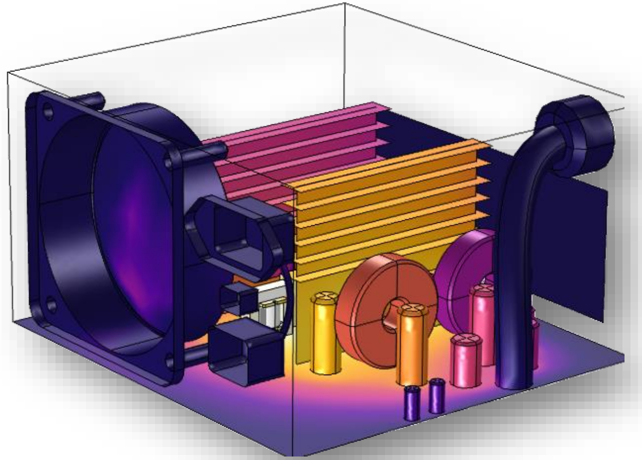
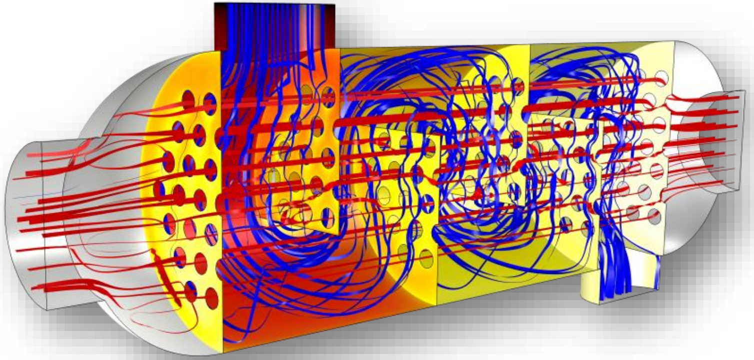
Heat Transfer, General Introduction, V 5.2a





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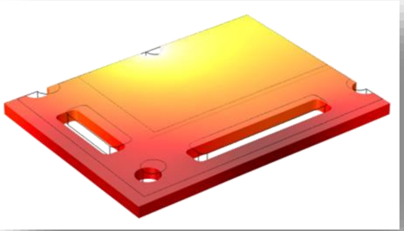
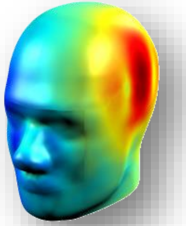
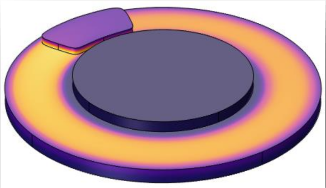
Heat Transfer Phenomena



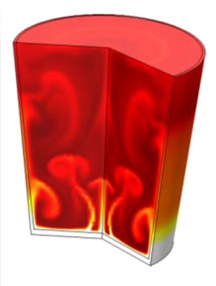
Conduction



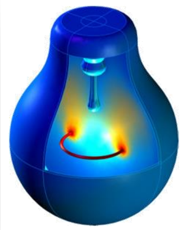
Bioheating



Heat transfer by
translation of solids



Convection in fluids



Radiation

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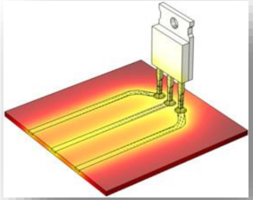
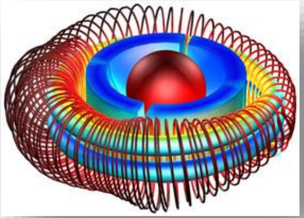
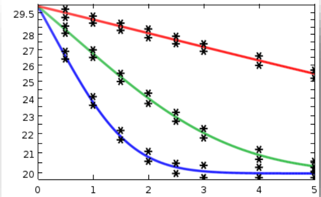
Multiphysics Couplings



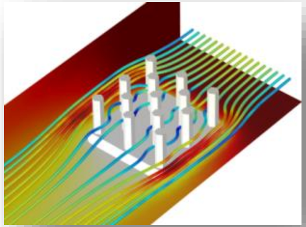
Joule Heating



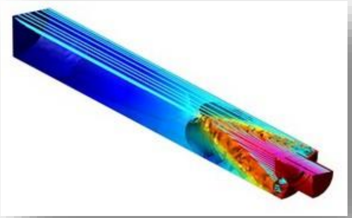
Inductive Heating



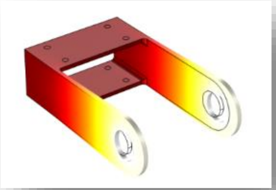
Heat and Moisture



Conjugate Heat Transfer



Phase Change



Thermal Expansion

Product Suite – COMSOL® 5.2a

COMSOL Multiphysics®

COMSOL Server™

ELECTRICAL

- AC/DC Module
- RF Module
- Wave Optics Module
- Ray Optics Module
- Plasma Module
- Semiconductor Module
- MEMS Module

STRUCTURAL & ACOUSTICS

- Structural Mechanics Module
- Nonlinear Structural Materials Module
- Geomechanics Module
- Fatigue Module
- Multibody Dynamics Module
- Rotordynamics Module
- Acoustics Module

FLUID & HEAT

- CFD Module
- Mixer Module
- Subsurface Flow Module
- Pipe Flow Module
- Microfluidics Module
- Molecular Flow Module
- Heat Transfer Module

CHEMICAL

- Chemical Reaction Engineering Module
- Batteries & Fuel Cells Module
- Electrodeposition Module
- Corrosion Module
- Electrochemistry Module

MULTIPURPOSE

- Optimization Module
- Material Library
- Particle Tracing Module

INTERFACING

- LiveLink™ *for* MATLAB®
- LiveLink™ *for* Excel®
- CAD Import Module
- Design Module
- ECAD Import Module
- LiveLink™ *for* SOLIDWORKS®
- LiveLink™ *for* Inventor®
- LiveLink™ *for* AutoCAD®
- LiveLink™ *for* Revit®
- LiveLink™ *for* PTC® Creo® Parametric™
- LiveLink™ *for* PTC® Pro/ENGINEER®
- LiveLink™ *for* Solid Edge®
- File Import *for* CATIA® V5

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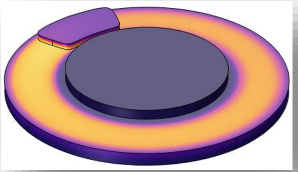
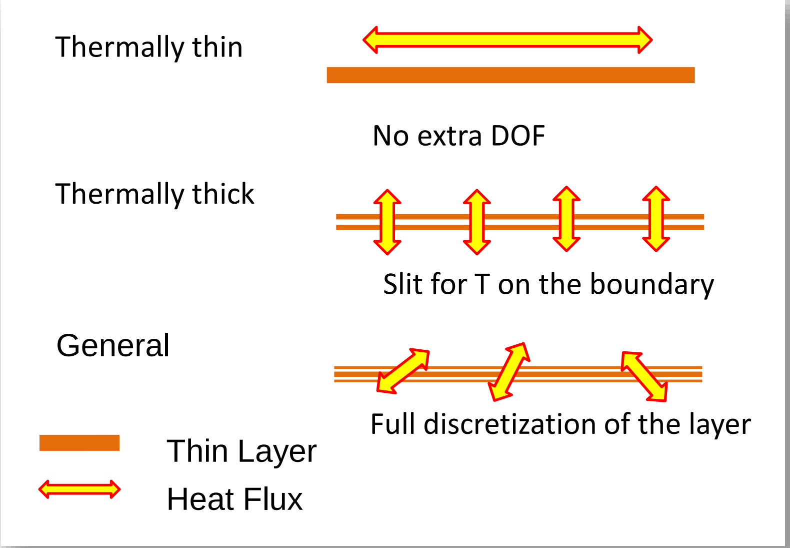
HEAT TRANSFER MODELING CAPABILITIES

Heat Transfer in Solids

- Isotropic or anisotropic, linear or nonlinear materials
- Heat transfer by translation of solids
- Heat source, user defined or from other physics
- Thermoelastic damping
- Heat transfer in thin layers
  - Thermally thin
  - Thermally thick
  - General



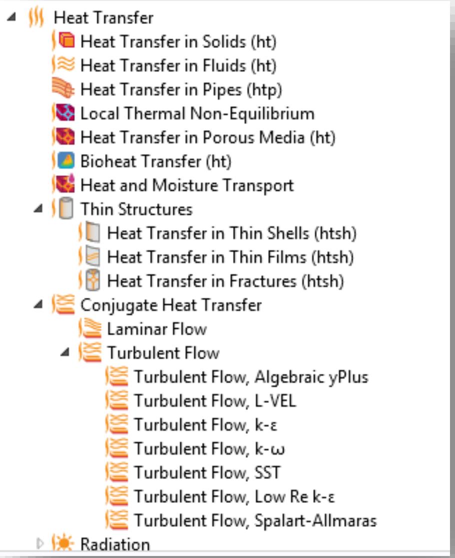
Temperature of a disc brake of a car in brake-and-release sequence



Thin Layer types

Heat Transfer in Fluids

- Laminar and turbulent flows
- Viscous dissipation
- Pressure work
- Fluid / solid interface
  - with temperature continuity
  - with boundary layer approximation
- Dedicated boundary conditions
  - Inflow heat flux,
  - Outflow
  - Open boundary
  - Screen, fan
- Heat Transfer in Thin Films



Part of the Heat Transfer interfaces list in COMSOL Multiphysics

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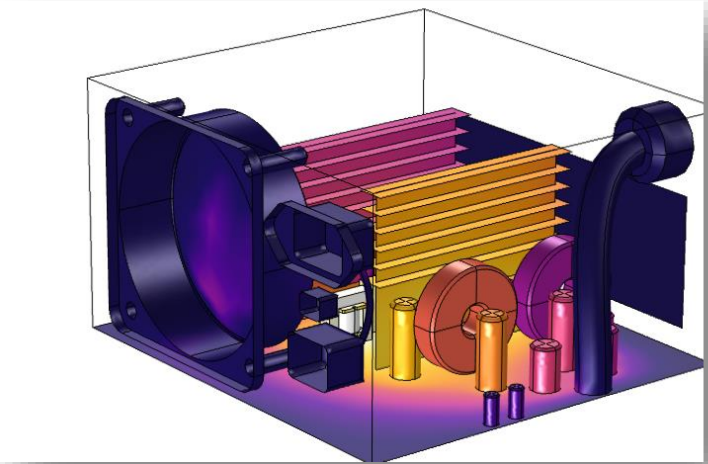
Heat Transfer in Fluids

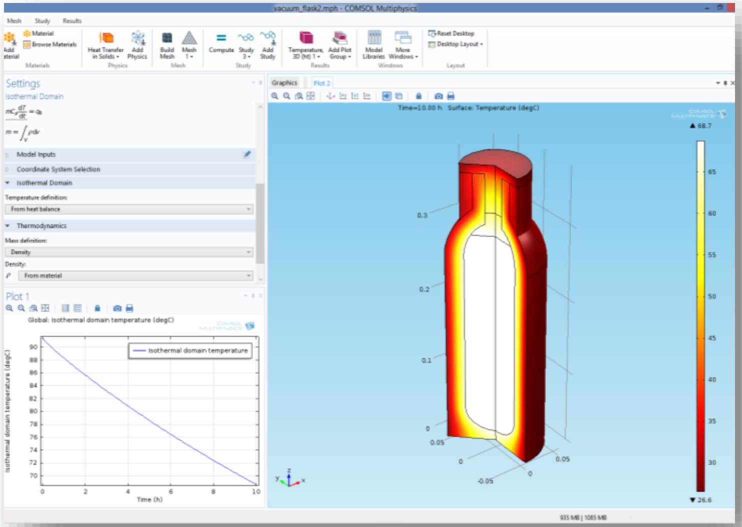
- Conjugate heat transfer
  - Natural convection (free convection)
  - Forced convection
  - Laminar and turbulent flow regimes
  - Temperature boundary layer for turbulence models
- Predefined library of heat transfer coefficients and of equivalent thermal conductivity based on Nusselt correlations
- Fan and screen boundary condition
- Marangoni effect with a predefined library of surface tension coefficient



Temperature profile in a power supply unit. An extracting fan and a perforated grille cause an air flow in the enclosure to cool internal devices.

Isothermal Domains

- Lumped model to represent isothermal regions
- Fully compatible with other heat transfer features
- Predefined interface conditions
  - Thermal insulation
  - Ventilation
  - Convective heat flux
  - Thermal contact



Coffee temperature change in a version of vacuum flask model with isothermal domain for coffee. Other domains are handle using classical FEM features.

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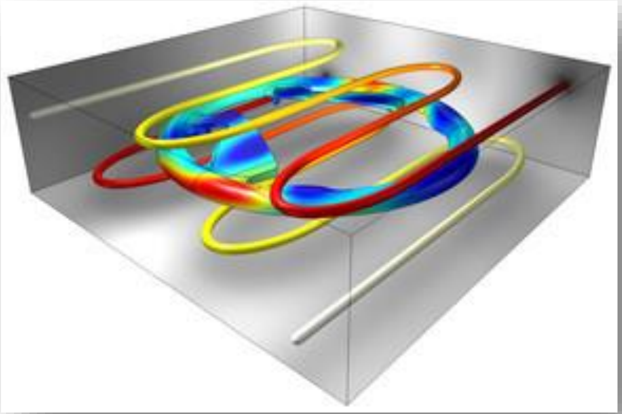
Pipe Flow

- Heat transfer in pipes
  - Conduction and advection (convection)
- Non-isothermal flow in pipes
  - Automatic transition between laminar and turbulent flow
- Bidirectional couplings between pipes and 2D or 3D domains
- Pipe properties
  - Cross-sections
  - Surface roughness



Cooling of a steering wheel plastic mold including pipe flow and heat transfer in cooling channels.

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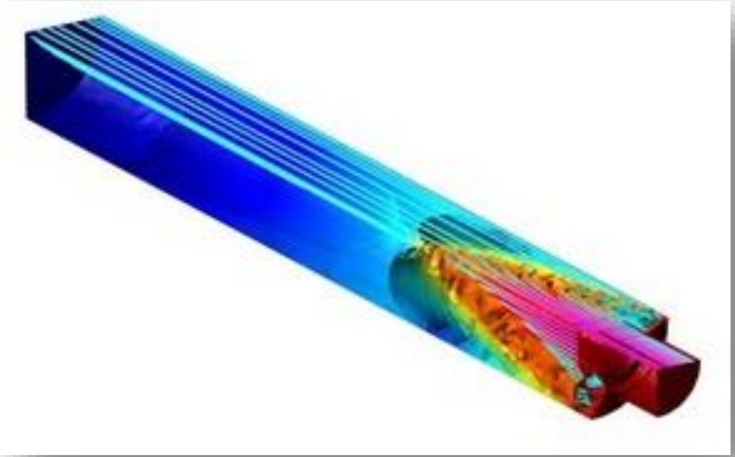
Heat Transfer with Phase Change

- Phase Change Material using apparent heat capacity formulation
- Material properties for each phase
- Phase change temperature
- Latent heat
- Material properties smoothing during phase changea

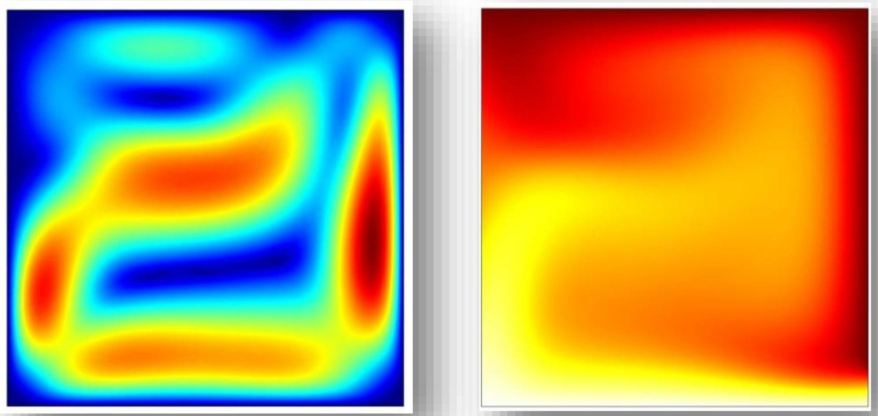


Phase change modeling for continuous casting of a metal rod from melted to solid state.

COMSOL

Heat Transfer in Porous Media

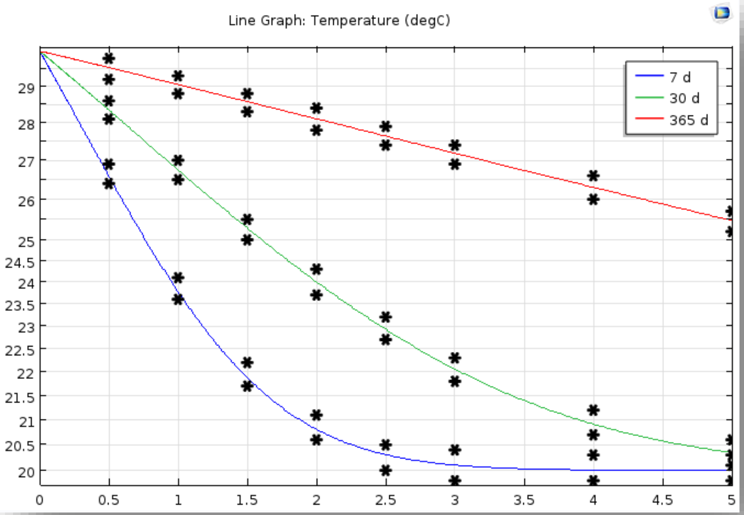
- Coupling between fluid and solid matrix parts
- Local Thermal Non-Equilibrium (LTNE) option
- Geothermal heating
- Immobile fluids
- Thermal dispersion due to tortuous paths in porous media
- Volume averaging of material properties



Velocity field (left) and temperature (right) profile due to buoyancy in porous media

Heat and Moisture in Building Material

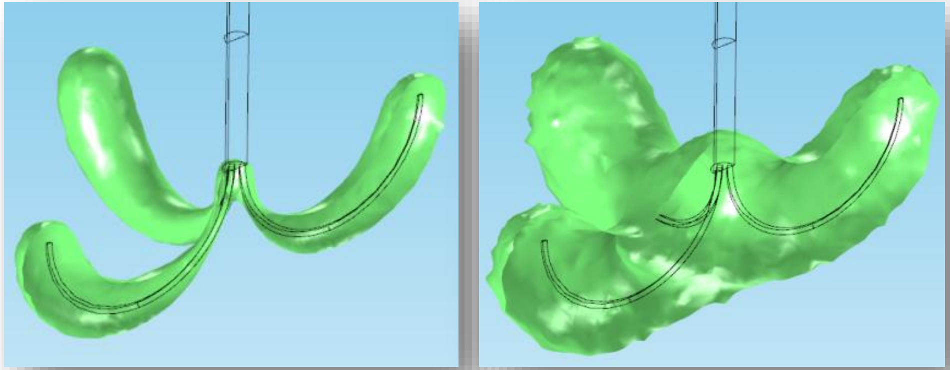
- Predefined multiphysics coupling for Moisture Transport and Heat Transfer in building material.
- Follow ISO 15026 specifications
- Solves for the relative humidity and the temperature
- Thermal properties are dependent of the moisture content, account for latent heat of evaporation



Comparison of COMSOL Multiphysics temperature profile (solid lines) with ISO 15026 benchmark data (*)

Heat Transfer in Biological Tissues

- Heat transfer in living tissue
  - Tissue and blood properties
  - Blood perfusion rate
  - Arterial blood temperature
  - Metabolic heat rate
- Bioheat source
- Damage in living tissues
  - Temperature threshold model
  - Energy absorption model
  - Cryogenic damage
- External heat sources (RF, DC current)



Tissue necrosis area during tumor ablation process at 100s (left) and 300s (right).

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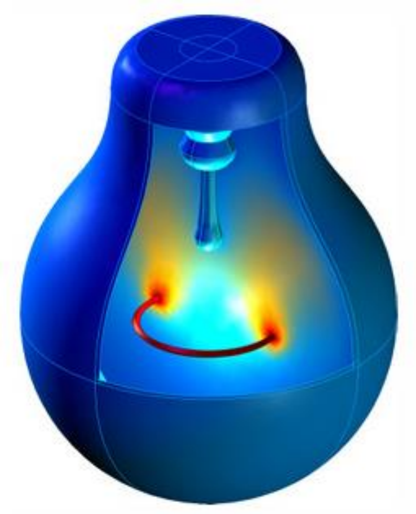
Surface-to-Surface Radiation

- Calculation of gray body radiation view factors with shadowing effects
- Wavelength dependent properties
- Diffuse reflection
- Temperature-dependent emissivity
- External radiation sources
  - User defined
  - From the sun (automatic position computation)
- Supports plane and sector symmetry



Temperature distribution in a light bulb generated by the radiating filament

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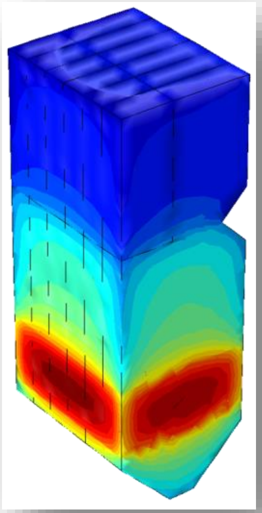
Radiation in Participating Media

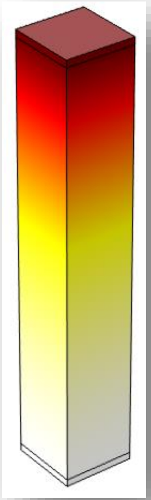
- Emission/absorption in participating media
- Ray scattering
  - Isotropic,
  - Linear anisotropic,
  - Nonlinear Anisotropic Scattering
- Radiation discretization methods
  - Rosseland approximation
  - P1 approximation
  - Discrete Ordinate Method



Radiative heat transfer in a utility boiler with internal obstacles

Thermoelectric Effect

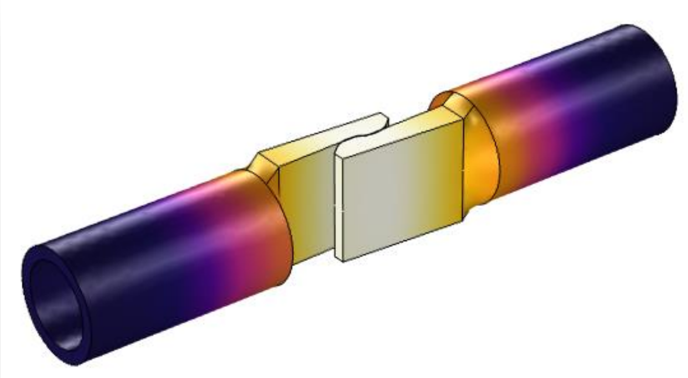
- Multiphysics coupling between
  - Heat transfer interfaces and
  - Electric currents interfaces
- Combines different effects:
  - Joule
  - Peltier
  - Seebeck
  - Thomson



Temperature drop demonstrating Peltier effect in a thermoelectric leg.

Thermal Contact

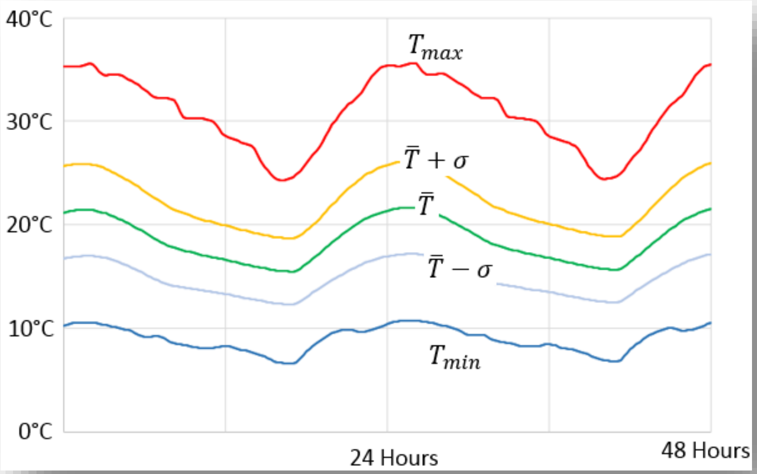
- Predefined models for:
  - Pressure dependent thermal conductance (constriction conductance)
  - Conductance through the fluid (gap conductance)
  - Surface-to-surface radiation contribution (radiative conductance)
- Coupling with structural mechanics contact and electrical contact
- Friction heat source with partition coefficient definition



Temperature in two contacting parts of a switch inducted by Joule heating. Electrical current and the heat flow from one part to the other through the contact surface. Thermal and electrical apparent resistances are coupled to the mechanical contact pressure.

Meteorological Data

- Historical data for 6000+ weather stations all other the world (Weather Data Viewer 5.0, ASHRAE 2013)
- Temperature, dew point, air pressure, wind speed, and direct and diffuse solar irradiation as a function of calendar day and time
- Integrate in heat transfer interfaces and features



Temperature variation during two days.

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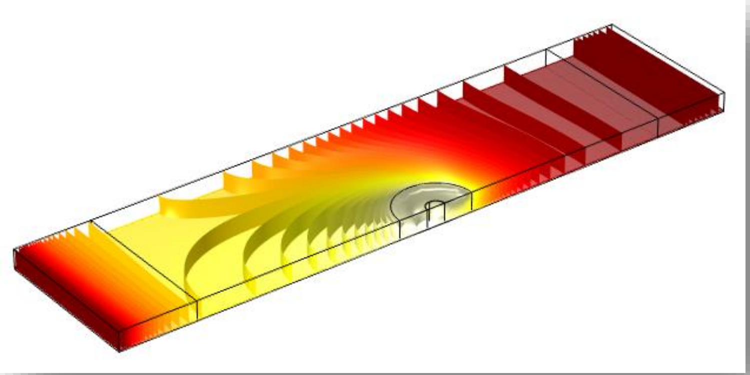
Additional Features Overview

- Geometry, assembly
  - Heat continuity across pairs
  - Thermally Resistive Layers between pair sides
  - Coupling between shells and solids
- Optimized settings for default mesh
- Periodicity
- Infinite elements
- Predefined properties for liquids and gases including temperature and pressure dependency
- Arbitrary user defined properties



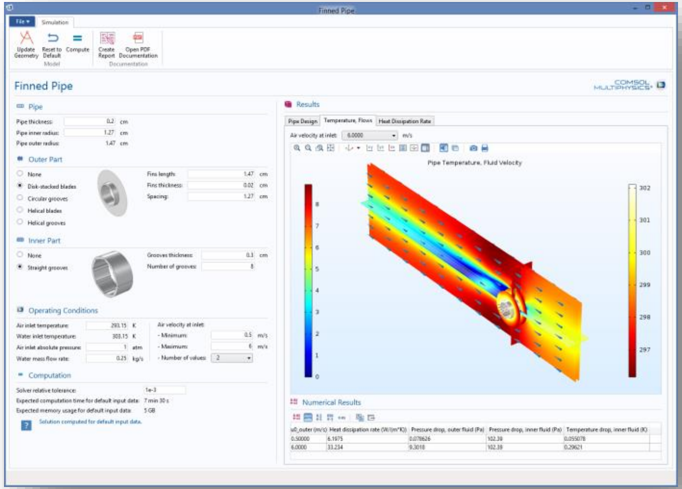
Two aluminum plates, modeled as infinitely long, are joined by generating friction heat with a rotating tool.

Complete features list available on http://www.comsol.com/products/specifications/heat-transfer/

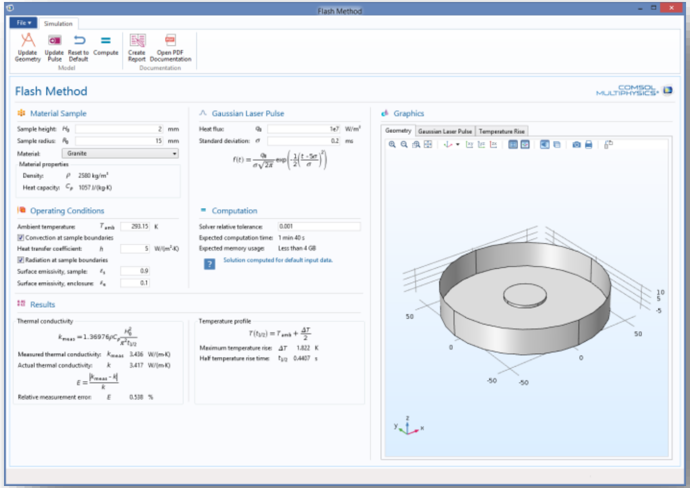
Available in the Application Library or the Application Gallery
more on www.comsol.com/showroom/product/ht/

HEAT TRANSFER EXAMPLES

Heat Transfer Module in COMSOL Apps

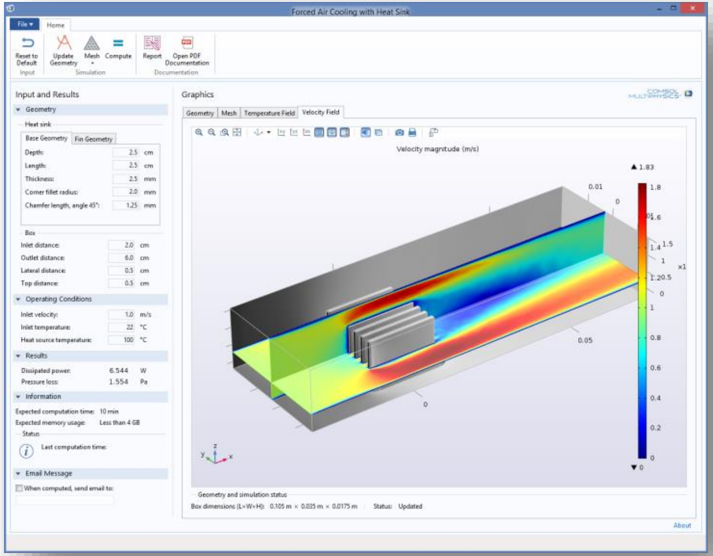


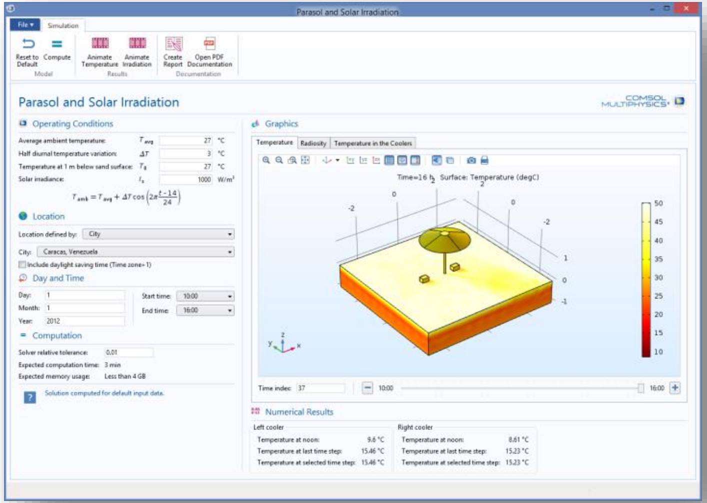
The app calculates the thermal performance of a pipe that is filled with water and then cooled or heated by surrounding air with forced convection. Various geometric configurations are available. The app computes the dissipated power and the pressure drop as functions of the geometry and air velocity.



The Flash Method simulation app reproduces a flash method experiment and provides options to define experiment parameters that can affect the accuracy of the method and your experiment.

Heat Transfer Module Embedded in Apps

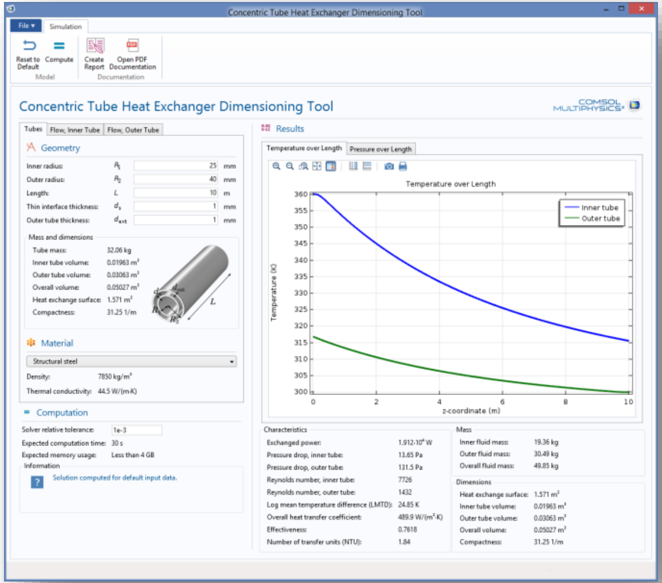




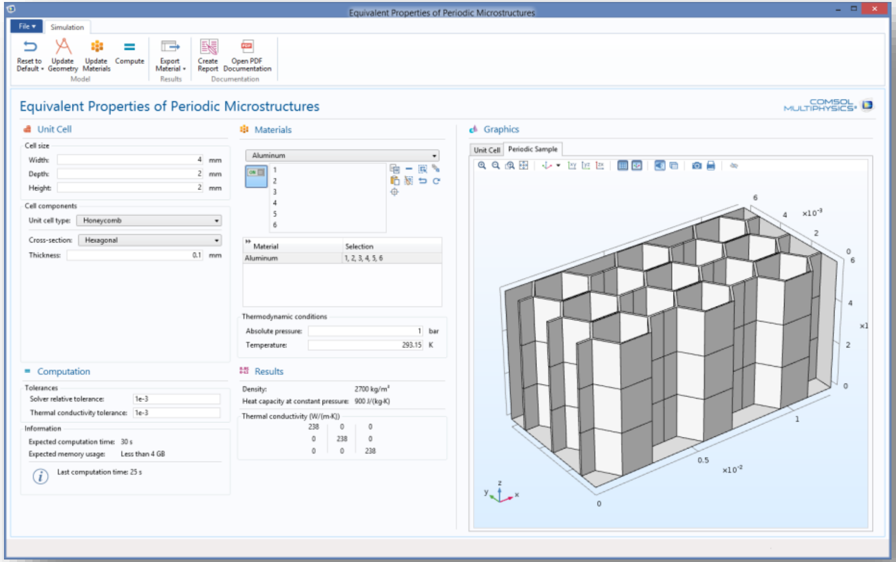
The application can simulate different heat sink widths, base thickness, and fin dimensions at a given cooling air velocity. The number of fins can also be varied. The output gives the cooling power and the average pressure drop over the length of the system.

This app simulates the solar irradiation on a beach with frosty beverage cans enclosed in two coolers under a parasol. Depending on the location on Earth and daytime moment in the year, the parasol shadows the cans at a determined angle, affecting the solar irradiation and hence the coolers' temperature profiles in time.

Heat Transfer Module Embedded in Apps

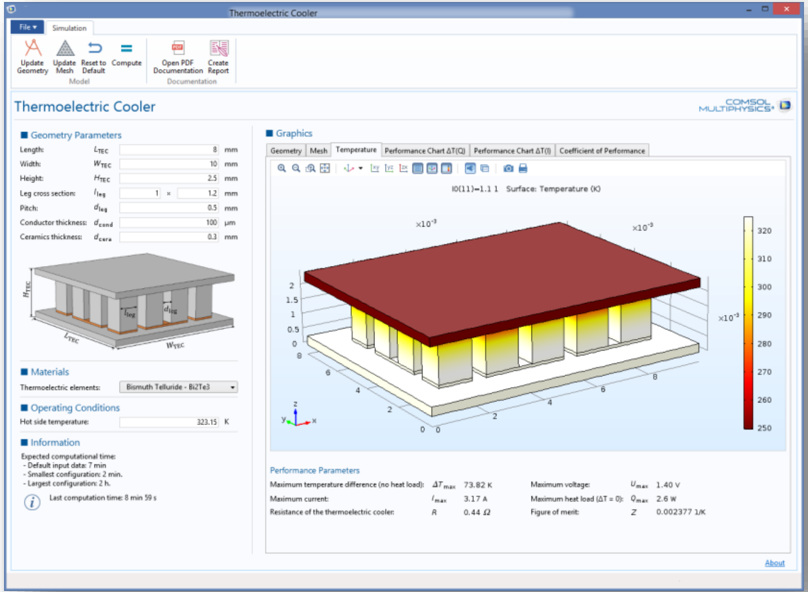


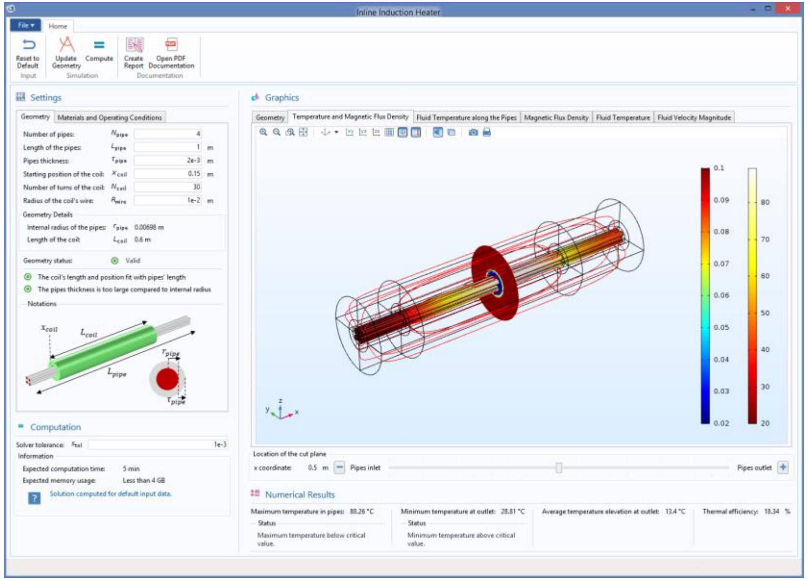
This application computes quantities that characterize the heat exchanger such as exchanged power, pressure drop, and effectiveness. The tube structure, fluid properties, and boundary conditions are customizable.



This app computes the equivalent thermal properties of a material with a periodic structure. Various shapes are available for the unit cell. Among them, multiple parallel layers, cylindrical fibers or spherical particles in a homogeneous matrix, and honeycomb patterns.

Heat Transfer Module Embedded in Apps





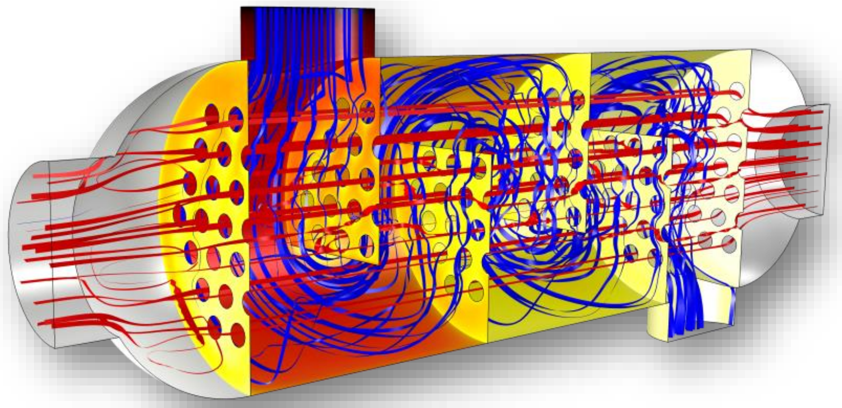
The Thermoelectric Cooler app covers the basic design of a single-stage thermoelectric cooler of different sizes with different thermocouple sizes and distributions. You can use the app to help find the best thermoelectric cooler for a specific application. Manufacturers can also use it to optimize designs and provide application-related performance values.

This app computes the efficiency of a magnetic induction apparatus for the heating of liquid food flowing in a set of ferritic stainless steel pipes. A circular electromagnetic coil is wound around a set of pipes in which a fluid flows. The alternating current passing through the coil generates an alternating magnetic field that penetrates the pipes, generates eddy currents inside them, and heats them up

Heat Exchanger

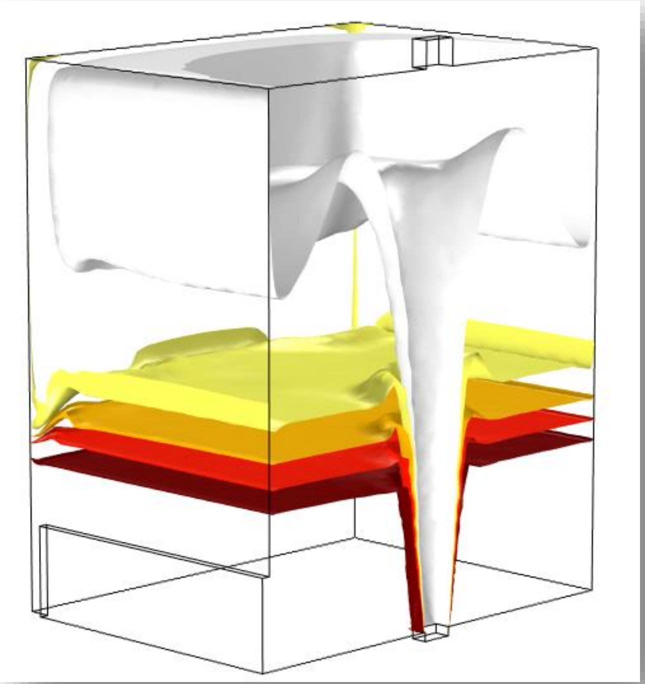
- This figure shows the temperature profile and the streamlines in a shell and tube heat exchanger.

- Two separated fluids at different temperatures flow through the heat exchanger, one through the tubes (tube side, red streamlines) and the other through the shell around the tubes (shell side, blue streamlines).



Ventilation

- The model investigates the performance of a displacement ventilation system.
- The flow is modeled using the Non-Isothermal Turbulent Flow, k-ω Model interface.
- This figure shows the isotherms in a room.



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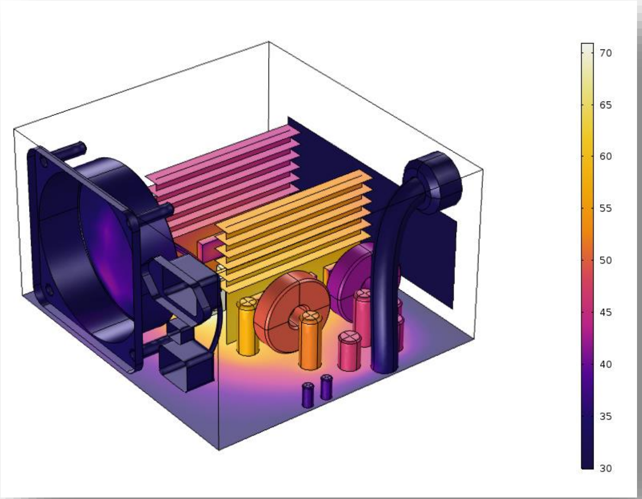
Electronic Cooling

- The model examines the air cooling of a power supply unit (PSU) with multiple electronics components acting as heat sources. Fins are used to improve cooling efficiency. To achieve high accuracy, the simulation accounts for heat transport in combination with fluid flow.
- This figure shows an horizontal board with forced convection (fan cooling).



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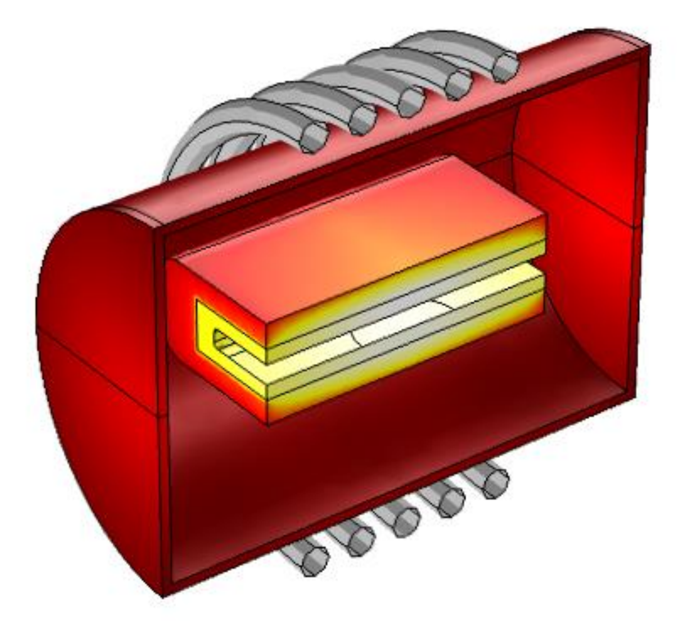
Furnace Reactor

- This model shows a furnace reactor design that heats a susceptor of graphite, using an 8 kW RF signal at 20 kHz. The temperature distribution over the wafer is extracted, as well as the temperature on the outer Quartz tube. At these high temperature (~2000 ^{o}C) the heat flux is dominated by radiation.
- The design of the chamber is crucial to reach a uniform temperature, efficient heating, and control of high temperature regions.



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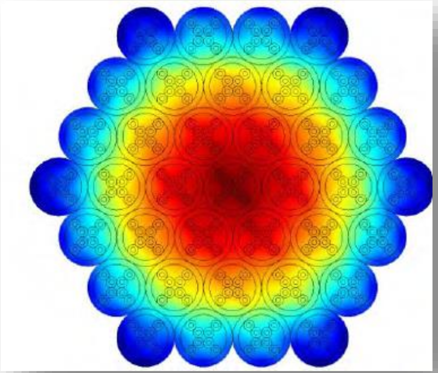
Heat Losses in Wires

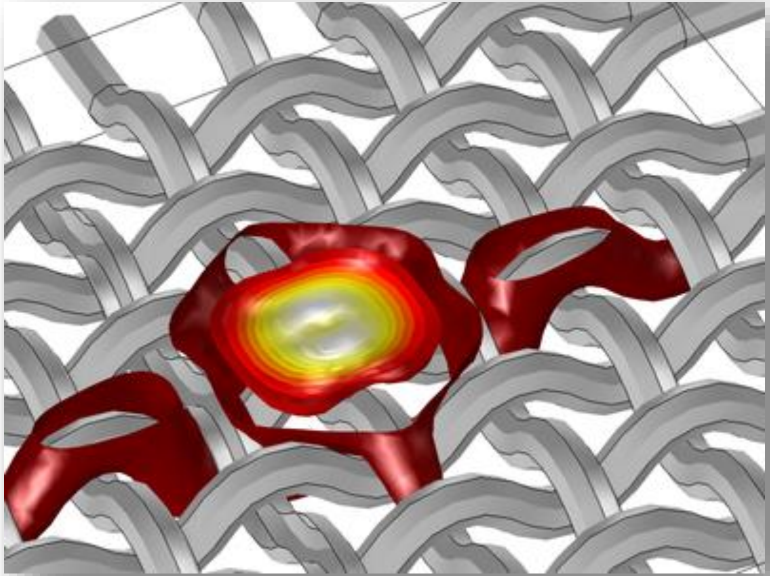
- Temperature raise in a cable with PoE/PoE+ technology.
- In this model, the heat source is due to the Joule heating effect. This, developed by Nexans, takes into consideration several configurations of cable bundles in order to optimize temperature distribution.



Finite Element Analysis of Cables Heating Due to PoE/PoE+
S. Francois[1] , and P. Namy[2]
[1] Nexans Research Center, Lyon cedex, France
[2] SIMTEC, Grenoble, France
Presented at COMSOL Conference 2010 Paris

Anisotropic Heat Transfer Through Woven Carbon Fibers

- Carbon-fiber-reinforced polymers contain woven carbon fibers that have a thermal conductivity along the fiber axis is much higher than perpendicular to it. This tutorial model shows how to use the curvilinear coordinates interface to compute the local fiber orientation and to use it to define anisotropic thermal conductivity of fibers.
- Because the carbon-fiber-reinforced polymer sample dimensions are rather small, infinite elements are used to avoid setting boundary conditions too close to the heat source.



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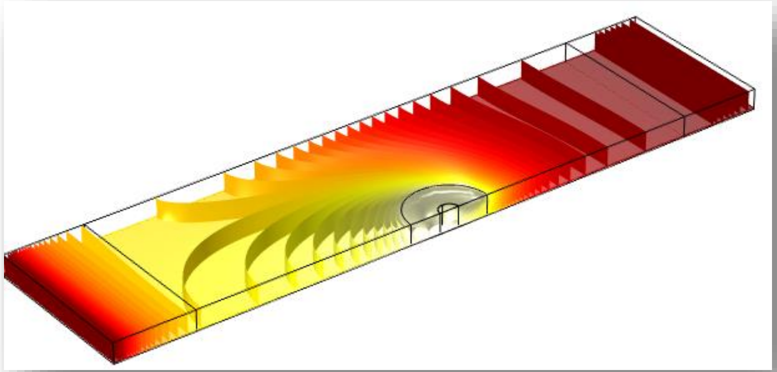
Friction Stir Welding

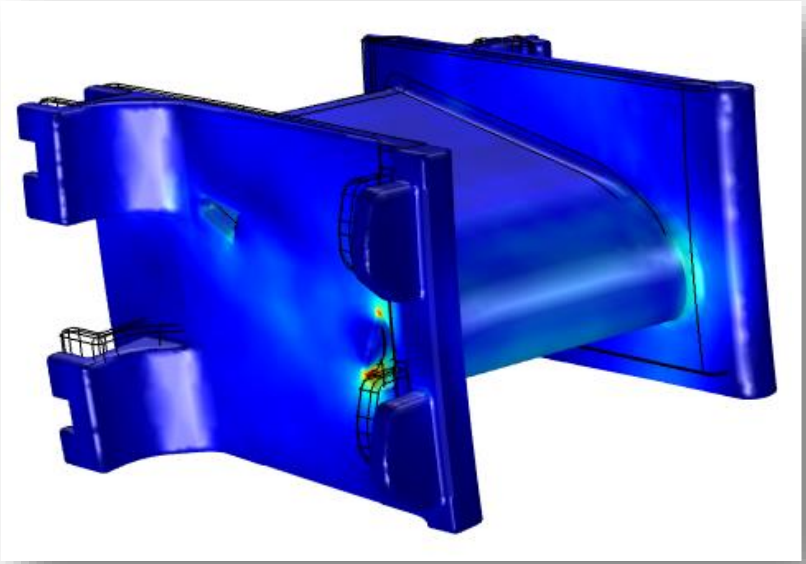
- In this model, two aluminum plates are joined by generating friction heat with a rotating tool. Heat is transferred by conduction from the tool into the plates. The movement of the tool is taken into account by adding translation as an advective term. The plate surfaces are cooled through free convection and surface-to-ambient radiation.



Thermal Stress

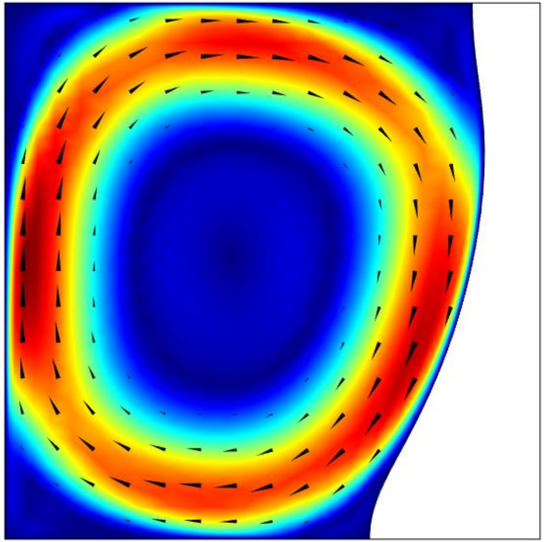
- This models accounts for heat transport and structural stresses and strains resulting from high temperature gradients in a stator blade.
  It couples the Heat Transfer in Solids and Solid Mechanics interfaces.

- This plot shows the von Mises stress and the deformed shape of the blade.



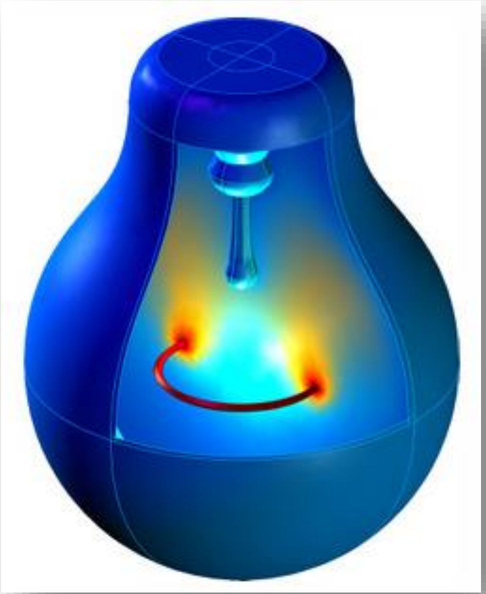
Tin melting Front

- Phase transition in a cavity containing both solid and liquid tin is submitted to a temperature difference between left and right boundaries.
- Fluid and solid parts are solved in separate domains sharing a moving melting front. The position of this boundary through time is calculated according to the Stefan energy balance condition.
- In the melt, motion generated by natural convection is expected due to the temperature gradient. This motion, in turn, influences the front displacement.



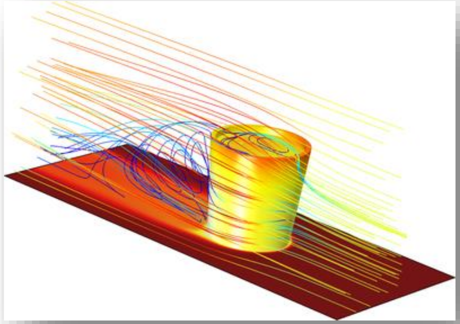
Light Bulb

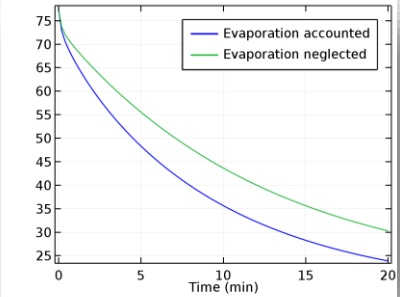
- This model treats the free convection of argon gas within a light bulb.
- It shows the coupling of heat transport (conduction, radiation, and advection) to momentum transport (non-isothermal flow) induced by density variations caused by temperature (free convection).



Latent Heat of Evaporation

- This tutorial shows how to model evaporative cooling.
- The effects need to be taken into account are heat transfer, transport of water vapor and fluid flow.
- User-defined expressions are used to implement the source term for the water vapor and evaporative heat source, as well as the moist air feature to accurately describe the material properties.

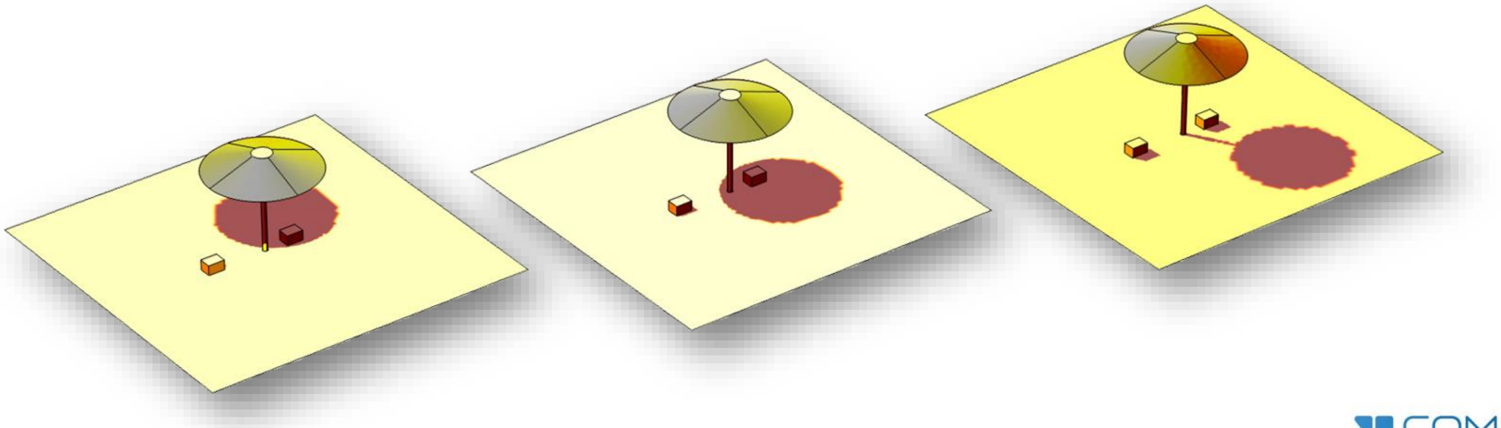




COMSOL

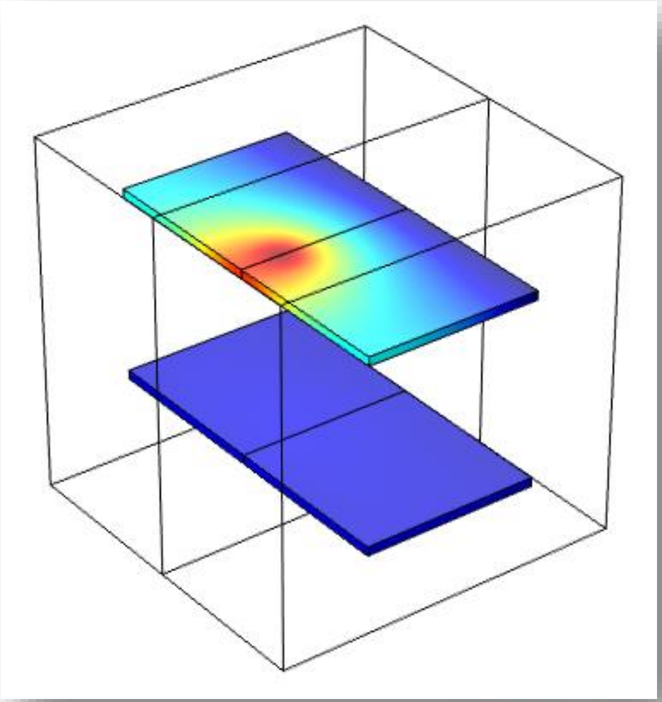
Solar and Ambient Radiation

- This model uses the external radiative heat source feature with solar position option.
- The sun's position and shadow effects are automatically updated during the simulation.
- The wavelength dependency of surface emissivity is considered



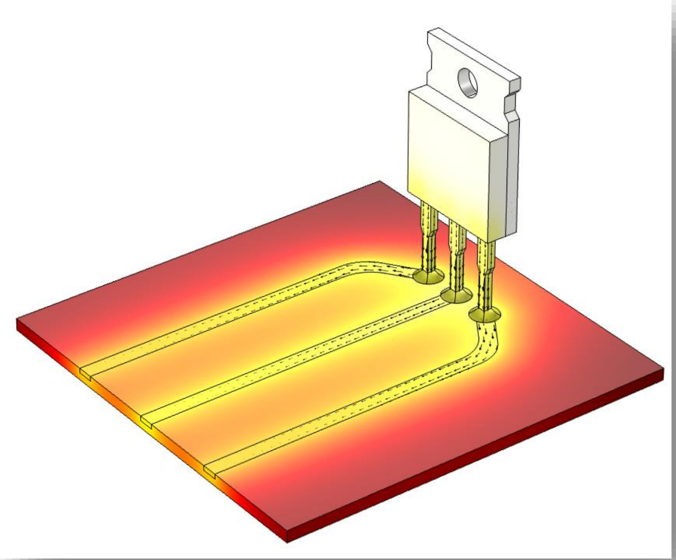
Mixed Diffuse-Specular Radiation

- This model shows how to use the Mathematical Particle Tracing interface to simulate mixed diffuse-specular reflection between surfaces in an enclosure.
- The first part compares the heat fluxes computed by the Mathematical Particle Tracing interface with the exact analytical solution for two identical infinitely long parallel gray plates under mixed diffuse-specular reflection at constant temperature.
- The second part couples the Mathematical Particle Tracing interface with the Heat Transfer in Solids interface for the parallel plate geometry but with different characteristics and spatially varying temperatures.



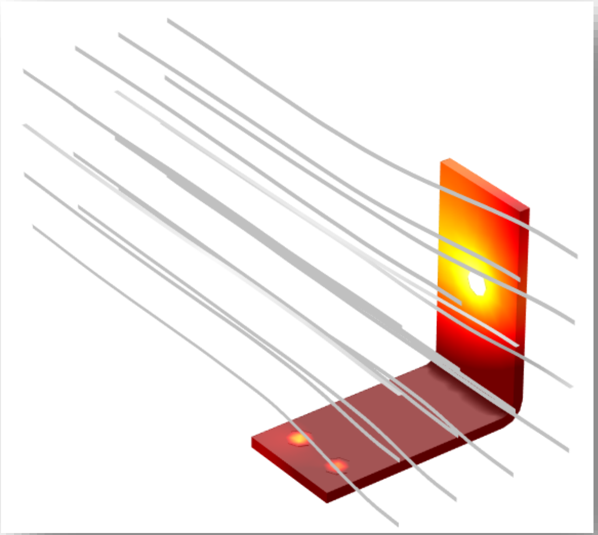
Power Transistor

- This model simulates a system consisting of a small part of a circuit board containing a power transistor and the copper pathways connected to the transistor.
- The simulation estimates the operating temperature of the transistor. We investigate if heat sink mounting is necessary or if the operating temperature can be low enough in the absence of a heat sink.



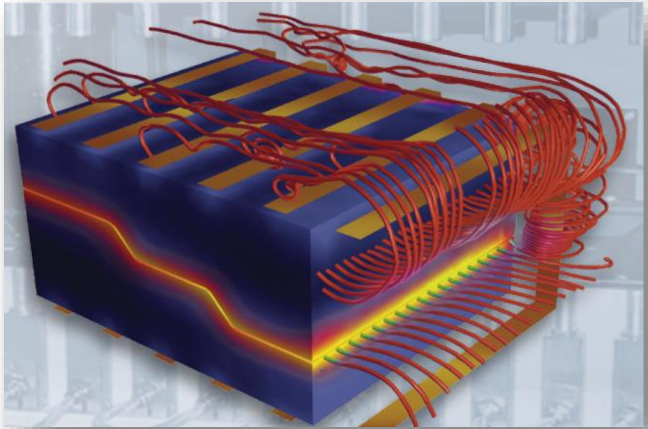
Fluid Flow with Joule Heating

- This model estimates the temperature field induced by Joule heating in a busbar cooled by an air flow.
- It shows the coupling between heat transfer, electric currents and fluid flow.



Induction Heating

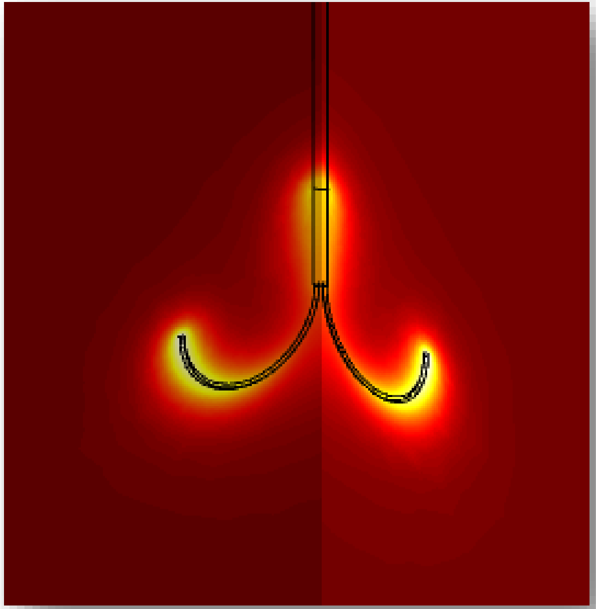
- The model shows the magnetic flux (streamlines) and temperature distribution (color plot) in the electromagnetic induction molding apparatus and composite material



Model and pictures courtesy of José Feigenblum, RocTool, Le Bourget Du Lac, France.

Tumor Ablation

- This example accomplishes localized heating by inserting a four-armed electric probe through which an electric current runs.
- The heat source resulting from the electric field is also known as resistive heating or Joule heating.
- This model uses the Bioheat Transfer interface and the Electric Currents interface to implement a transient analysis.
- Damage integral analysis is used to predict the tissue necrosis



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