National Renewable Energy Laboratory
Innovation for Our Energy Future

CoolCab Thermal Load Reduction Project: CoolCalc HVAC Tool Development

U.S. Department of Energy
Annual Merit Review

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Overview

Timeline

- Project start date: FY06
- Project end date: FY13
- Percent complete: 50%

Barriers

- Industry lacks key performance data on HVAC loads and truck cab thermal load reduction technologies
- Truck fleets operate on small profit margins and are sensitive to purchase costs for equipment

Budget

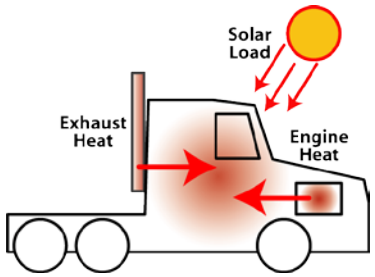
- Total project funding
  - DOE share: $1700k
  - Contractor share: $0.00
- FY09 Funding: $300k
- FY10 Funding: $900k

Partners

- Interactions
  - Kenworth (PACCAR)
  - Volvo Truck
  - International
  - Freightliner
  - Schneider National
  - Webasto
- Project lead: NREL

Project Description - Relevance

THE CHALLENGE



- Sleeper cab hotel load idling uses more than 838 million gallons of fuel annually*
  - More than 2 billion gallons with workday idling **
- Idling is done to
  - Heat or cool the cab/sleeper
  - Keep the fuel warm (gelling)
  - Keep the engine warm (startup)
- Varying thermal conditions inhibit the use of idle reduction technologies

THE OPPORTUNITY

- Reducing the load will enable idle reduction technologies
- Fleet owners and operators economically motivated
  - 3 year payback
  - Direct impact on bottom line

Data Source: EIA Short-Term Energy Outlook

** Stodolsky et al, Analysis of Technology Options to Reduce the Fuel Consumption of Idling Trucks. 2000. ANL/ESD-43*

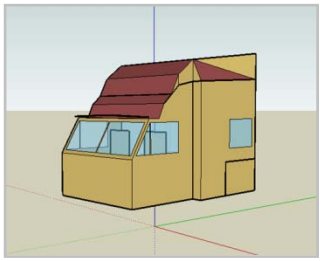
*** Gaines et al, Estimation of Fuel Use by Idling Commercial Trucks. 2006. Paper No. 06-2567*

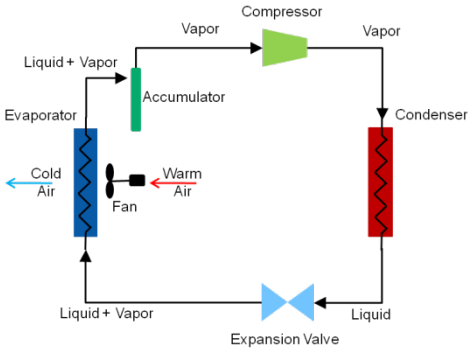
Objectives - Relevance

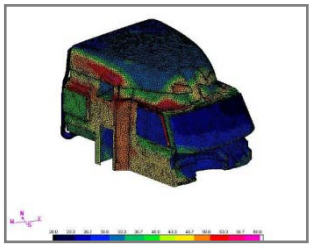
- Overall Objectives
  - Design efficient thermal management systems that keep the cab comfortable without the need for engine idling, helping to reduce the 838 million gallons of fuel used for truck hotel loads every year
  - Research and develop technologies to reduce truck cab thermal load through testing and analysis
  - Develop tools and test methods to assess idle reduction technologies
  - Work with industry partners to develop and apply viable solutions
- FY10 Objectives
  - Develop a tool to help predict HVAC load reduction in sleeper cabs
  - Validate tool using data from vehicle thermal testing

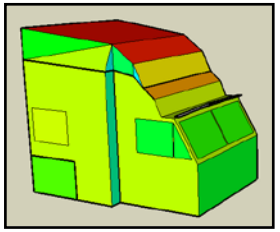
Milestones - Relevance

Dates	Month	Key Milestone
2009	Apr	• CoolCalc concept assessed using test data
2009	Aug	• Developed working prototype of the CoolCalc Thermal Load Estimation Tool
2009	Sept	• Completed testing of Kenworth Truck • DOE Milestone summary report • CRADAs executed with two major industry partners: PACCAR and Volvo
2010	Apr	• Completed developing simple A/C model framework
2010	Aug	• Complete validation of CoolCalc tool using NREL test data • Complete summer testing of Volvo truck
2010	Sept	• Develop mobile air conditioning system model and integrate with CoolCalc • Demonstrate CoolCalc and A/C model link to PSAT vehicle model

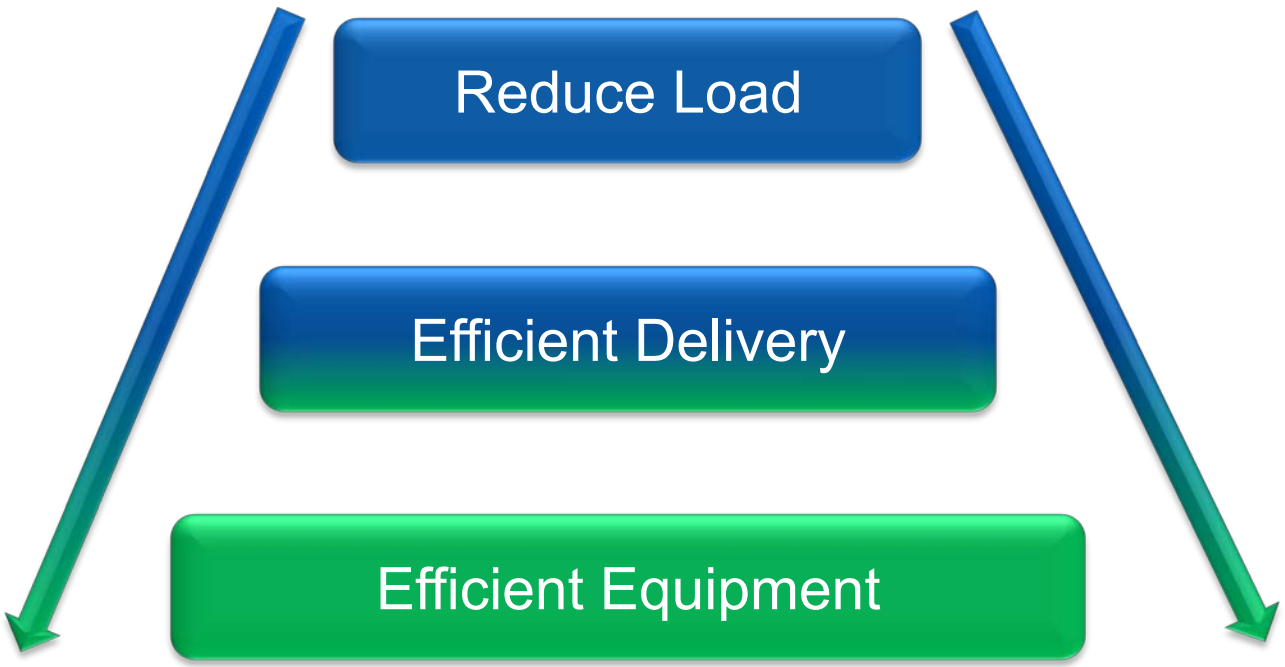






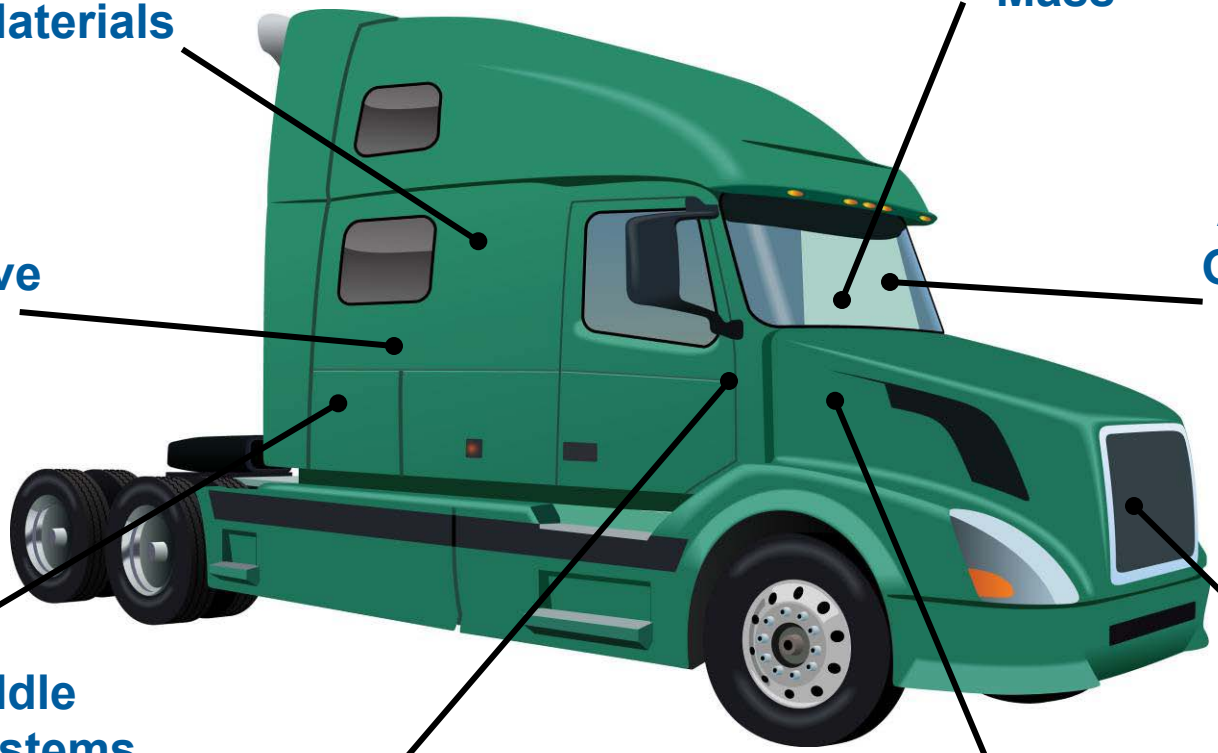


System Level Solution - Approach



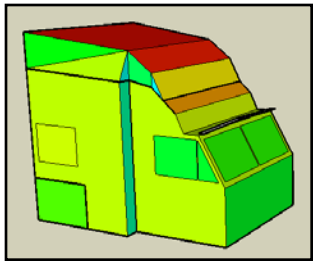
Decreases in load have a larger impact on fuel use due to equipment and delivery losses.

Advanced Technologies - Approach



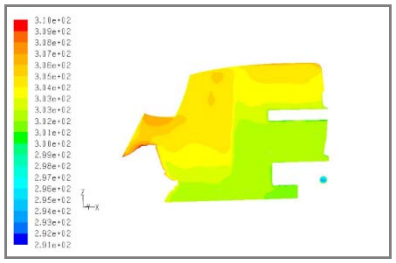
Suite of Tools - Approach

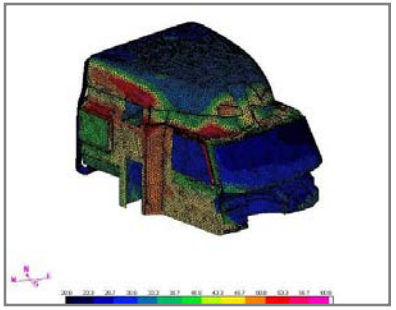
CoolCalc



Load Estimation

CFD



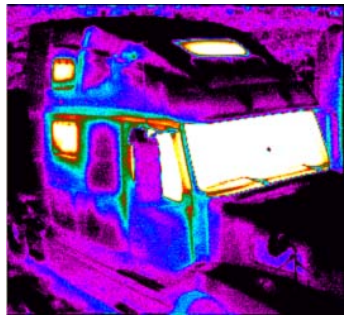


Detailed Flow Analysis

Fuel Consumption

In-Use Validation

Testing

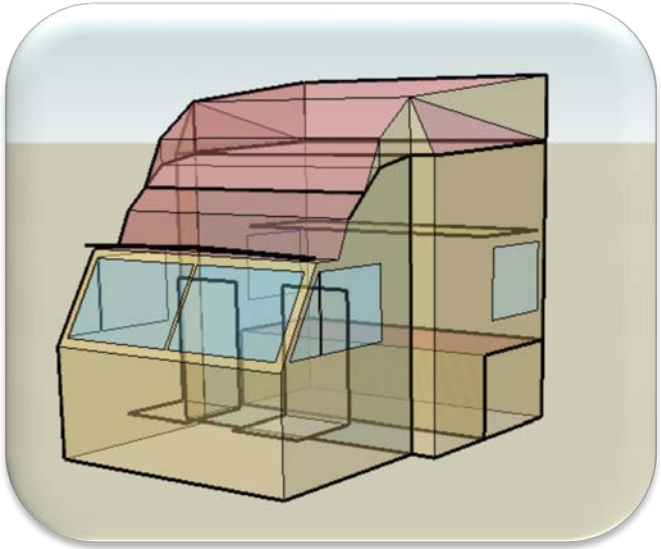


Vehicle Modeling

CoolCalc - Accomplishments

- Physics-based model
  - No meshing
  - Flexible geometry
  - Less time intensive
  - Excludes unnecessary detail
  - Easy to use
- Applications
  - Trade-off studies
  - Technology impact estimation
  - Preliminary design, focus detailed CFD

HVAC Load Estimation Tool Concept: CoolCalc

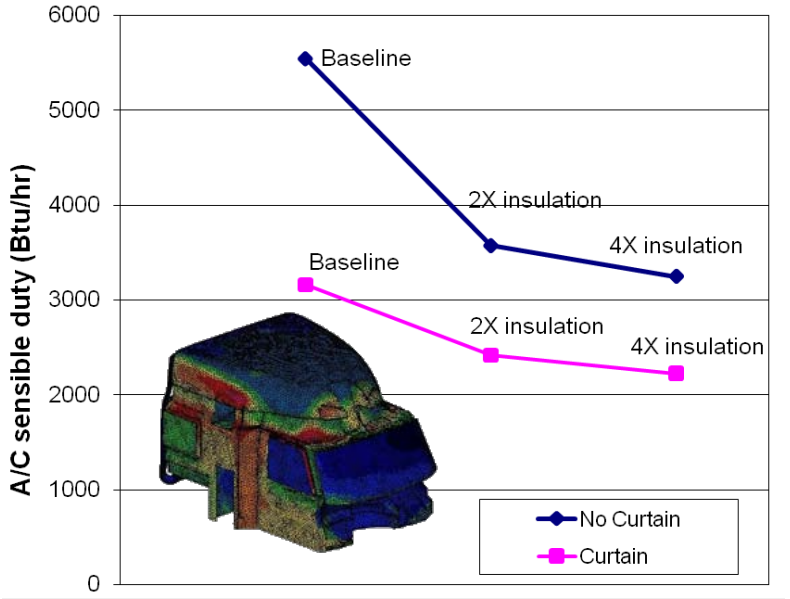


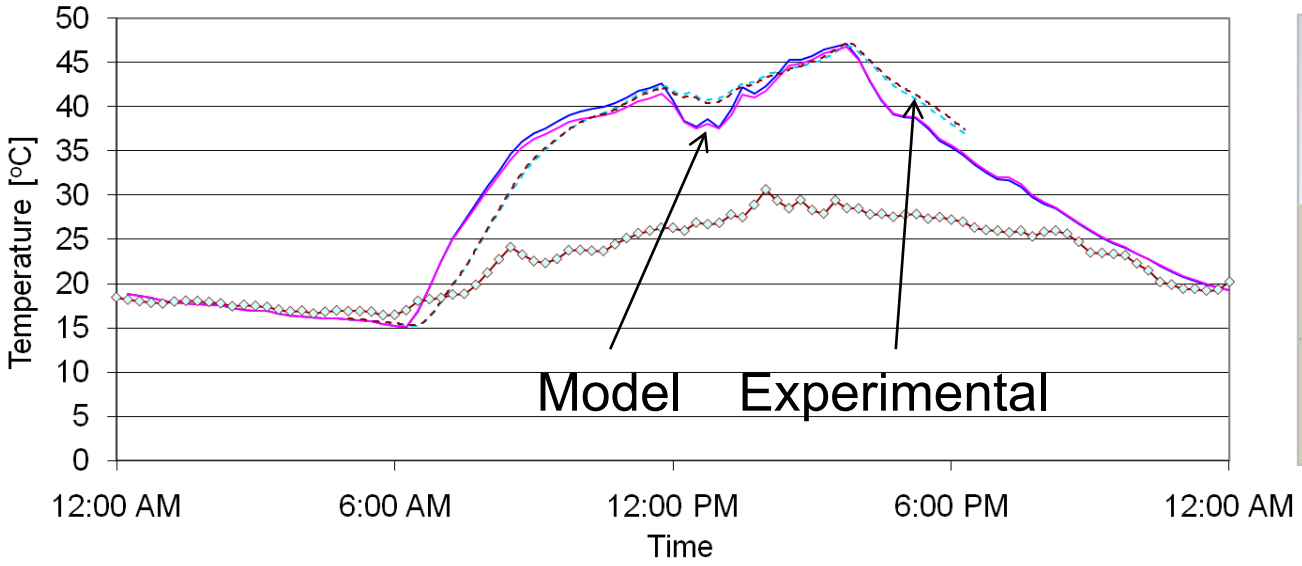
- Approach, leverage:
  - NREL's Open Studio Plug-In (2008)
    - DOE's EnergyPlus
    - SketchUp:
      - "3D for Everyone"
      - Designed to be "intuitive, flexible, and easier to use"

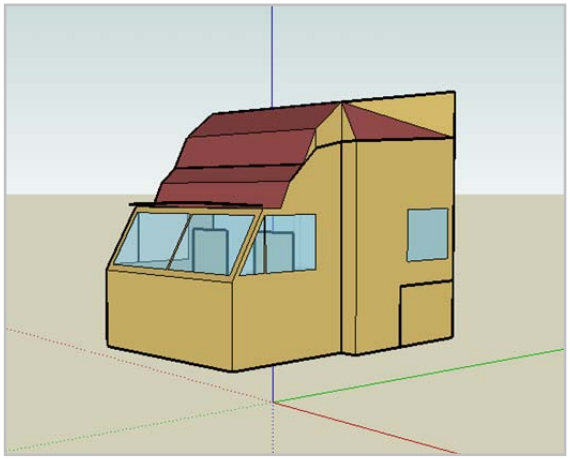
CoolCalc - Accomplishments

Previous - Accomplishments

- Developed CFD model of International truck
  - Validated with NREL data
  - Applied model to insulation study
- Tested Volvo and International trucks at NREL
- Assessed CoolCalc thermal load estimation tool concept using test data





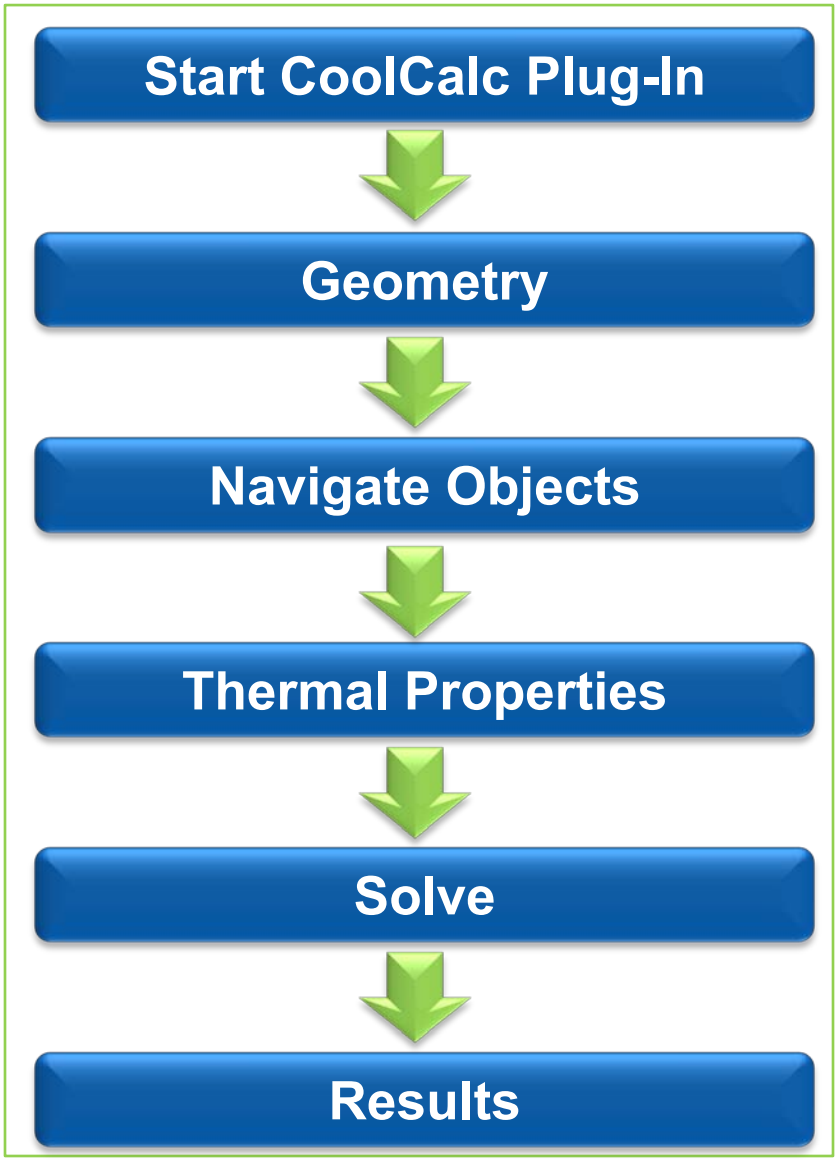


CoolCalc Development - Accomplishments

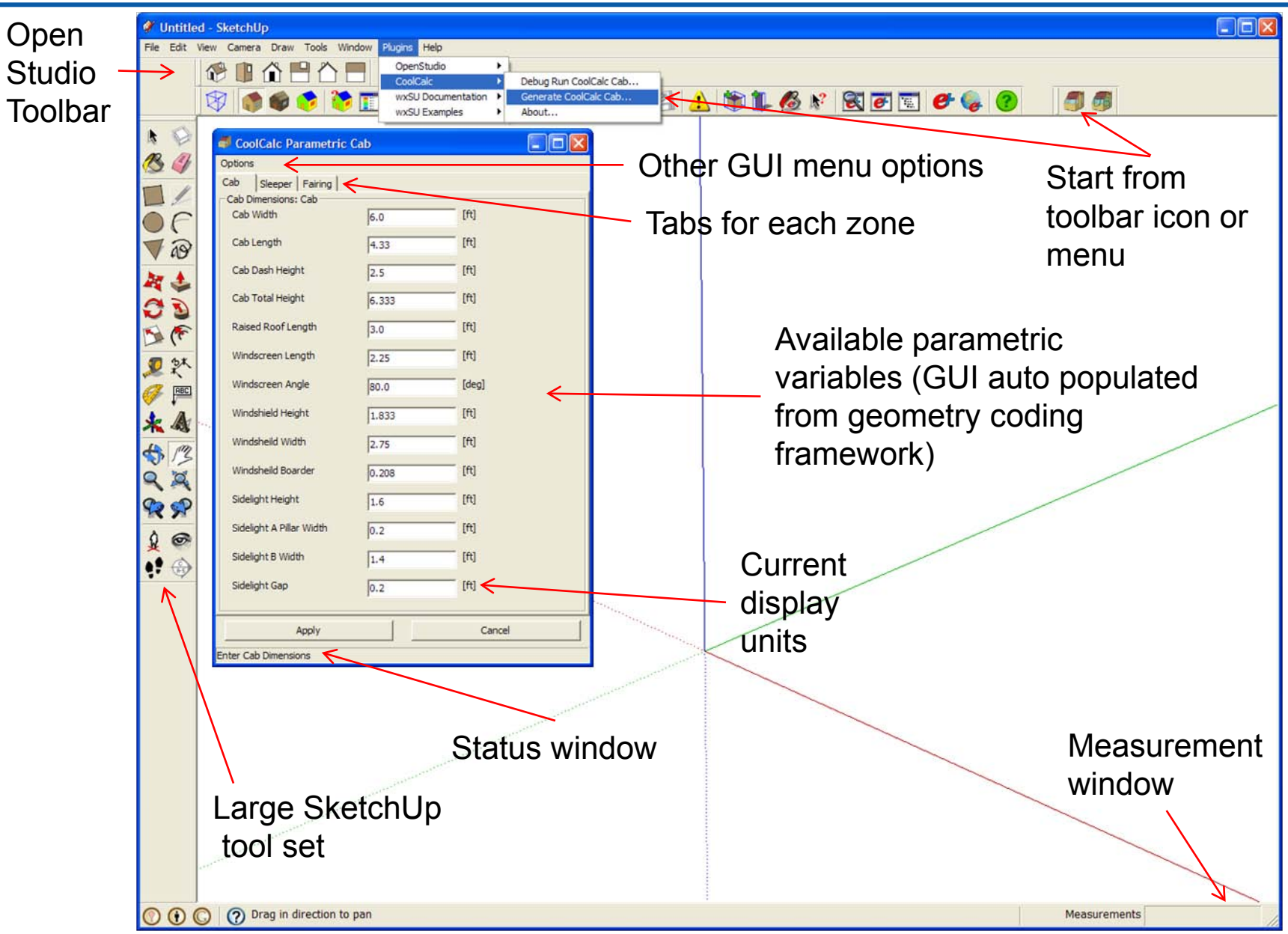
CoolCalc Accomplishments

- Geometry
  - Parametric cab creation
  - Manual modification
- Material property assignment
  - Thermal mass
  - Conductivity
  - Layered structures
  - Solar radiation properties
- Simple object browser
  - Access to all model objects
  - Text editing capability
- Coding framework
  - Interface to OpenStudio
  - Interface to SketchUp
  - Structure for geometry

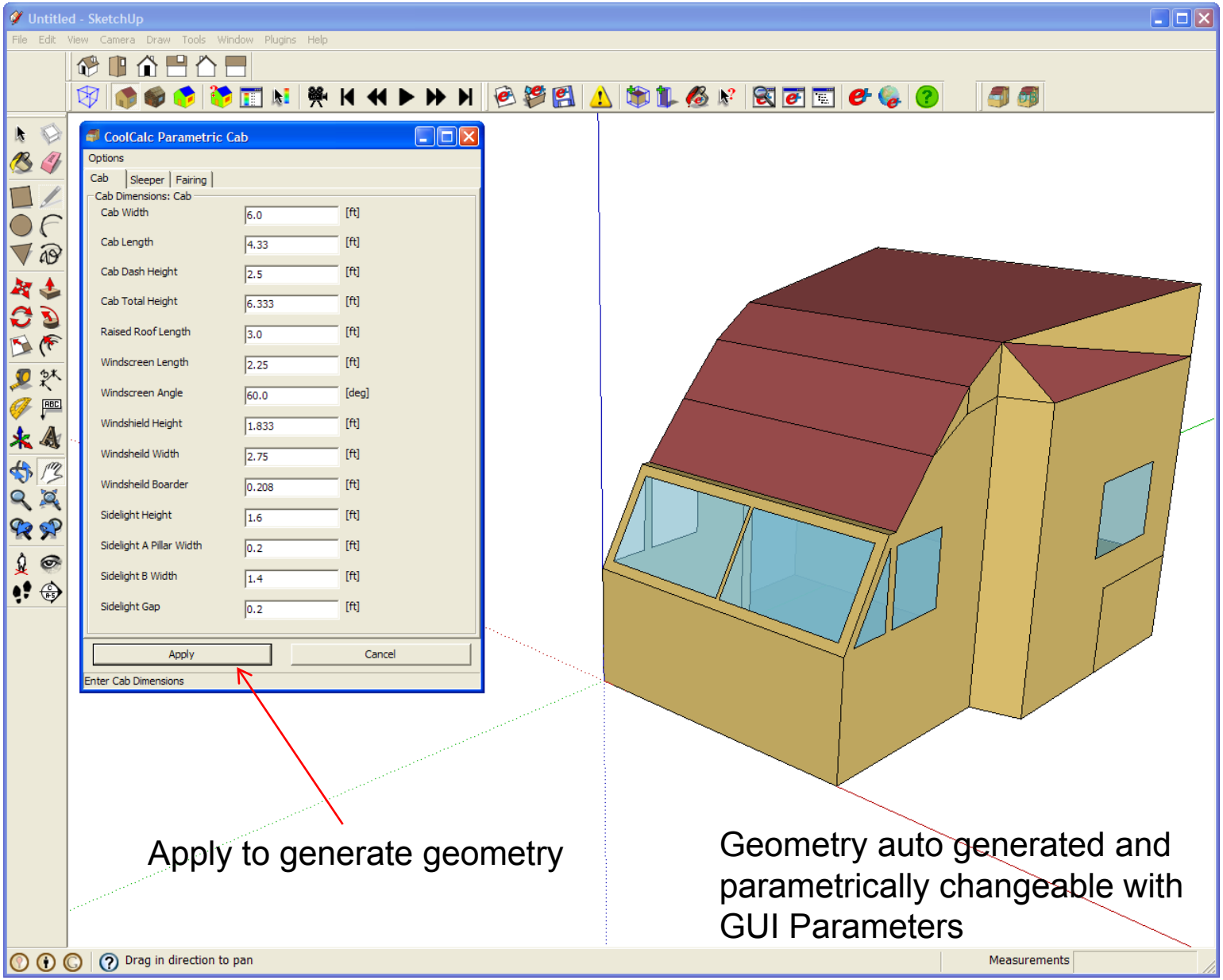
Modeling Flow Chart



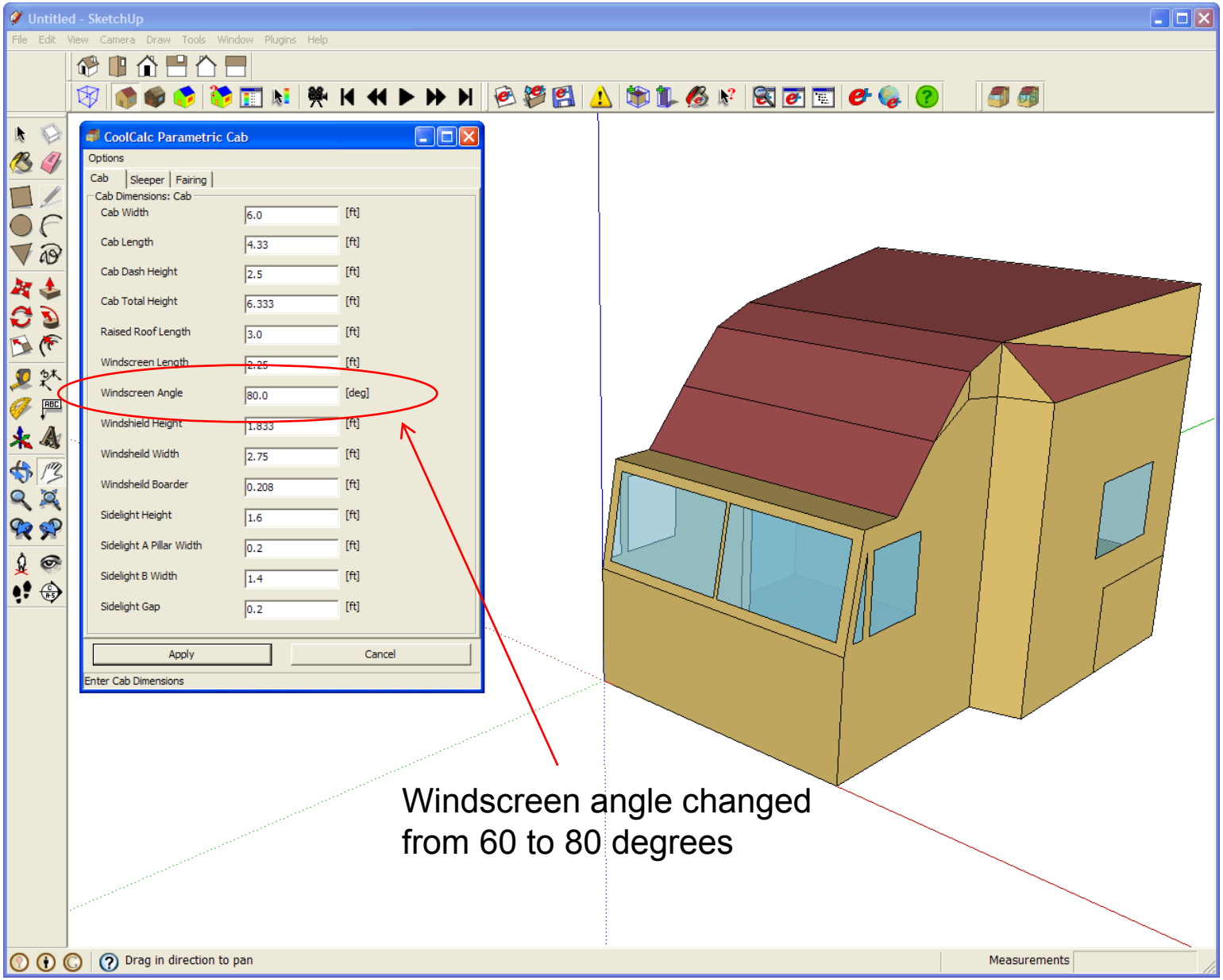
Start CoolCalc Plug-in



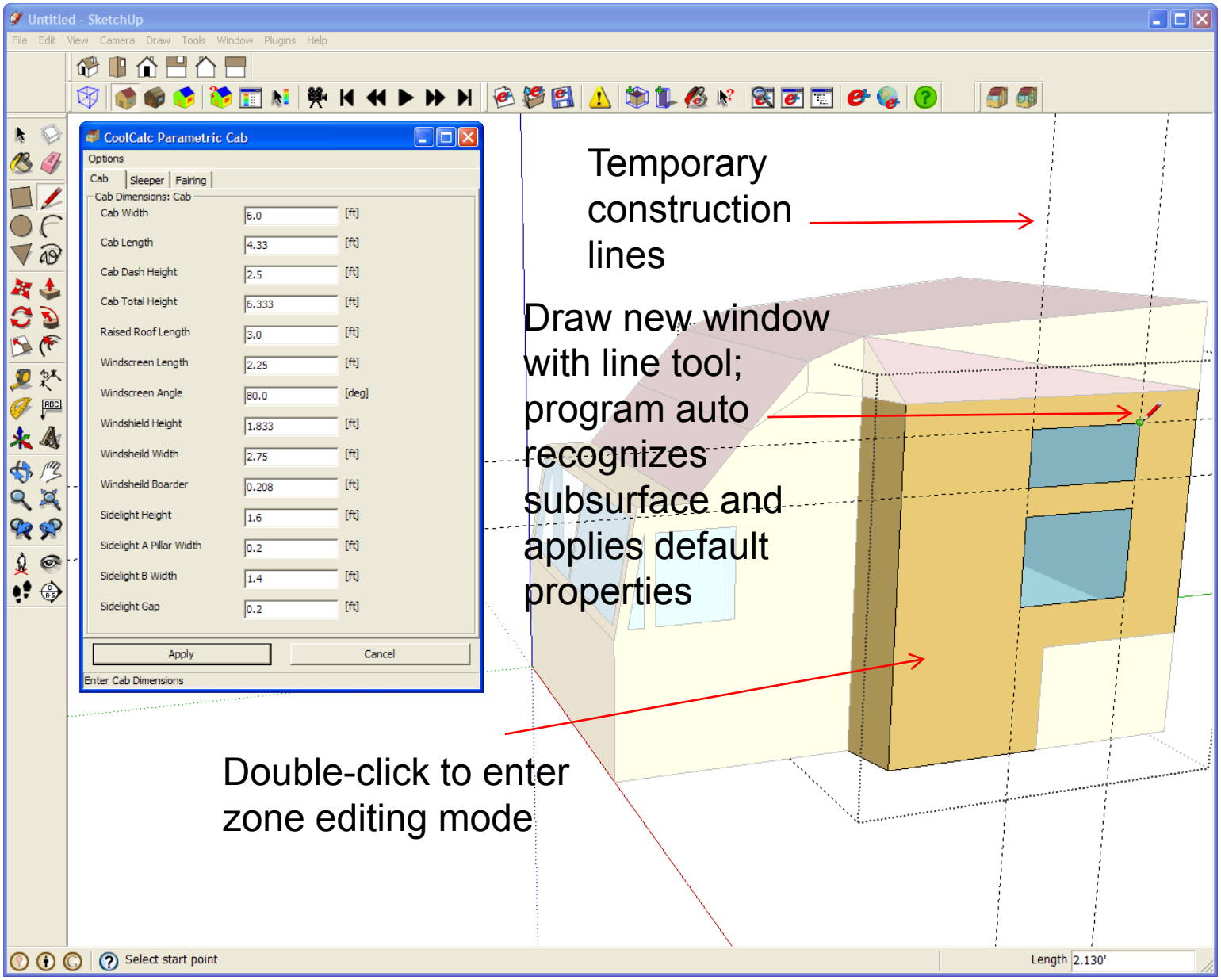
Geometry: Creation



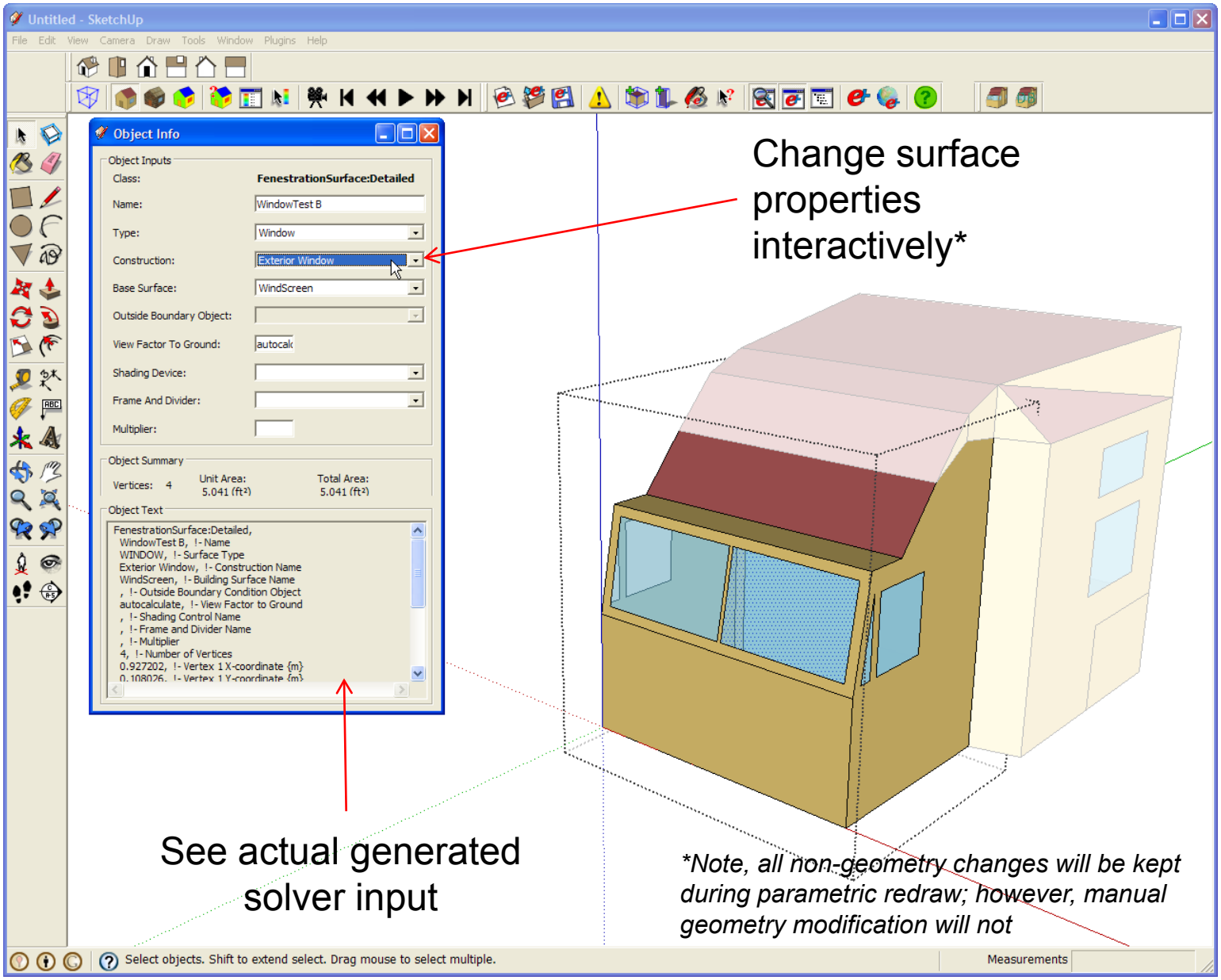
Geometry: Modify Parametrically



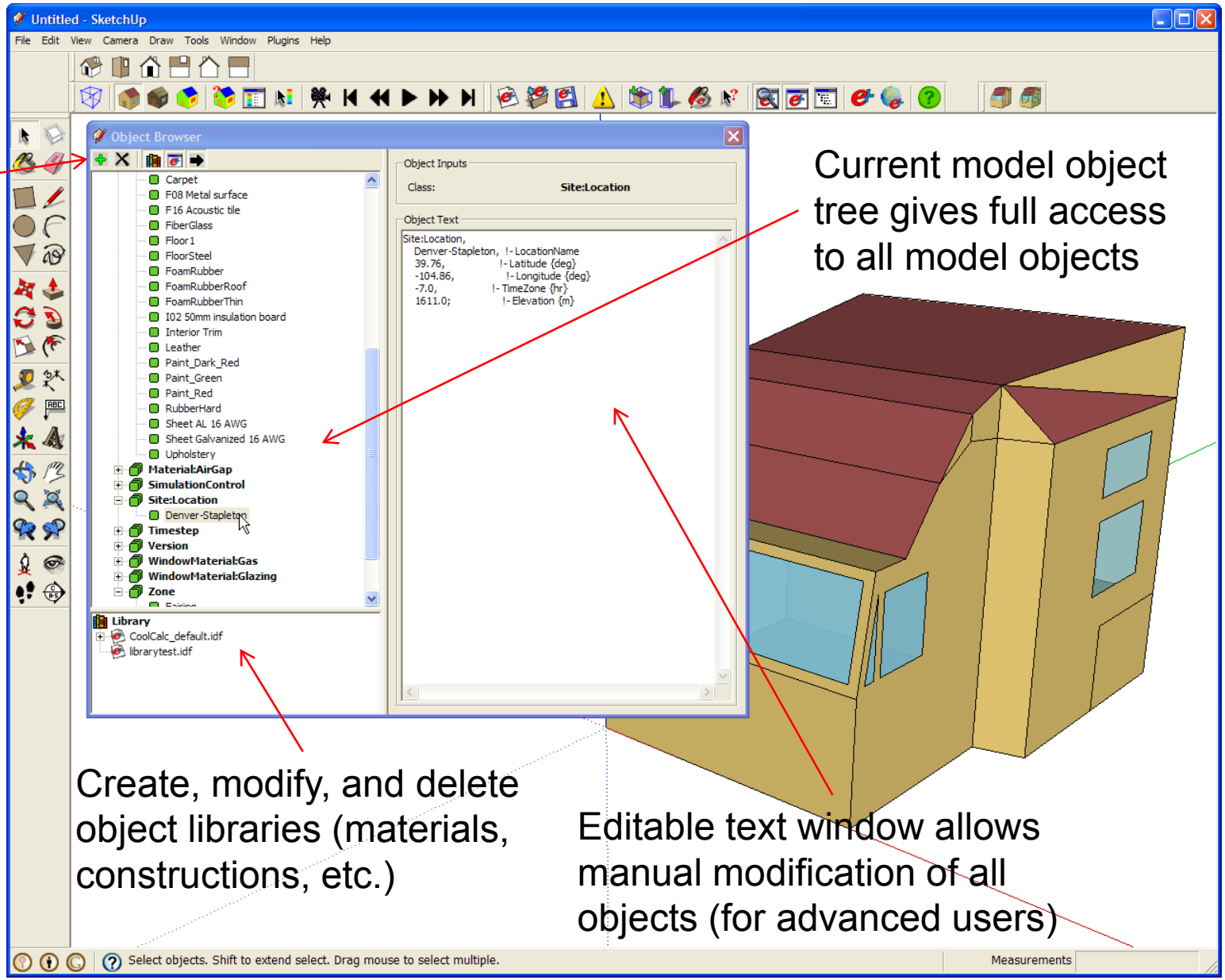
Geometry: Manual Modification



Navigate Objects: Interactive Surface Properties



Navigate Objects: Simple Object Browser



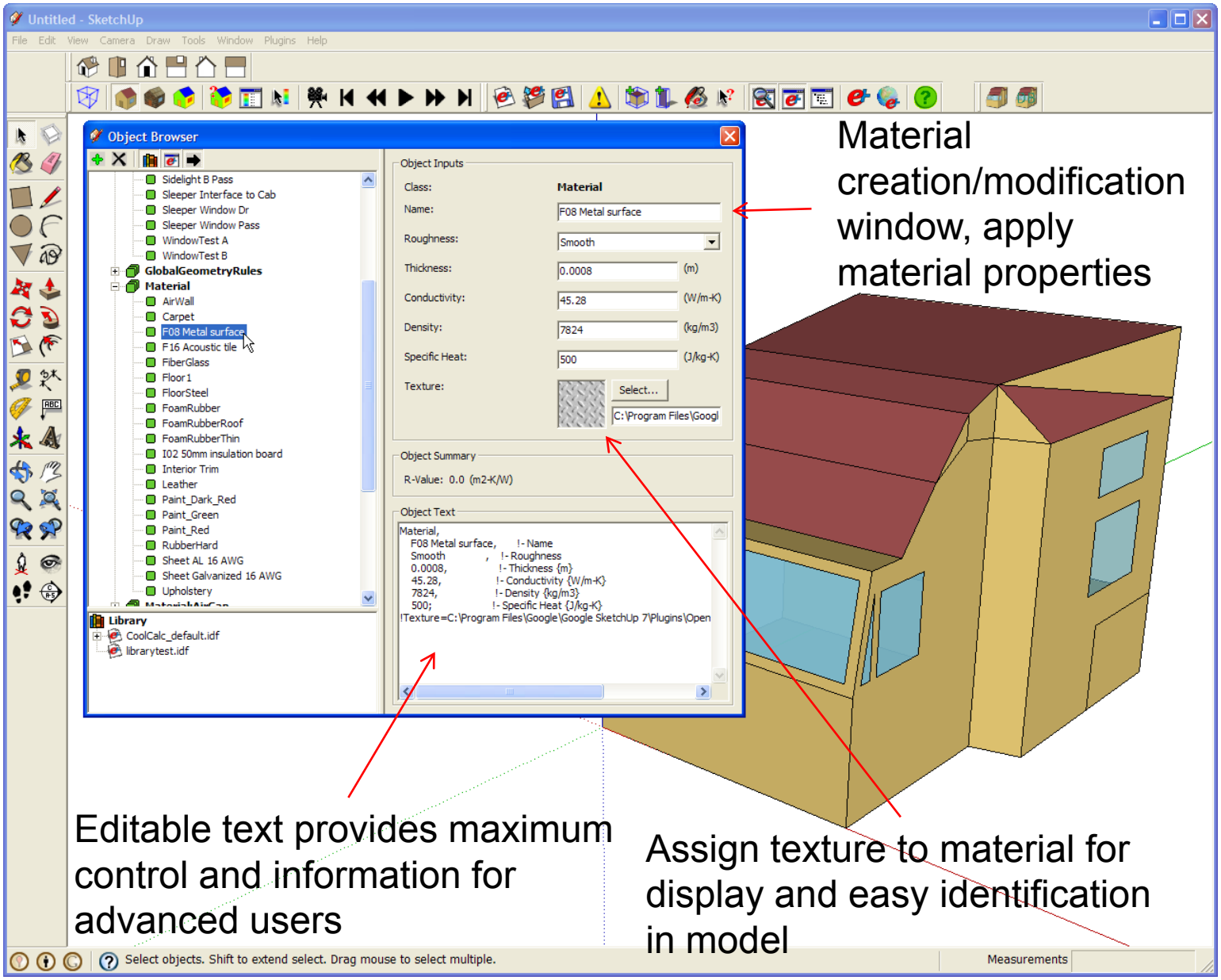
Toolbar

Current model object tree gives full access to all model objects

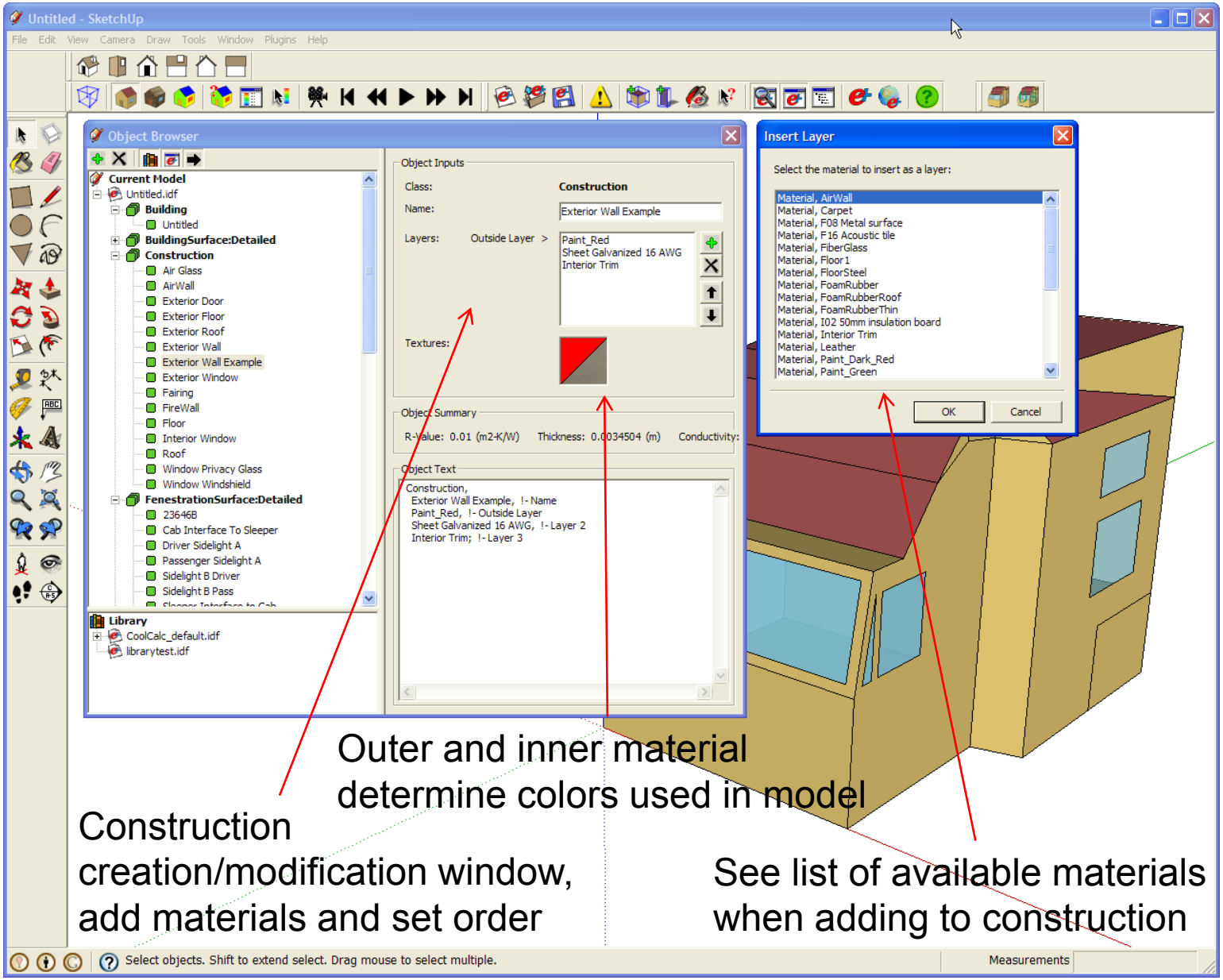
Create, modify, and delete object libraries (materials, constructions, etc.)

Editable text window allows manual modification of all objects (for advanced users)

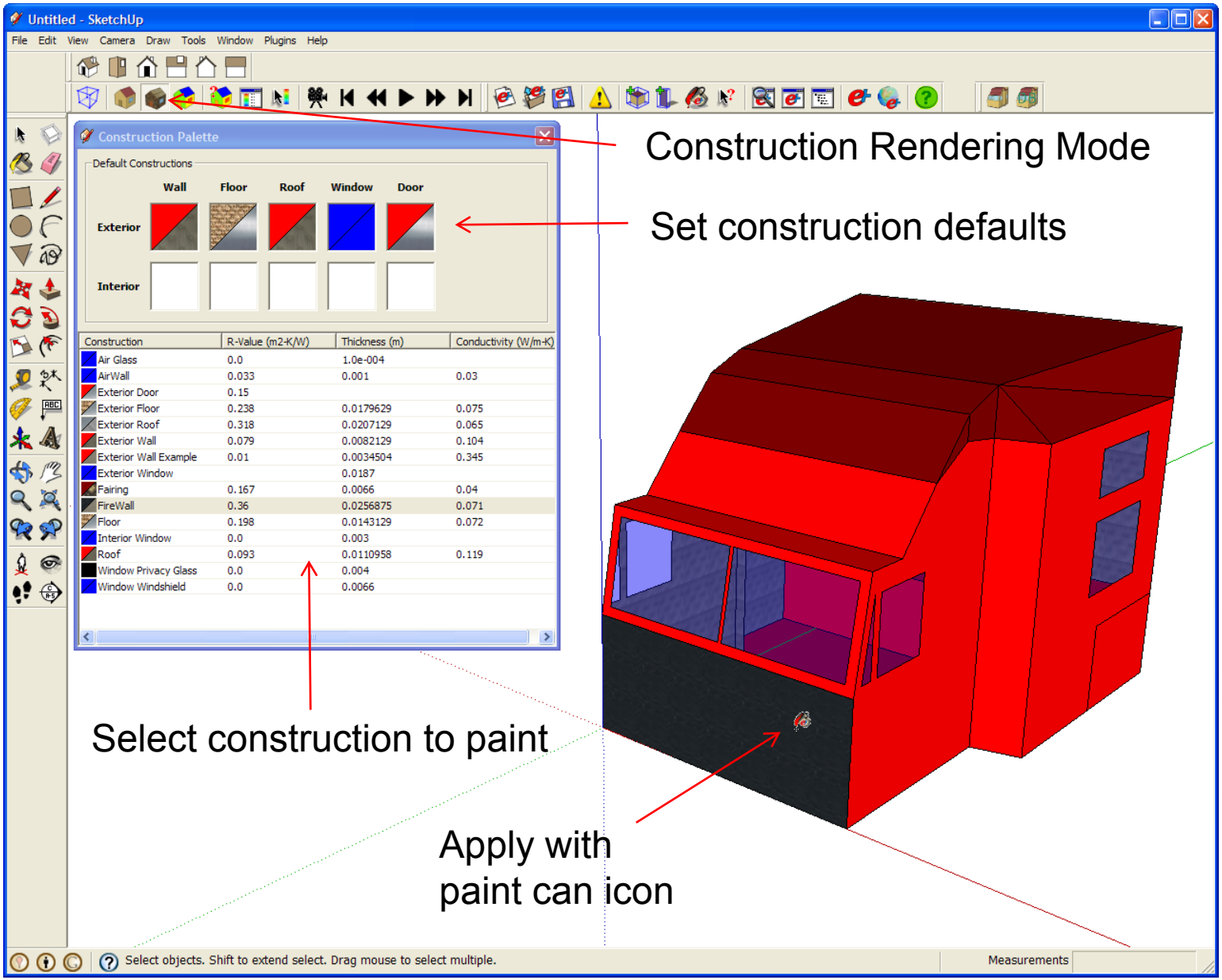
Thermal Properties: New Material



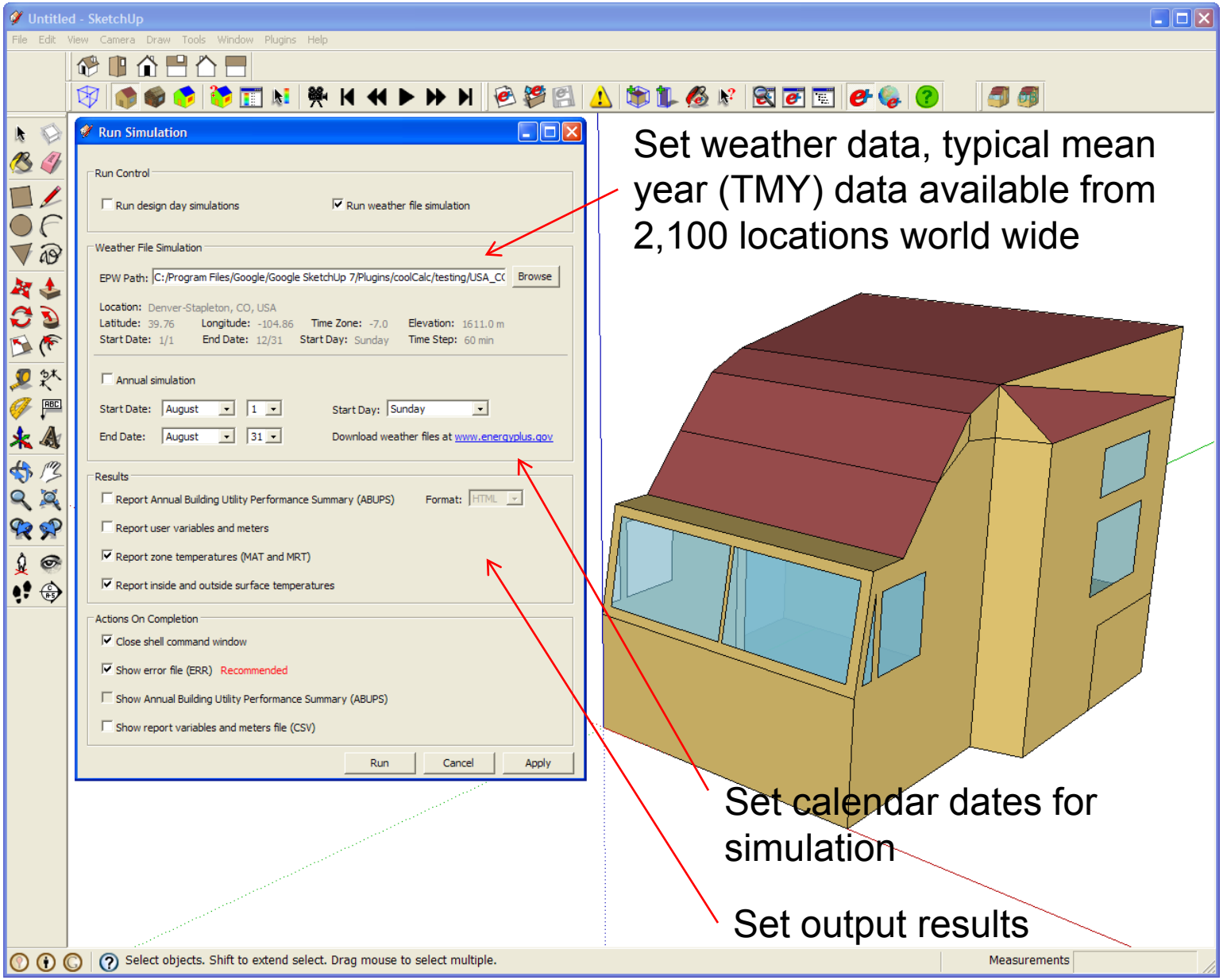
Thermal Properties: New Construction



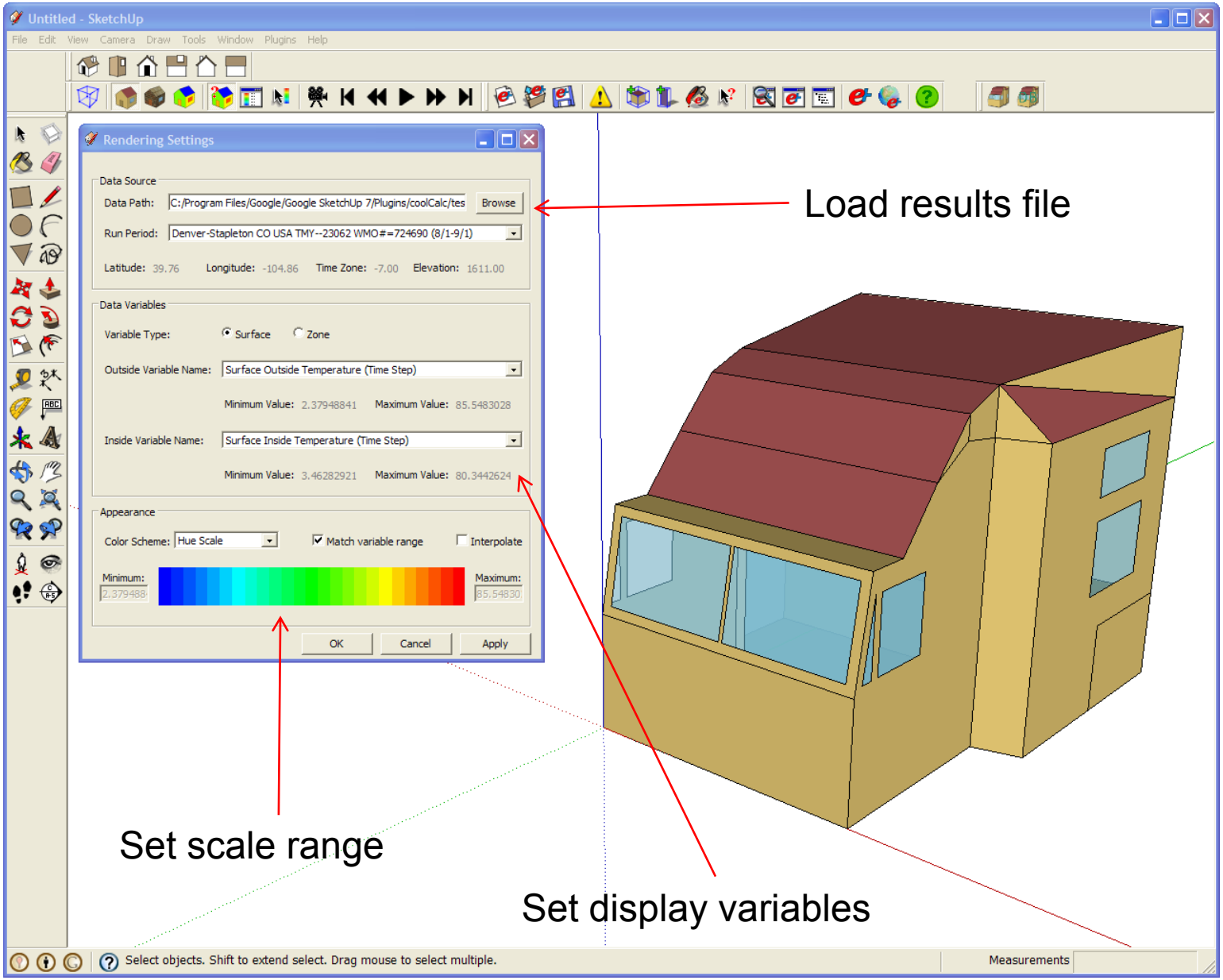
Thermal Properties: Apply Constructions



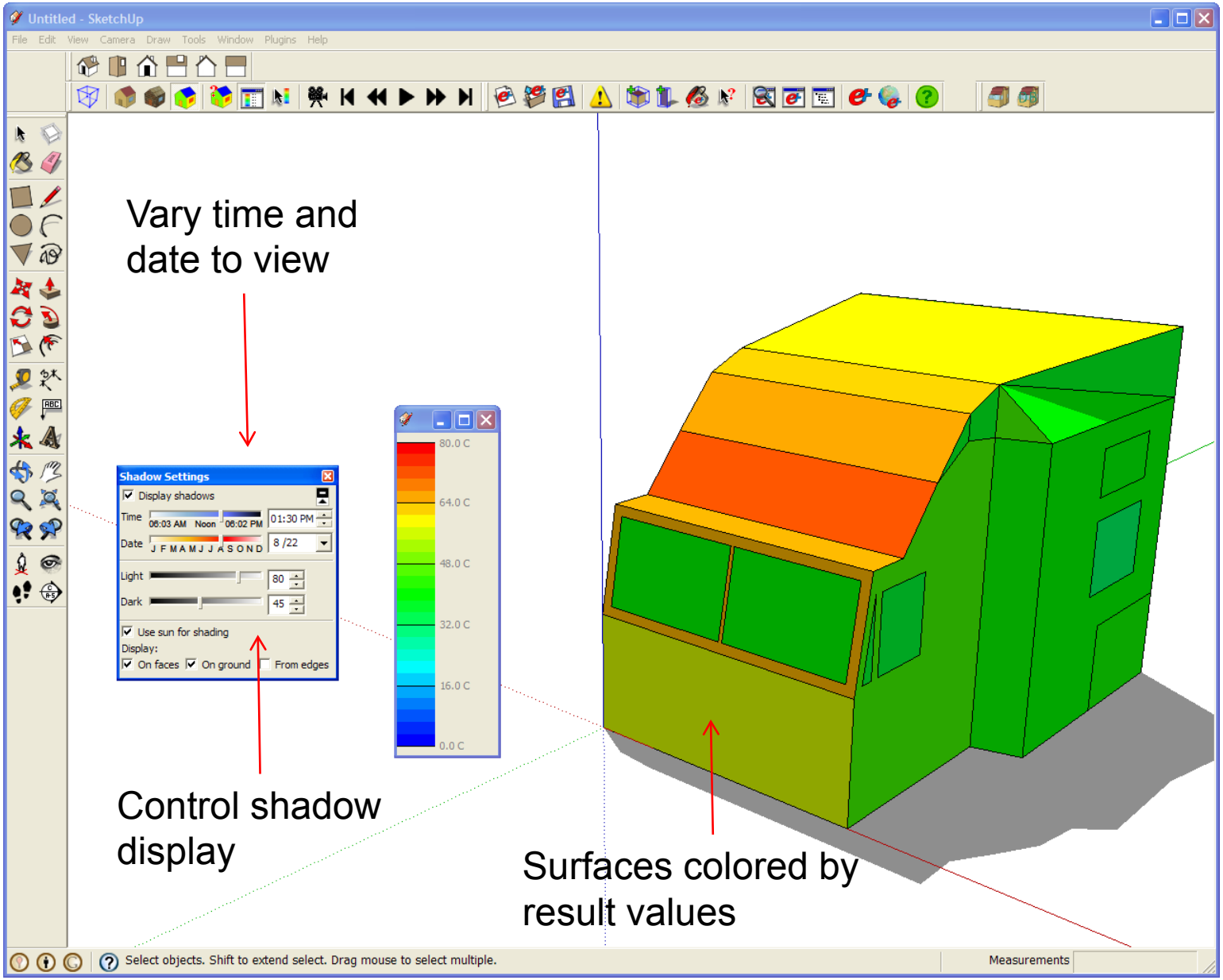
Solve: Setup Simulation



Results: Display Settings



Results: View



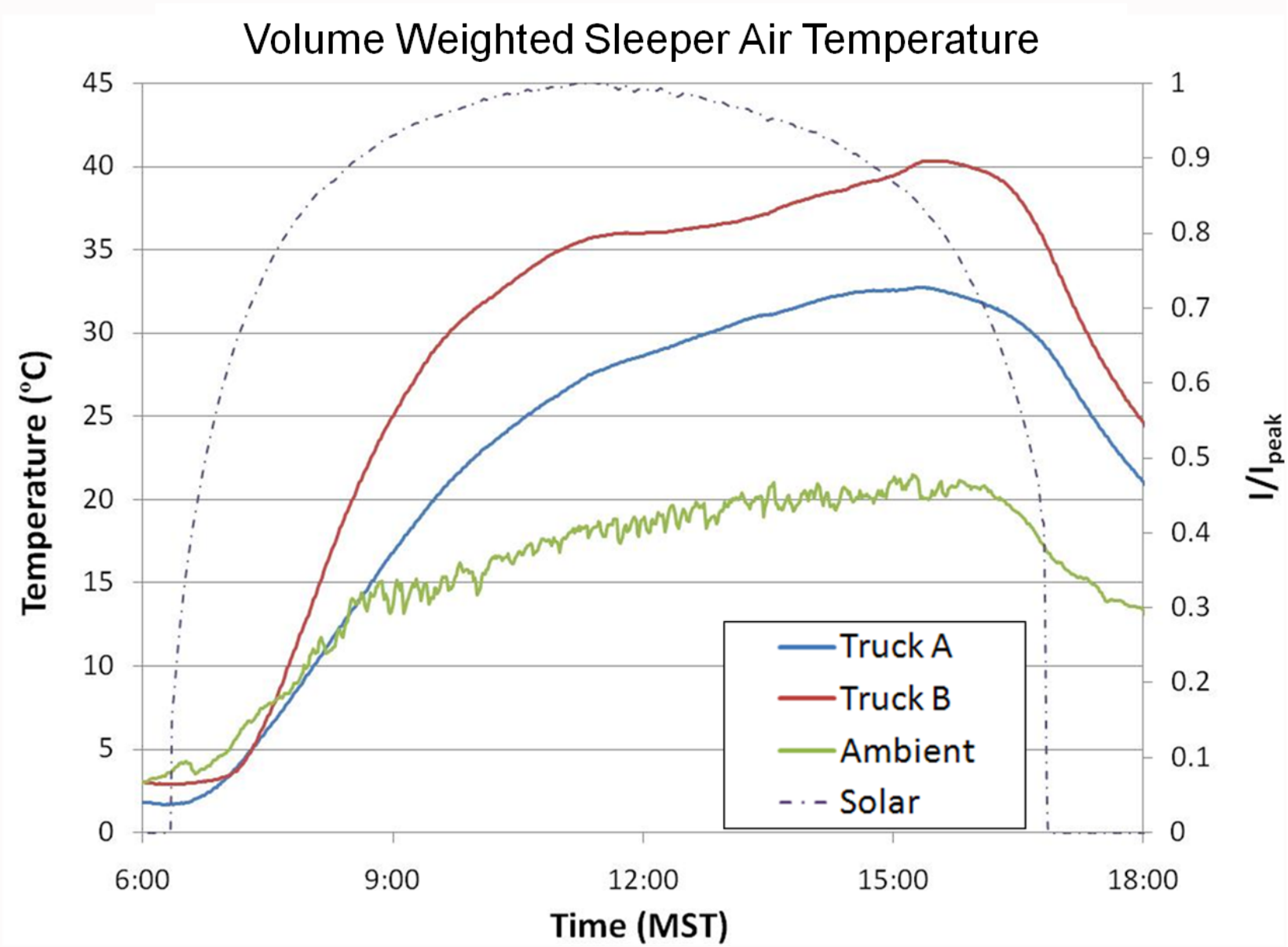
Vehicle Testing - Accomplishments

- Kenworth, Volvo, and baseline truck
- Instrumentation
  - 42 thermocouples/truck
    - 26 air & 16 surface
  - 2 humidity sensors
  - 1 pyranometer
  - 1 anemometer
  - Environmental data collected at NREL's weather station

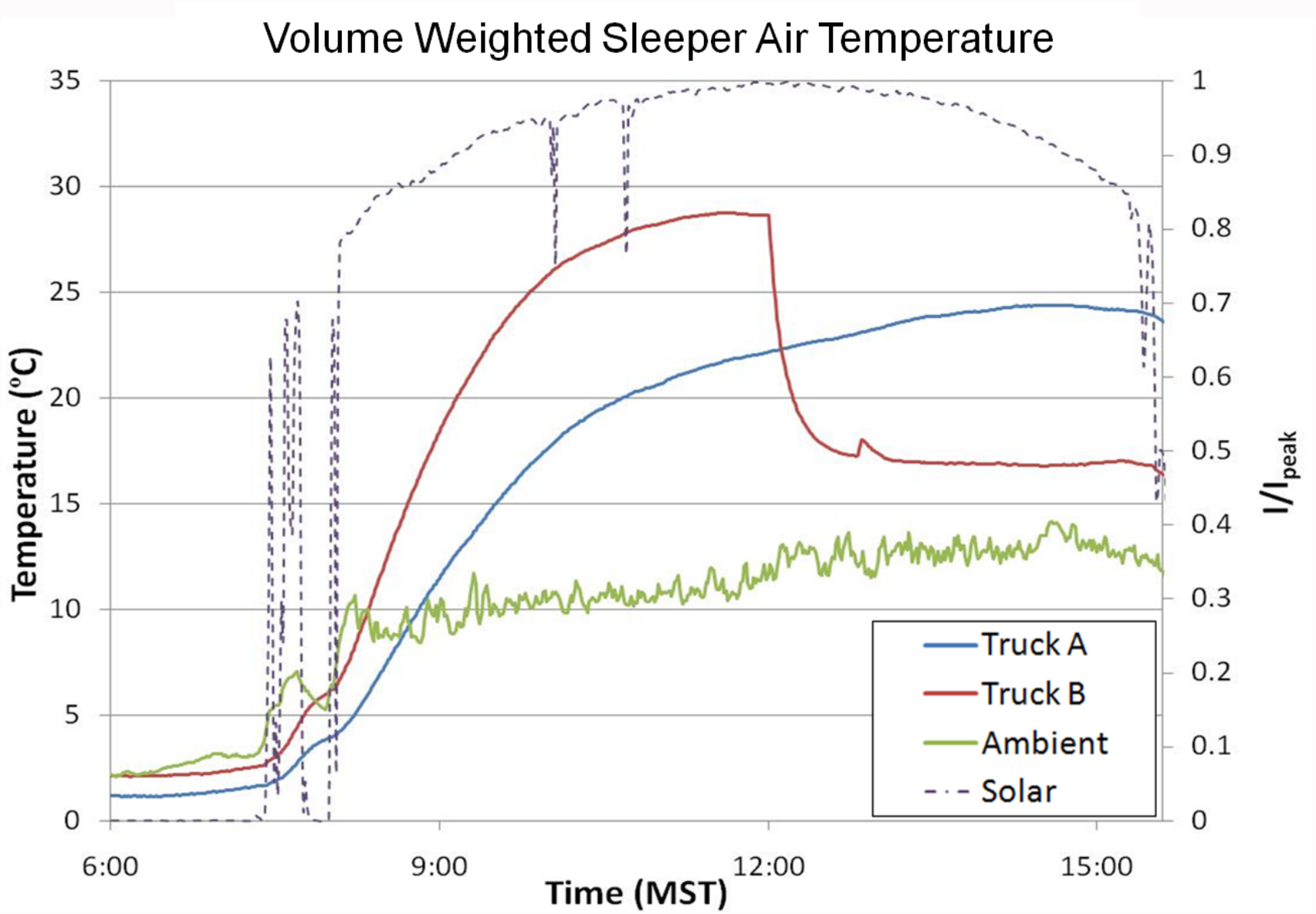
Goals

- Collect data for CoolCalc validation
- Characterize trucks' thermal load
- Investigate idle reduction technology

Thermal Soak - Accomplishments



Cool down - Accomplishments



UA Testing- Accomplishments

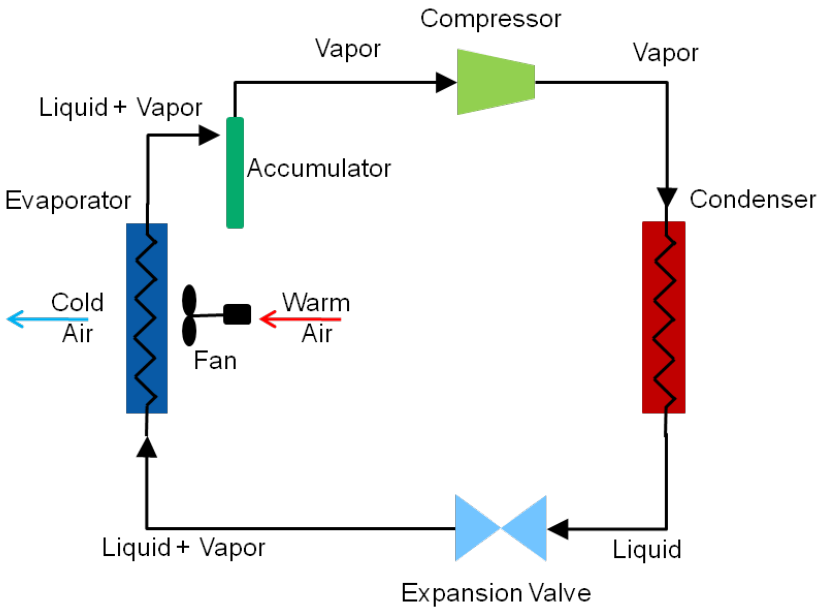
- Heater ran overnight
- 1:00 – 3:00 AM examined
- UA value calculated

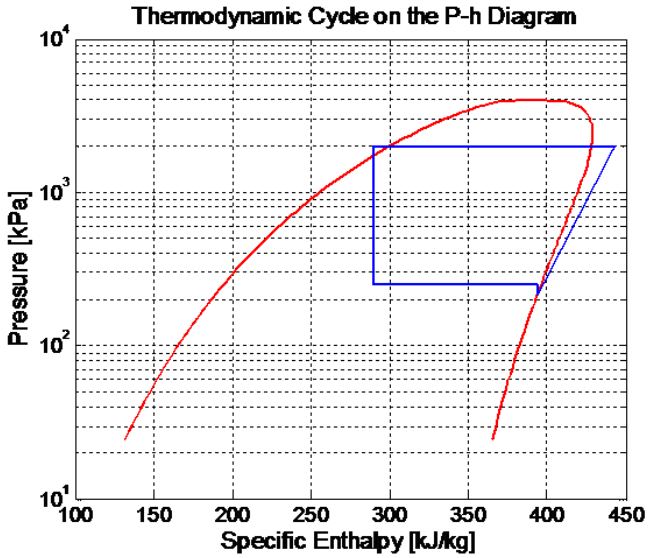
UA Calculations	
Test #	UA (W/K)
1	49.9
2	51.6
3	48.7
4	54.4
5	50.5
6	55.3
Average	51.7 ± 2.4

$$UA = \frac{Measured\ Heater\ Power}{\overline{T}_{air,truck} - \overline{T}_{air,ambient}}$$

A/C Model - Accomplishments

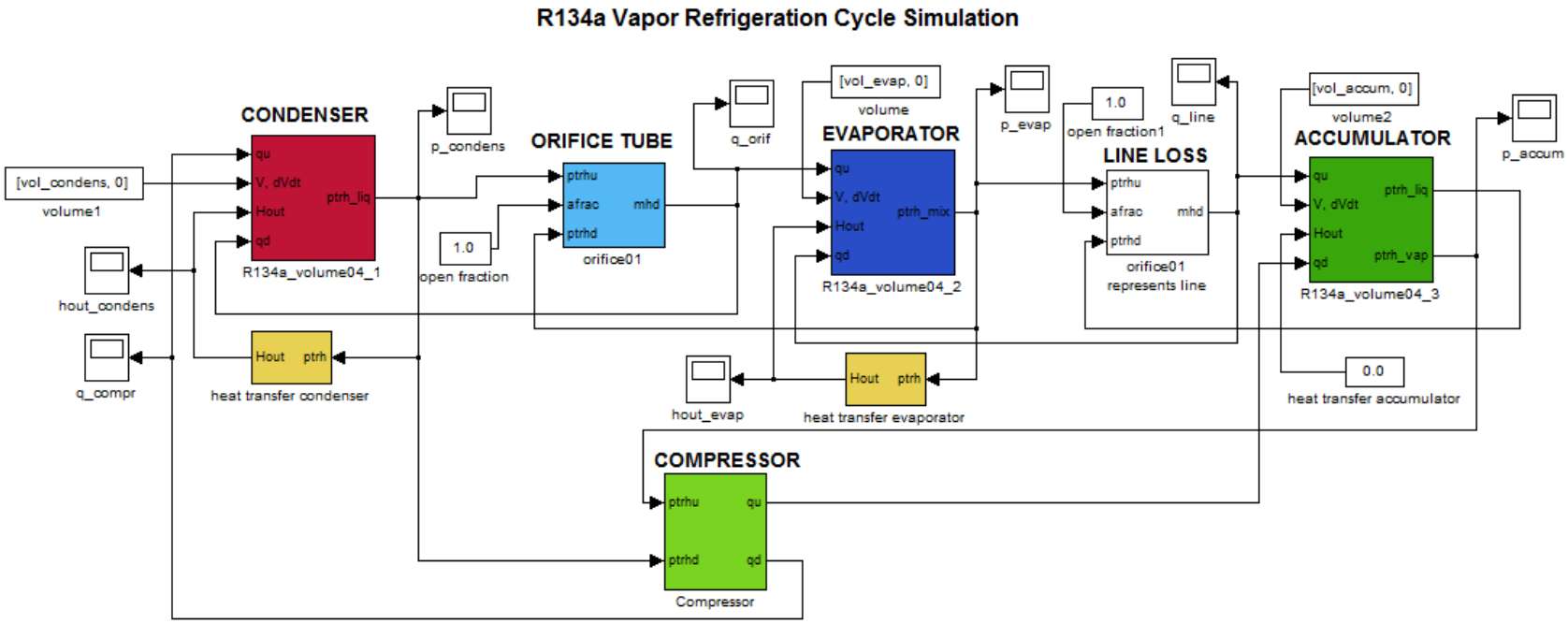
- A/C system model framework
  - Lump-sum model for condenser, evaporator and accumulator
  - Near isentropic compression with adiabatic efficiency as input
  - Simplified heat transfer models
- Allows for addition of detailed models one component at a time
- Uses property tables for R134a generated by 'REFPROP'





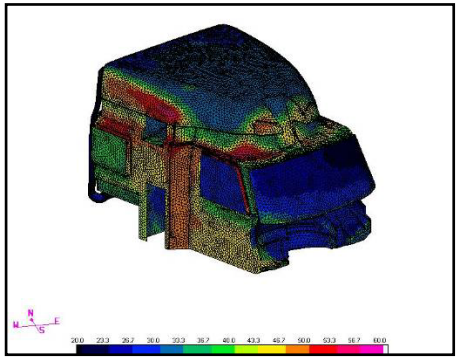
A/C Model - Accomplishments

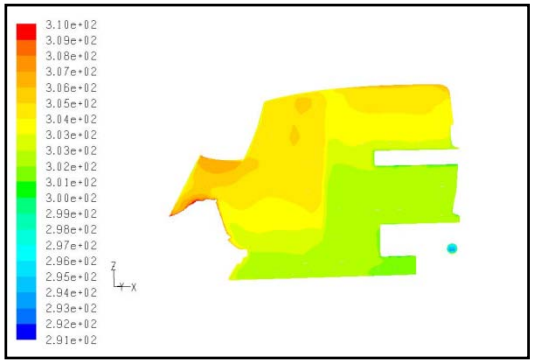
A/C Model Block Diagram



Collaboration

- 21st Century Truck Partnership
- International, ProStar
  - Developed CFD model, validated, and applied to thermal load reduction study
- Kenworth, T660 Sleeper Cab
  - Fully instrumented and tested for thermal-load measurements
  - Data will be used to validate the CoolCalc model
- Volvo, 770 Sleeper Cab
  - Back at NREL for further testing
  - Test bed for different materials, coatings, and glazings
  - Evaluate onboard idle reduction technologies
- In discussions with OEM's and suppliers on possible advanced idle reduction projects this summer





Future Work

- FY10
  - Complete CoolCalc validation
  - Share Beta version with industry partners for review and feedback
  - Develop air conditioning system model framework and integrate with CoolCalc
  - Complete thermal testing of Volvo 770
- FY11
  - Develop initial release version of CoolCalc, improved based on Beta version feedback
  - Validate and add detail to the air conditioning model, share with industry partners for initial review and feedback
  - Apply tools to idle reduction technology research
  - Test and improve advanced idle reduction systems with industry partners

Summary

DOE Mission Support

- Overcome barriers to the adoption of market viable and efficient thermal management systems that keep the cab comfortable without the need for engine idling, helping to reduce the 838 million gallons of fuel used for truck hotel loads every year.

Approach

- Work with industry partners to develop effective, market viable solutions using a system level approach to research, development and design.
- Address thermal load reduction of the cab, effective delivery of conditioning to the occupants for thermal comfort, and the use of efficient equipment.

Summary

Technical Accomplishments

- Developed a working prototype of the CoolCalc HVAC thermal load estimation tool
  - Parametric cab creation
  - Material and construction creation and assignment
  - Model object browser for full model control
- Created an air conditioning performance estimation tool framework to enable detailed model development and demonstrated a cycle solution using simplified lump sum component models
- Conducted outdoor truck thermal testing, created a validation data set and increased understanding of thermal behavior

Collaborations

- Collaborating with industry partners
  - Kenworth (PACCAR)
    - Completed testing of truck, creating data for CoolCalc validation
    - Kenworth provided truck and vehicle information for model validation
  - Volvo
    - Started testing truck, will complete thermal testing this summer

Contacts

Special thanks to:

Lee Slezak
Advanced Vehicle Technology Analysis and Evaluation
Vehicle Technologies Program

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