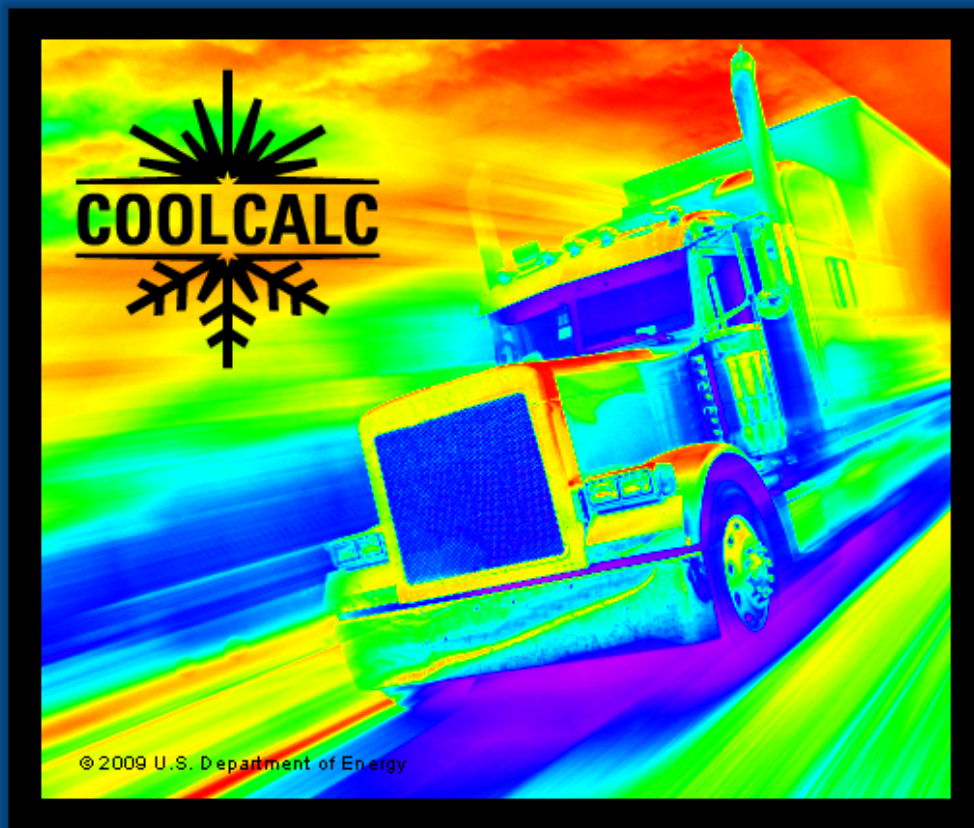


CoolCab Thermal Load Reduction Project: CoolCalc HVAC Tool Development



**U.S. Department of Energy
Annual Merit Review**

Presenter:
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National Renewable Energy Laboratory

P.I. : John Rugh

Wednesday June 9, 2010

Project ID: VSS022

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Timeline

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

Budget

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

Barriers

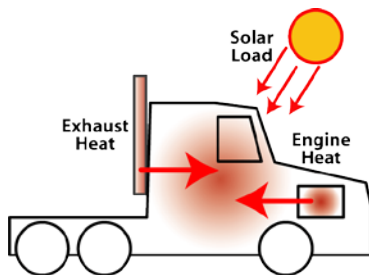
- Industry lacks key performance data on HVAC loads and truck cab thermal load reduction technologies
- Truck fleets operate on small profit margins and are sensitive to purchase costs for equipment

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

* 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

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

Objectives - Relevance

- Overall Objectives

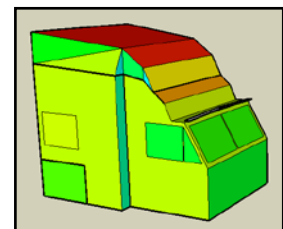
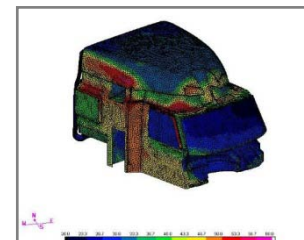
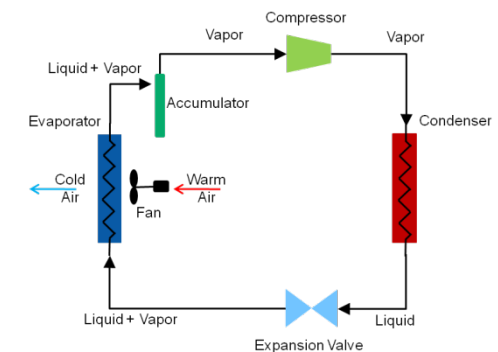
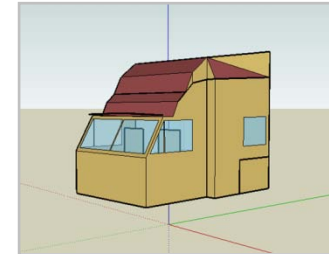
- Design efficient thermal management systems that keep the cab comfortable without the need for engine idling, helping to reduce the 838 million gallons of fuel used for truck hotel loads every year
- Research and develop technologies to reduce truck cab thermal load through testing and analysis
- Develop 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

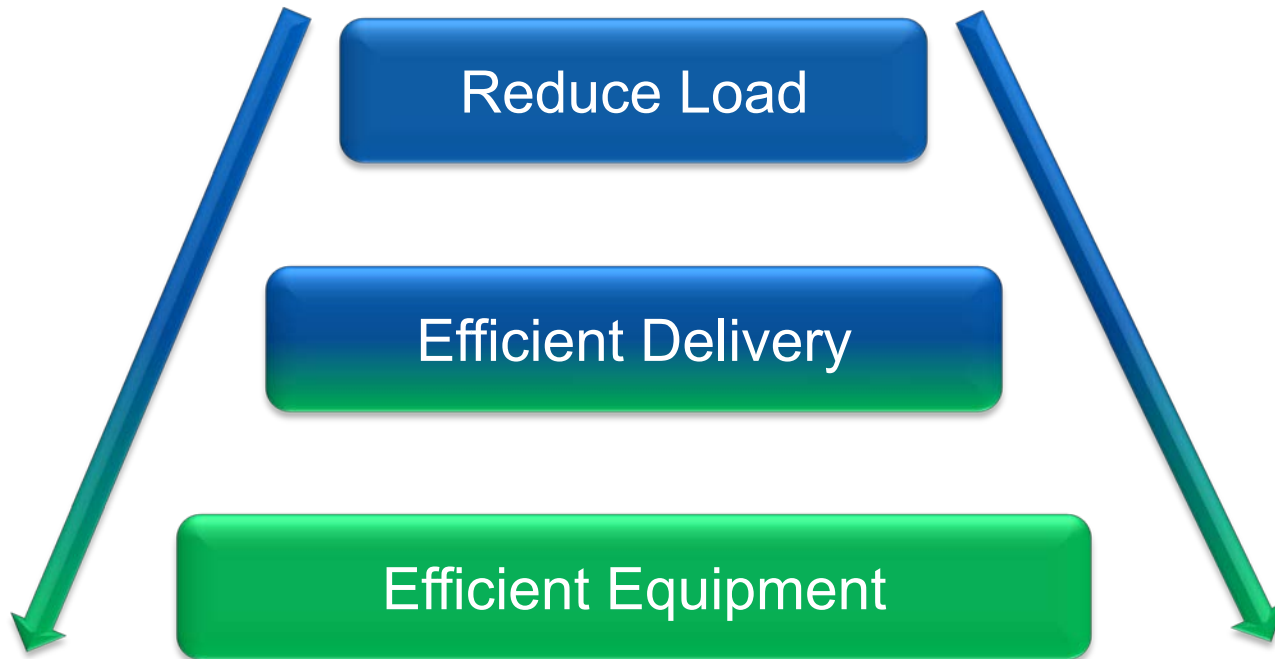
Milestones - Relevance

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



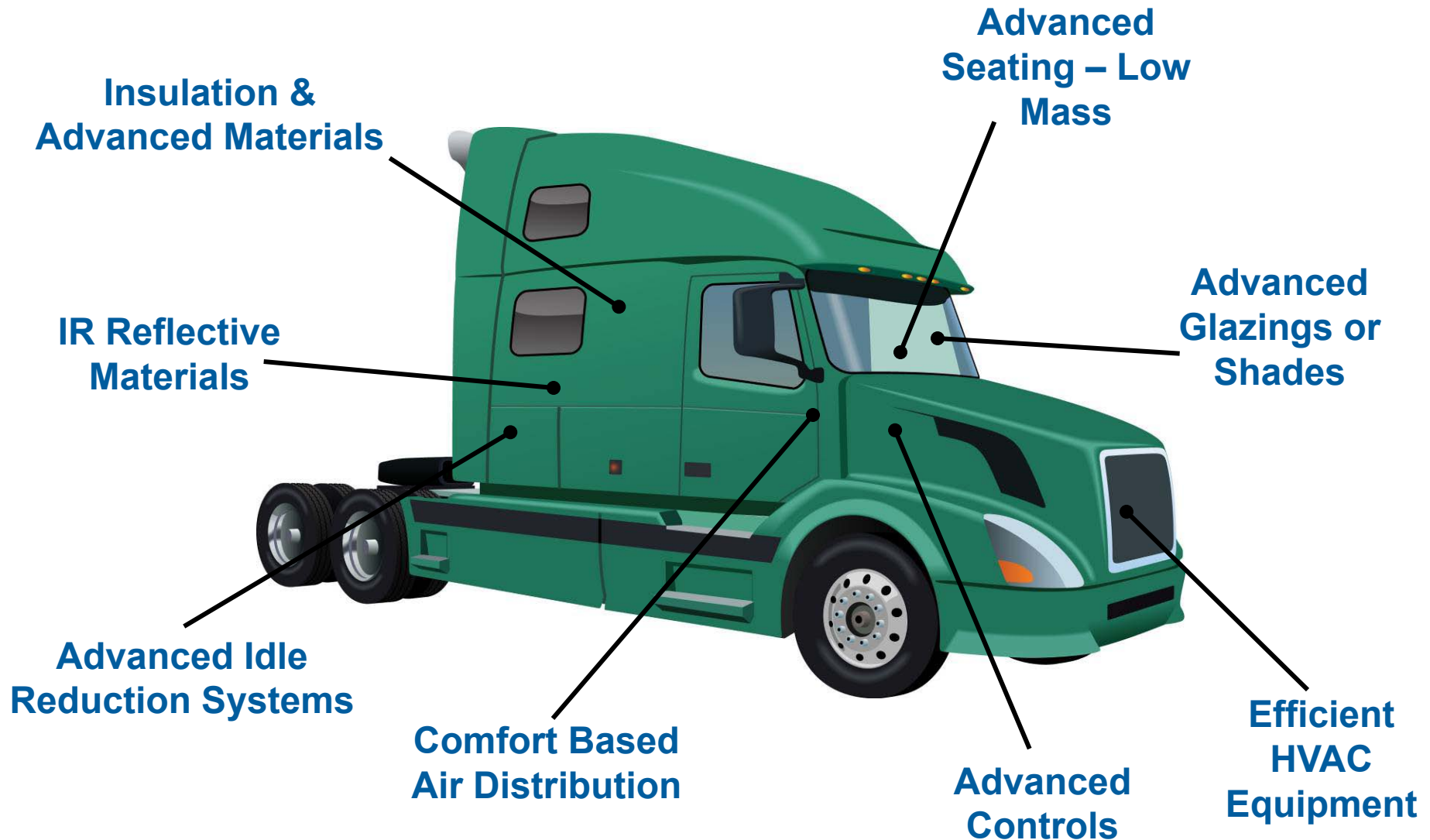
System Level Solution - Approach

System Level Solution

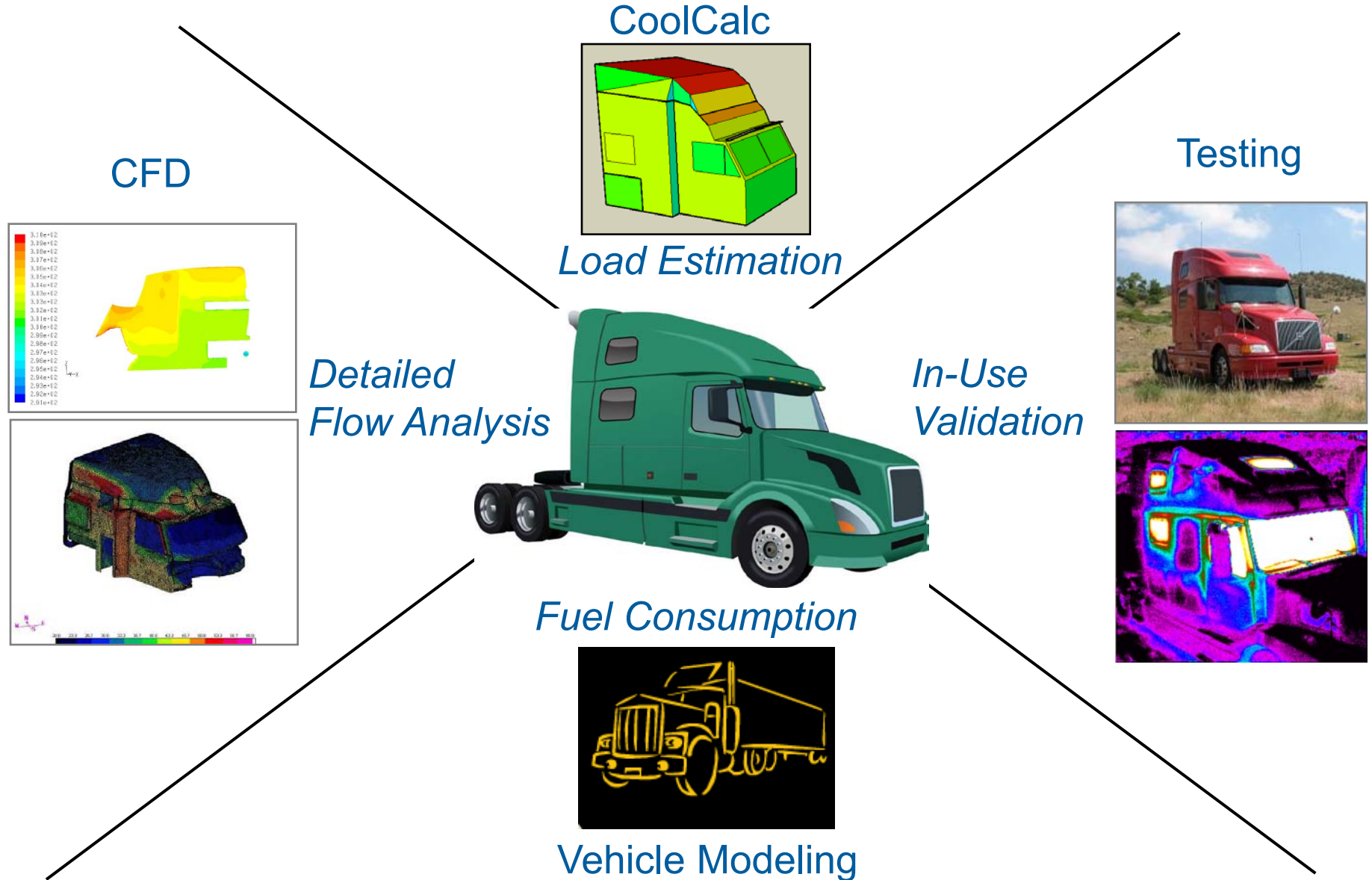


Decreases in load have a larger impact on fuel use due to equipment and delivery losses.

Advanced Technologies - Approach

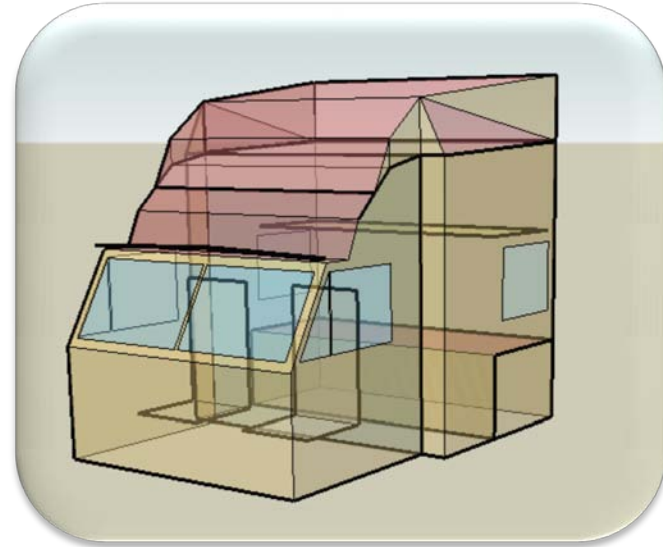


Suite of Tools - Approach



CoolCalc - Accomplishments

HVAC Load Estimation Tool Concept: CoolCalc



- 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

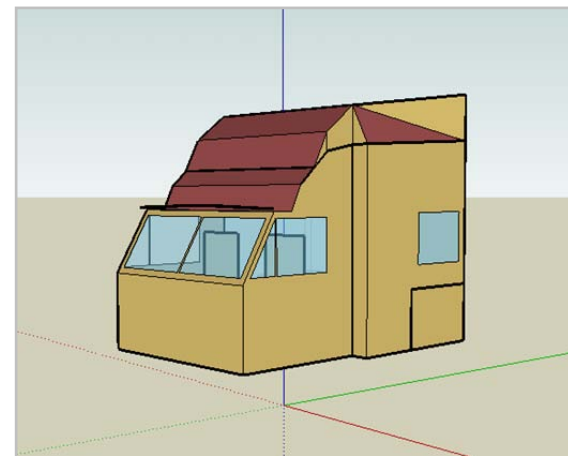
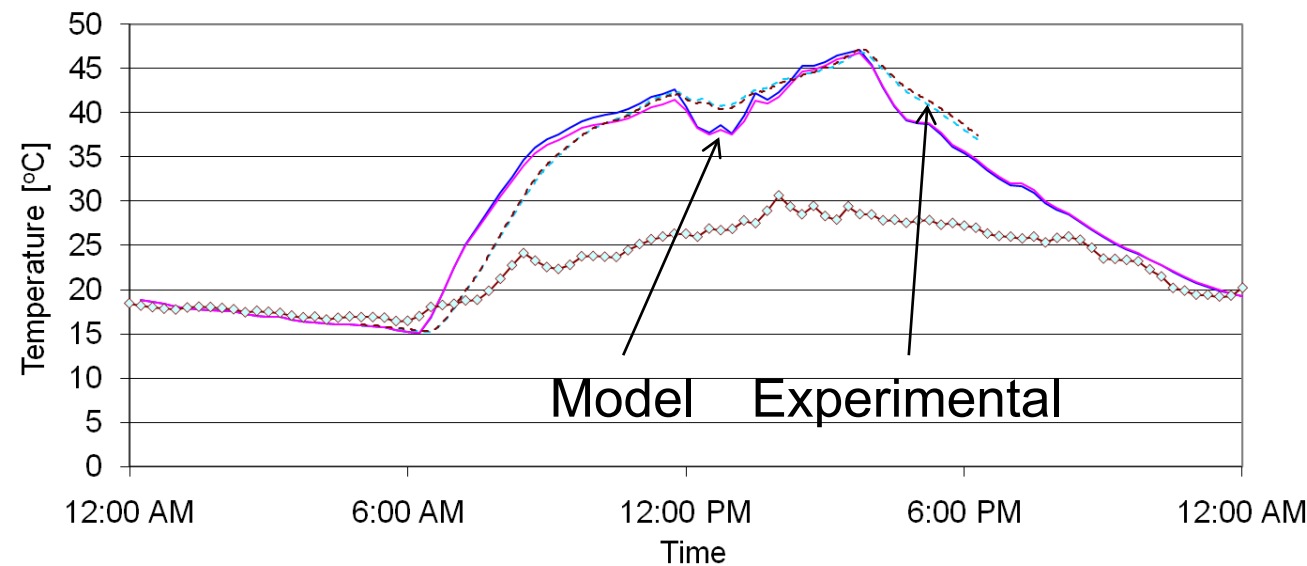
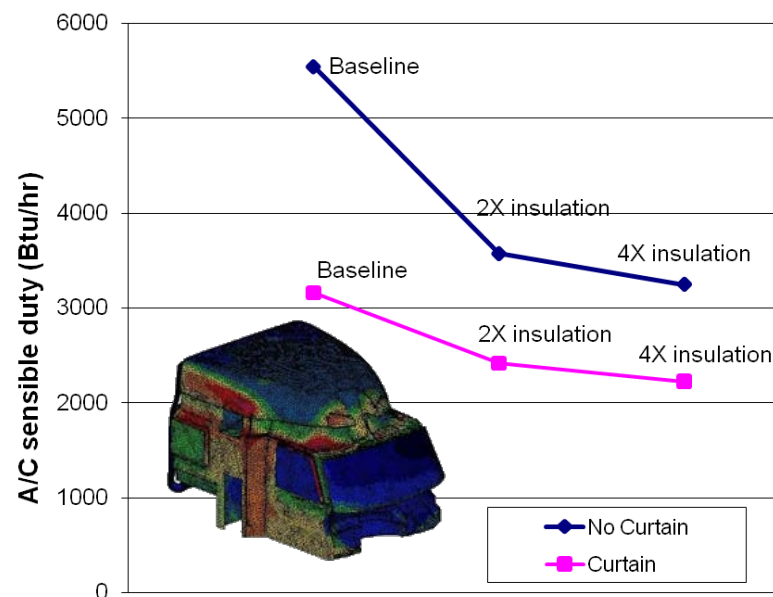
- Approach, leverage:
 - NREL's Open Studio Plug-In (2008)
 - DOE's EnergyPlus
 - SketchUp:
 - "3D for Everyone"
 - Designed to be "intuitive, flexible, and easier to use"

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

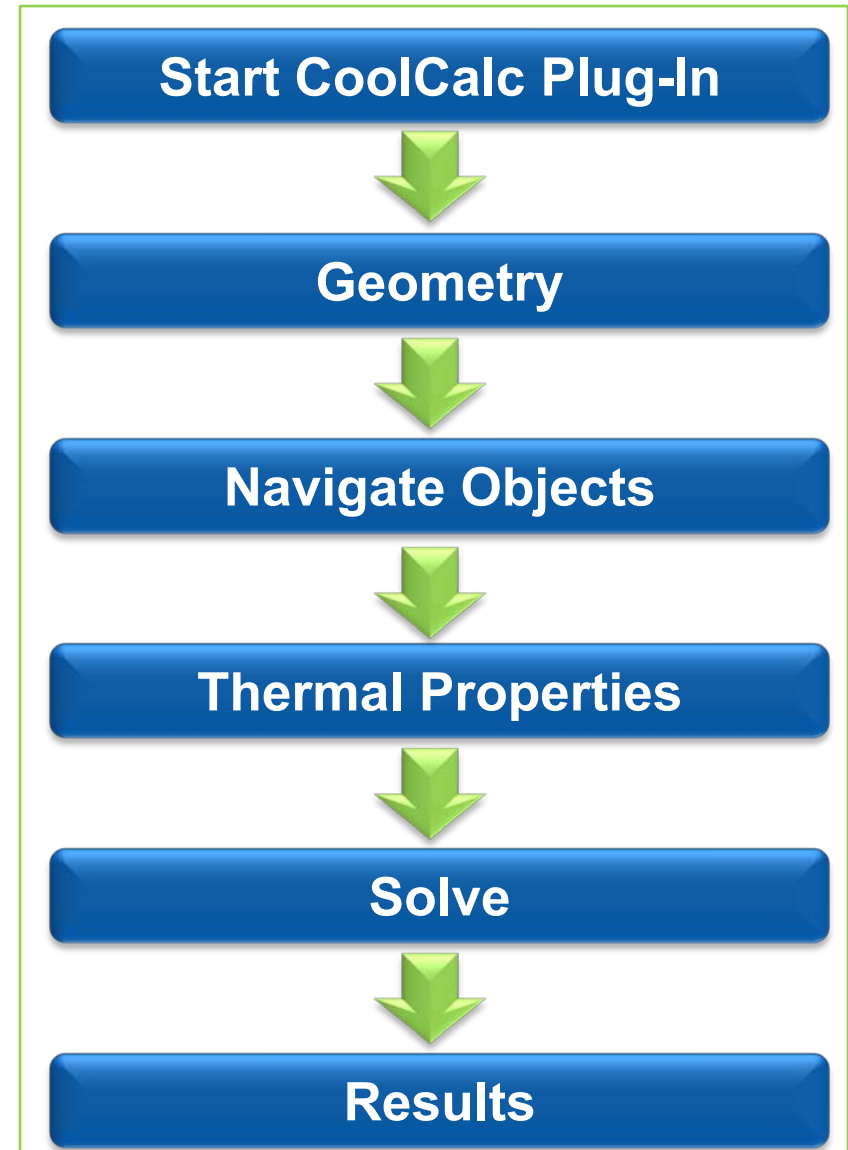


CoolCalc Development - Accomplishments

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

Open Studio Toolbar

Other GUI menu options

Start from toolbar icon or menu

Tabs for each zone

Available parametric variables (GUI auto populated from geometry coding framework)

Current display units

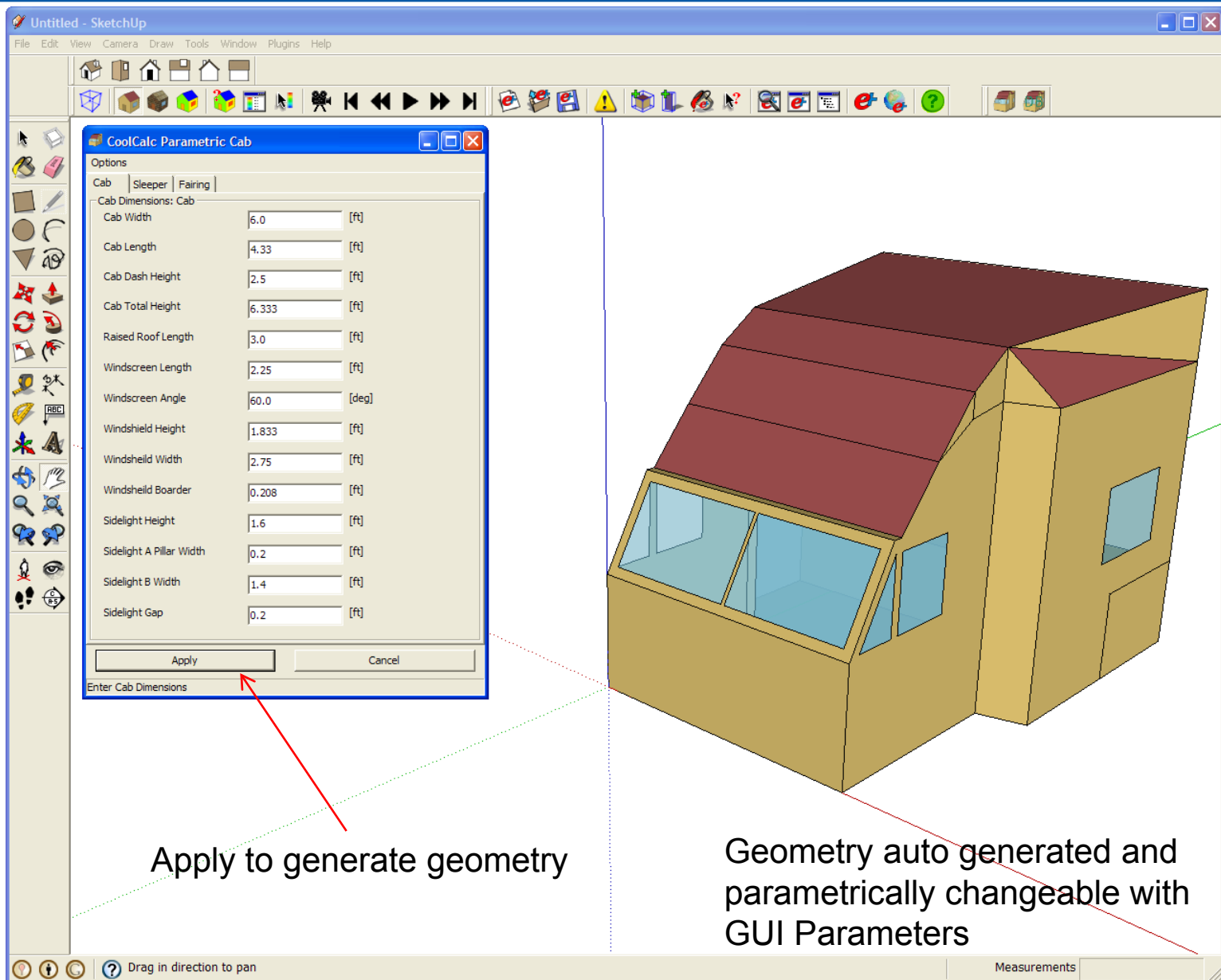
Status window

Large SketchUp tool set

Measurement window

Variable	Value	Unit
Cab Width	6.0	[ft]
Cab Length	4.33	[ft]
Cab Dash Height	2.5	[ft]
Cab Total Height	6.333	[ft]
Raised Roof Length	3.0	[ft]
Windscreen Length	2.25	[ft]
Windscreen Angle	80.0	[deg]
Windshield Height	1.833	[ft]
Windshield Width	2.75	[ft]
Windshield Boarder	0.208	[ft]
Sidelight Height	1.6	[ft]
Sidelight A Pillar Width	0.2	[ft]
Sidelight B Width	1.4	[ft]
Sidelight Gap	0.2	[ft]

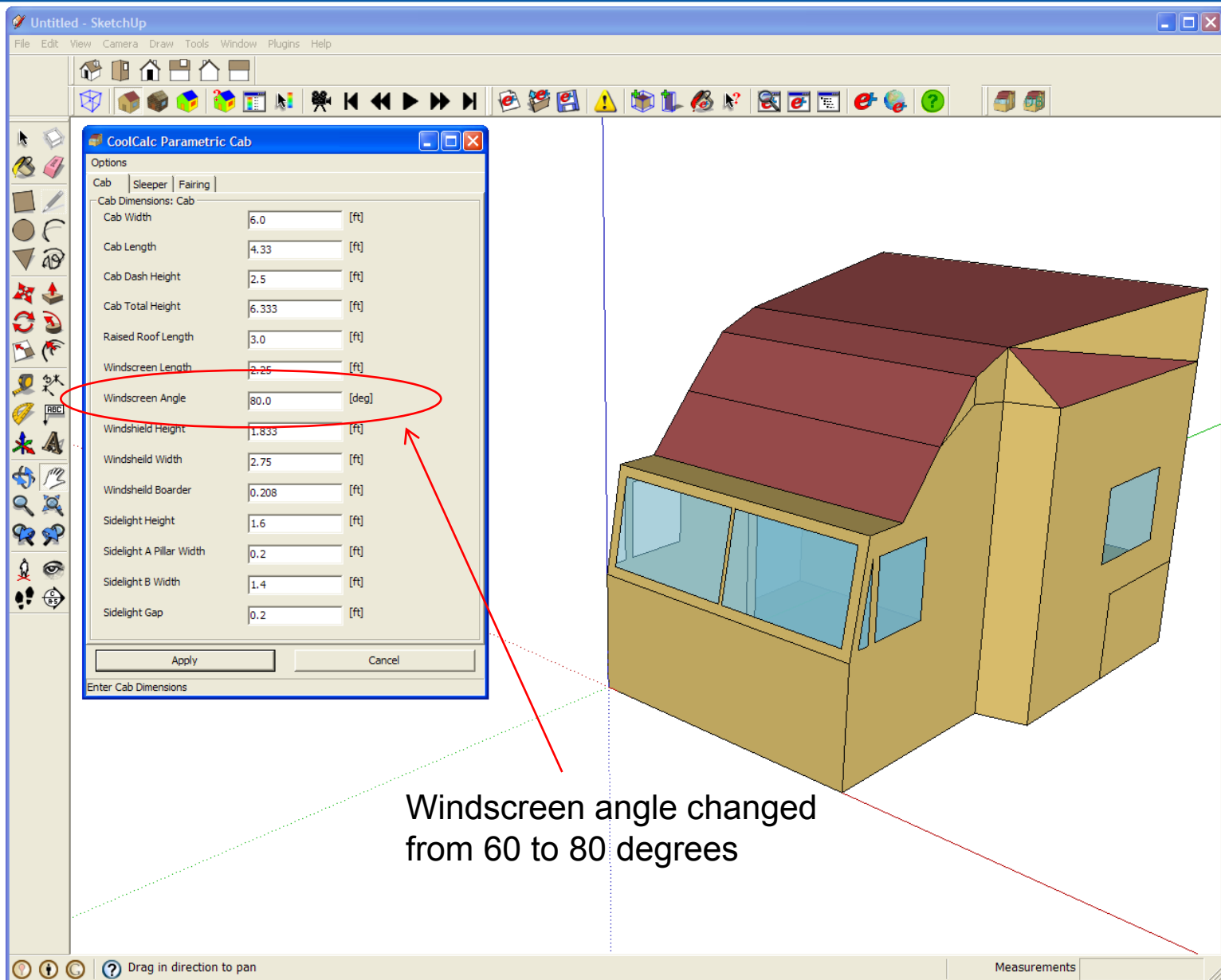
Geometry: Creation



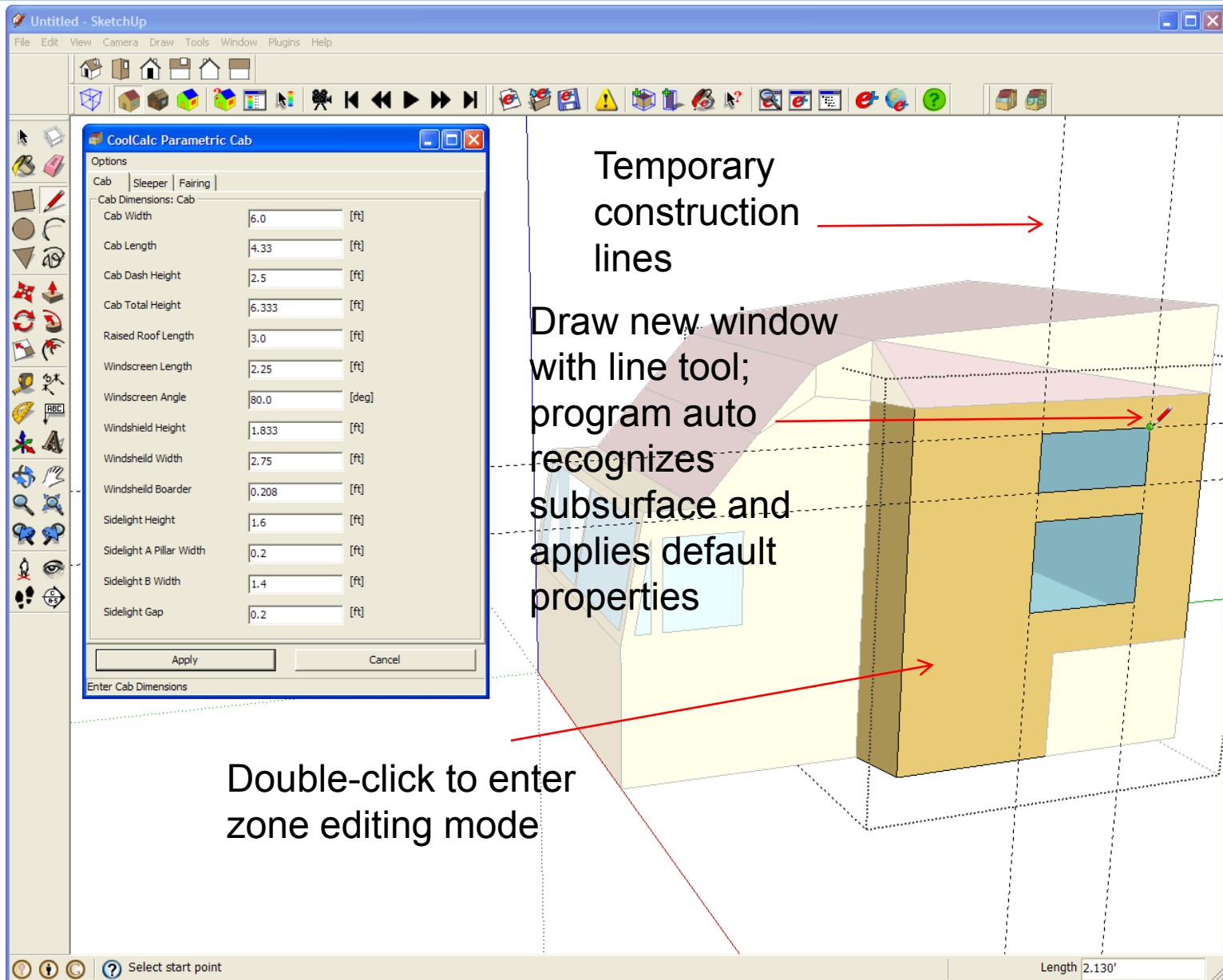
Apply to generate geometry

Geometry auto generated and
parametrically changeable with
GUI Parameters

Geometry: Modify Parametrically



Geometry: Manual Modification



Navigate Objects: Interactive Surface Properties

The screenshot displays the SketchUp interface with the 'Object Info' panel open. The panel shows the following details for the selected 'WindowTest B' object:

- Class:** FenestrationSurface:Detailed
- Name:** WindowTest B
- Type:** Window
- Construction:** Exterior Window (highlighted with a red arrow)
- Base Surface:** WindScreen
- Outside Boundary Object:**
- View Factor To Ground:** autocalc
- Shading Device:**
- Frame And Divider:**
- Multiplier:**

The **Object Summary** section shows:

Vertices:	Unit Area:	Total Area:
4	5.041 (ft²)	5.041 (ft²)

The **Object Text** section displays the following text:

```
FenestrationSurface:Detailed,  
WindowTest B, 1- Name  
WINDOW, 1- Surface Type  
Exterior Window, 1- Construction Name  
WindScreen, 1- Building Surface Name  
1- Outside Boundary Condition Object  
autocalculate, 1- View Factor to Ground  
1- Shading Control Name  
1- Frame and Divider Name  
1- Multiplier  
4, 1- Number of Vertices  
0.927202, 1- Vertex 1 X-coordinate {m}  
0.108026, 1- Vertex 1 Y-coordinate {m}
```

A red arrow points from the 'Exterior Window' dropdown in the Object Info panel to the text 'Change surface properties interactively*'. Another red arrow points from the 'Object Text' section to the text 'See actual generated solver input'. A green arrow points from the 3D model of the house to the text '*Note, all non-geometry changes will be kept during parametric redraw; however, manual geometry modification will not'.

Change surface properties interactively*

See actual generated solver input

*Note, all non-geometry changes will be kept during parametric redraw; however, manual geometry modification will not

Navigate Objects: Simple Object Browser

The image shows a screenshot of the SketchUp software interface with the Object Browser window open. The Object Browser is divided into three main sections: a list of objects on the left, a 'Library' section at the bottom left, and an 'Object Text' window on the right. The 'Object Text' window displays a tree structure for the 'Site:Location' object, showing its properties and values. A 3D model of a building is visible in the background, with red arrows pointing from the annotations to specific parts of the interface.

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)

Object Browser

Object Inputs

Class: Site:Location

Object Text

Site:Location,
Denver-Stapleton, I-LocationName
39.76, I-Latitude (deg)
-104.86, I-Longitude (deg)
-7.0, I-TimeZone (hr)
1611.0; I-Elevation (m)

Library

CoolCalc_default.idf
librarytest.idf

Select objects. Shift to extend select. Drag mouse to select multiple.

Measurements

Thermal Properties: New Material

The screenshot shows the SketchUp interface with the 'Material' dialog box open. The dialog box is divided into several sections: 'Object Inputs', 'Object Summary', and 'Object Text'. The 'Object Inputs' section contains fields for Class, Name, Roughness, Thickness, Conductivity, Density, Specific Heat, and Texture. The 'Object Summary' section shows the R-Value. The 'Object Text' section provides a detailed list of properties and their values. A 3D model of a house is visible in the background, with red arrows pointing from the annotations to specific parts of the dialog box and the model.

Material creation/modification window, apply material properties

Editable text provides maximum control and information for advanced users

Assign texture to material for display and easy identification in model

Object Browser

- Sidelight B Pass
- Sleeper Interface to Cab
- Sleeper Window Dr
- Sleeper Window Pass
- WindowTest A
- WindowTest B
- GlobalGeometryRules
- Material
 - AirWall
 - Carpet
 - F08 Metal surface
 - F16 Acoustic tile
 - FiberGlass
 - Floor1
 - FloorSteel
 - FoamRubber
 - FoamRubberRoof
 - FoamRubberThin
 - I02 50mm insulation board
 - Interior Trim
 - Leather
 - Paint_Dark_Red
 - Paint_Green
 - Paint_Red
 - RubberHard
 - Sheet AL 16 AWG
 - Sheet Galvanized 16 AWG
 - Upholstery
- Library
 - CoolCalc_default.idf
 - librarytest.idf

Object Inputs

Class: Material

Name: F08 Metal surface

Roughness: Smooth

Thickness: 0.0008 (m)

Conductivity: 45.28 (W/m-K)

Density: 7824 (kg/m³)

Specific Heat: 500 (J/kg-K)

Texture: [Texture Icon] Select... C:\Program Files\Googl

Object Summary

R-Value: 0.0 (m²-K/W)

Object Text

Material,
F08 Metal surface, I- Name
Smooth, I- Roughness
0.0008, I- Thickness (m)
45.28, I- Conductivity (W/m-K)
7824, I- Density (kg/m³)
500, I- Specific Heat (J/kg-K)
!Texture=C:\Program Files\Google\Google SketchUp 7\Plugins\Open

Thermal Properties: New Construction

Outer and inner material determine colors used in model

Construction creation/modification window, add materials and set order

See list of available materials when adding to construction

Object Browser

Current Model

- Building
 - BuildingSurface:Detailed
 - Construction
 - Air Glass
 - AirWall
 - Exterior Door
 - Exterior Floor
 - Exterior Roof
 - Exterior Wall
 - Exterior Wall Example
 - Exterior Window
 - Fairing
 - FireWall
 - Floor
 - Interior Window
 - Roof
 - Window Privacy Glass
 - Window Windshield
 - FenestrationSurface:Detailed
 - 236468
 - Cab Interface To Sleeper
 - Driver Sidelight A
 - Passenger Sidelight A
 - Sidelight B Driver
 - Sidelight B Pass
 - Sleeper Interface to Cab

Library

- CoolCalc_default.idf
- librarytest.idf

Object Inputs

Class: Construction

Name: Exterior Wall Example

Layers: Outside Layer > Paint_Red, Sheet Galvanized 16 AWG, Interior Trim

Textures:

Object Summary

R-value: 0.01 (m2-K/W) Thickness: 0.0034504 (m) Conductivity:

Object Text

Construction, Exterior Wall Example, 1- Name Paint_Red, 1- Outside Layer Sheet Galvanized 16 AWG, 1- Layer 2 Interior Trim, 1- Layer 3

Insert Layer

Select the material to insert as a layer:

- Material: AirWall
- Material: Carpet
- Material: F08 Metal surface
- Material: F16 Acoustic tile
- Material: FiberGlass
- Material: Floor1
- Material: FloorSteel
- Material: FoamRubber
- Material: FoamRubberRoof
- Material: FoamRubberThin
- Material: 102 50mm insulation board
- Material: Interior Trim
- Material: Leather
- Material: Paint_Dark_Red
- Material: Paint_Green

OK Cancel

Thermal Properties: Apply Constructions

Construction Rendering Mode

Set construction defaults

Select construction to paint

Apply with paint can icon

Construction	R-Value (m ² -K/W)	Thickness (m)	Conductivity (W/m-K)
Air Glass	0.0	1.0e-004	
AirWall	0.033	0.001	0.03
Exterior Door	0.15		
Exterior Floor	0.238	0.0179629	0.075
Exterior Roof	0.318	0.0207129	0.065
Exterior Wall	0.079	0.0082129	0.104
Exterior Wall Example	0.01	0.0034504	0.345
Exterior Window		0.0187	
Fairing	0.167	0.0066	0.04
FireWall	0.36	0.0256875	0.071
Floor	0.198	0.0143129	0.072
Interior Window	0.0	0.003	
Roof	0.093	0.0110958	0.119
Window Privacy Glass	0.0	0.004	
Window Windshield	0.0	0.0066	

Solve: Setup Simulation

The image shows the 'Run Simulation' dialog box in SketchUp. The dialog is divided into several sections: 'Run Control', 'Weather File Simulation', 'Annual simulation', 'Results', and 'Actions On Completion'. Red arrows point from text annotations to specific fields in the dialog. A green arrow points from a 3D model of a house to the 'Download weather files at' link.

Run Simulation

Run Control

- ☐ Run design day simulations
- ☒ Run weather file simulation

Weather File Simulation

EPW Path:

Location: Denver-Stapleton, CO, USA
Latitude: 39.76 Longitude: -104.86 Time Zone: -7.0 Elevation: 1611.0 m
Start Date: 1/1 End Date: 12/31 Start Day: Sunday Time Step: 60 min

Annual simulation

☐ Annual simulation

Start Date: August 1 Start Day: Sunday
End Date: August 31 Download weather files at www.energyplus.gov

Results

- ☐ Report Annual Building Utility Performance Summary (ABUPS) Format: HTML
- ☐ Report user variables and meters
- ☒ Report zone temperatures (MAT and MRT)
- ☒ Report inside and outside surface temperatures

Actions On Completion

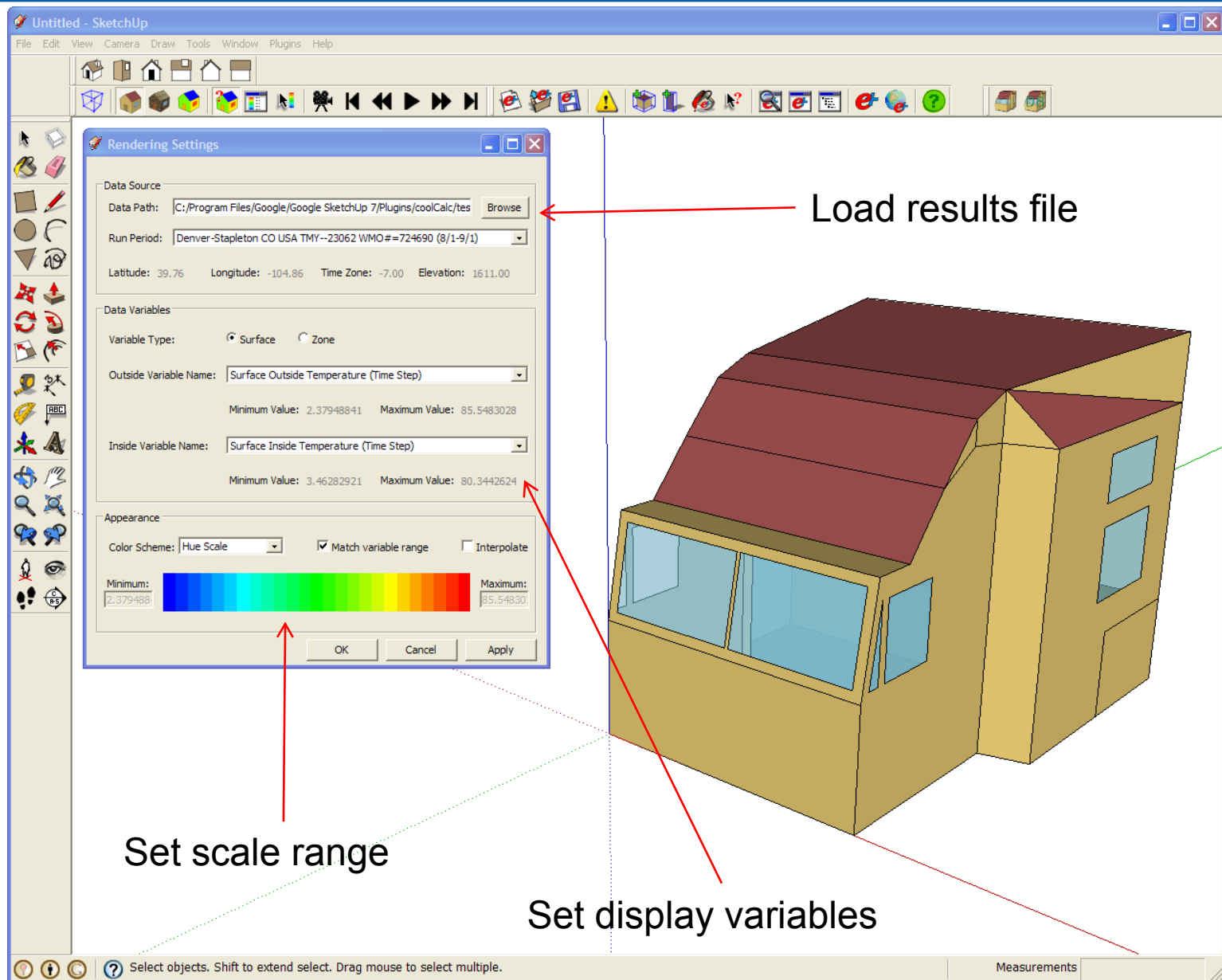
- ☒ Close shell command window
- ☒ Show error file (ERR) **Recommended**
- ☐ Show Annual Building Utility Performance Summary (ABUPS)
- ☐ Show report variables and meters file (CSV)

Annotations:

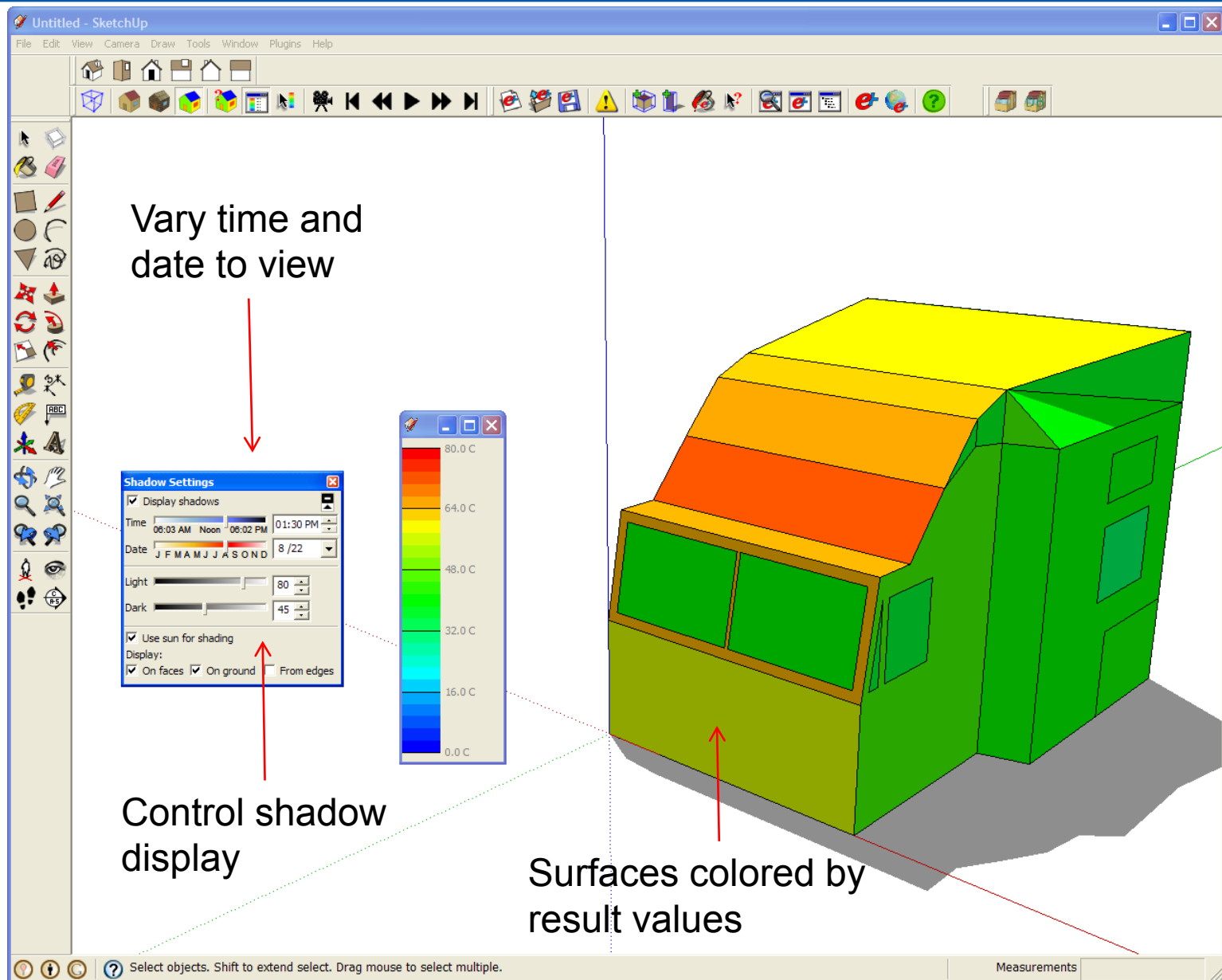
- Set weather data, typical mean year (TMY) data available from 2,100 locations world wide (points to EPW Path)
- Set calendar dates for simulation (points to Start Date/End Date)
- Set output results (points to Results section)

3D Model: A 3D model of a house with a red roof and yellow walls. A green arrow points from the 'Download weather files at' link to the model.

Results: Display Settings



Results: View



Vehicle Testing - Accomplishments

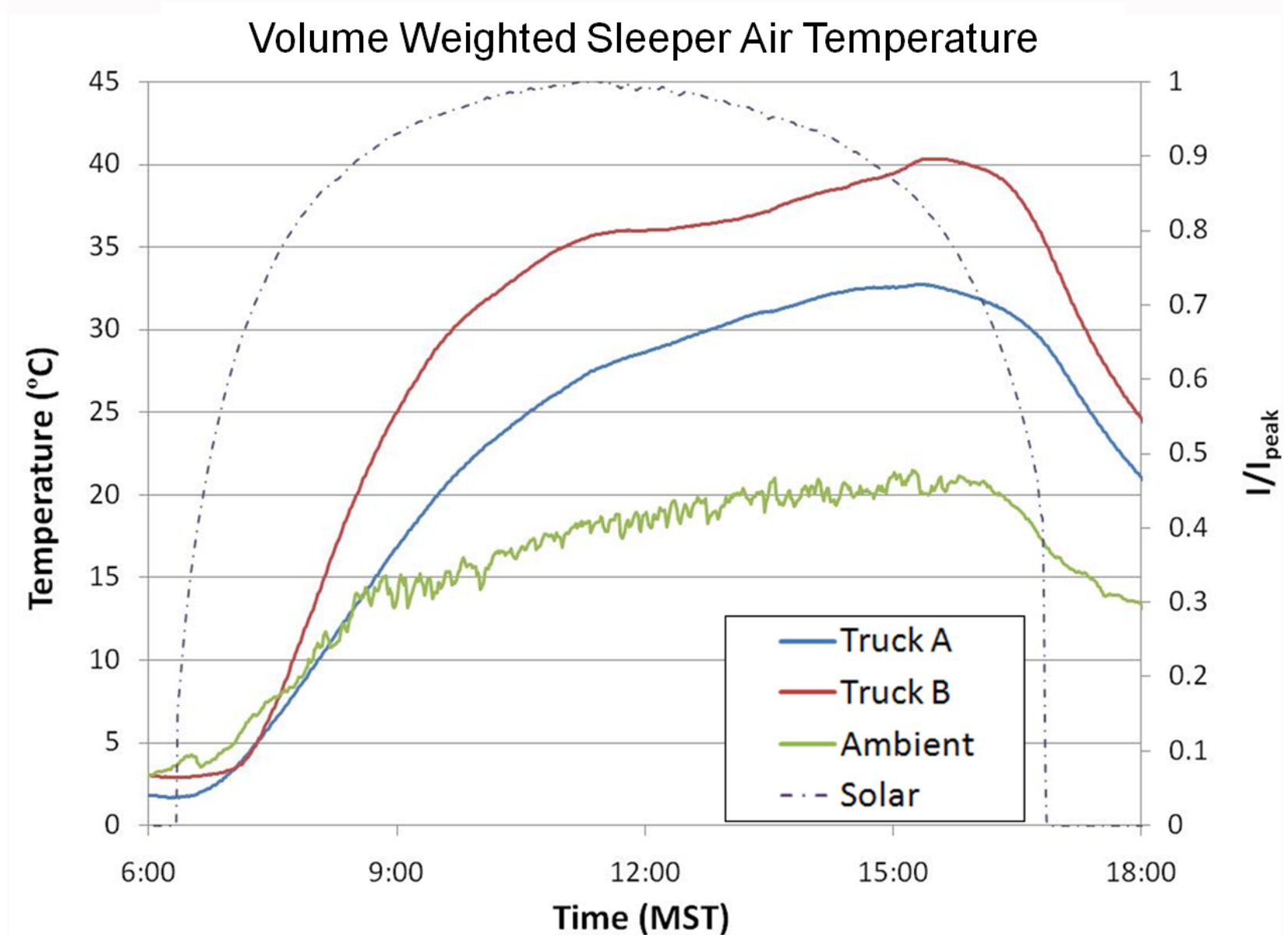
- Kenworth, Volvo, and baseline truck
- Instrumentation
 - 42 thermocouples/truck
 - 26 air & 16 surface
 - 2 humidity sensors
 - 1 pyranometer
 - 1 anemometer
 - Environmental data collected at NREL's weather station



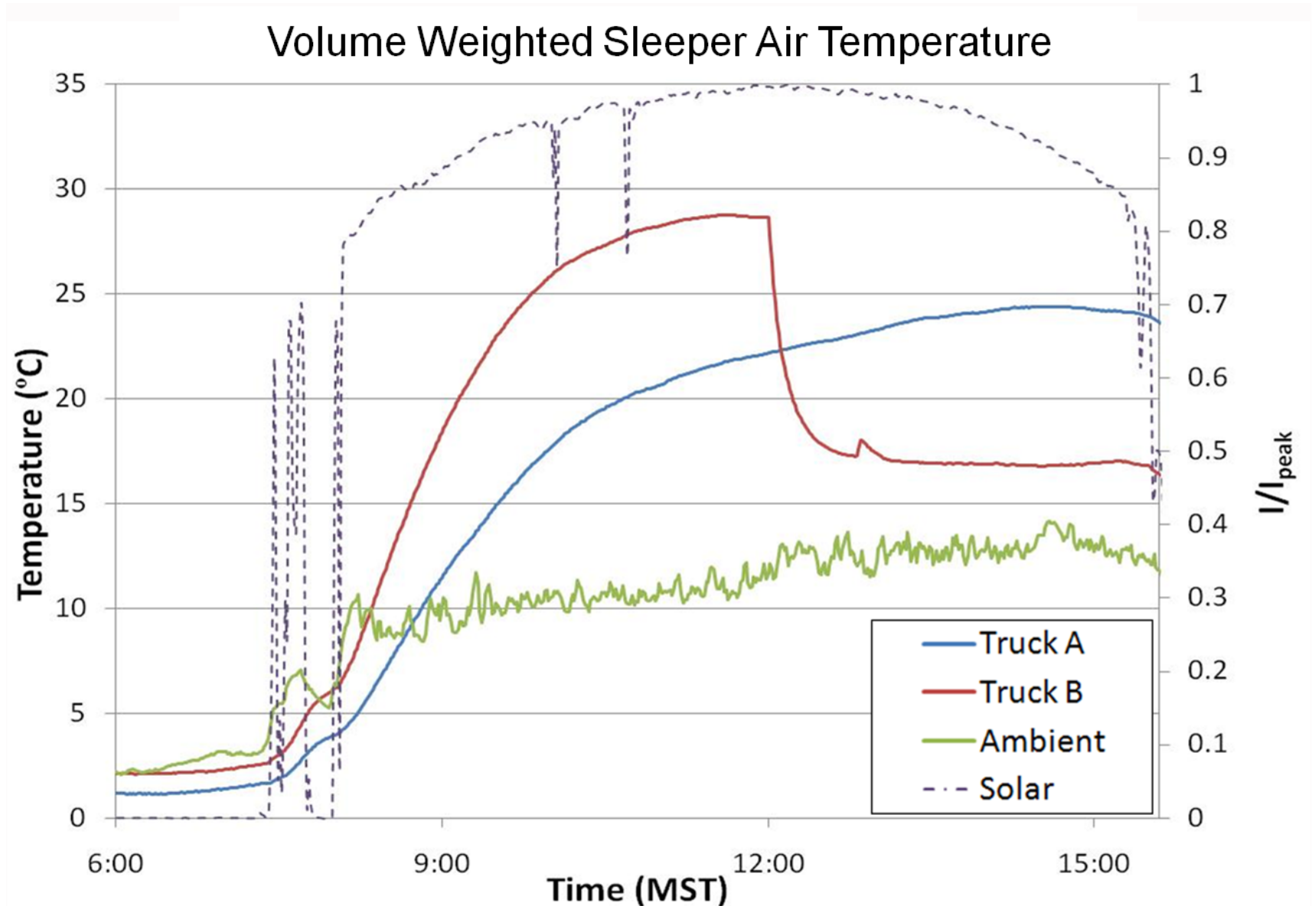
Goals

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

Thermal Soak - Accomplishments



Cool down - Accomplishments



UA Testing- Accomplishments

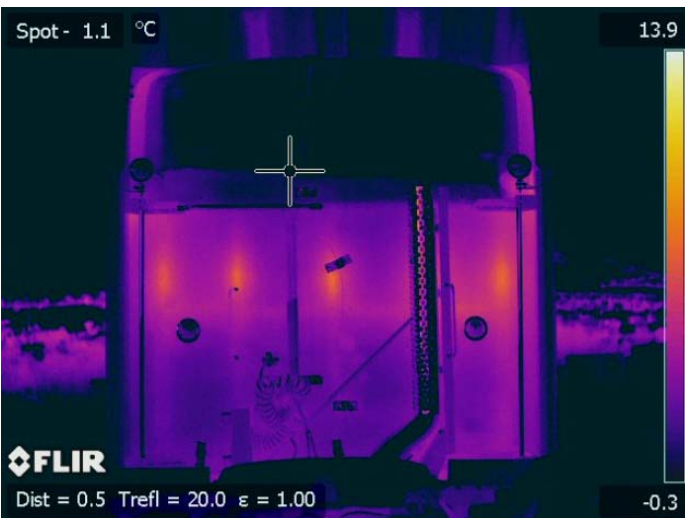


- Heater ran overnight
- 1:00 – 3:00 AM examined
- UA value calculated

UA Calculations

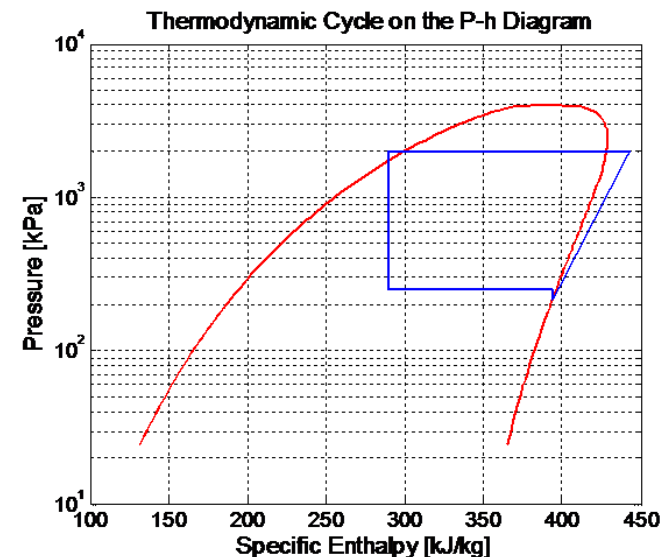
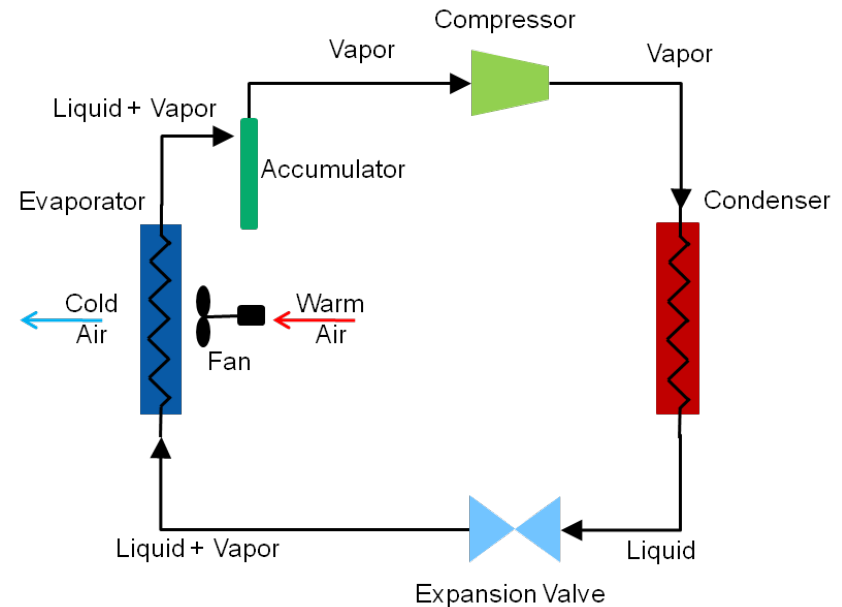
Test #	UA (W/K)
1	49.9
2	51.6
3	48.7
4	54.4
5	50.5
6	55.3
Average	51.7 ± 2.4

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



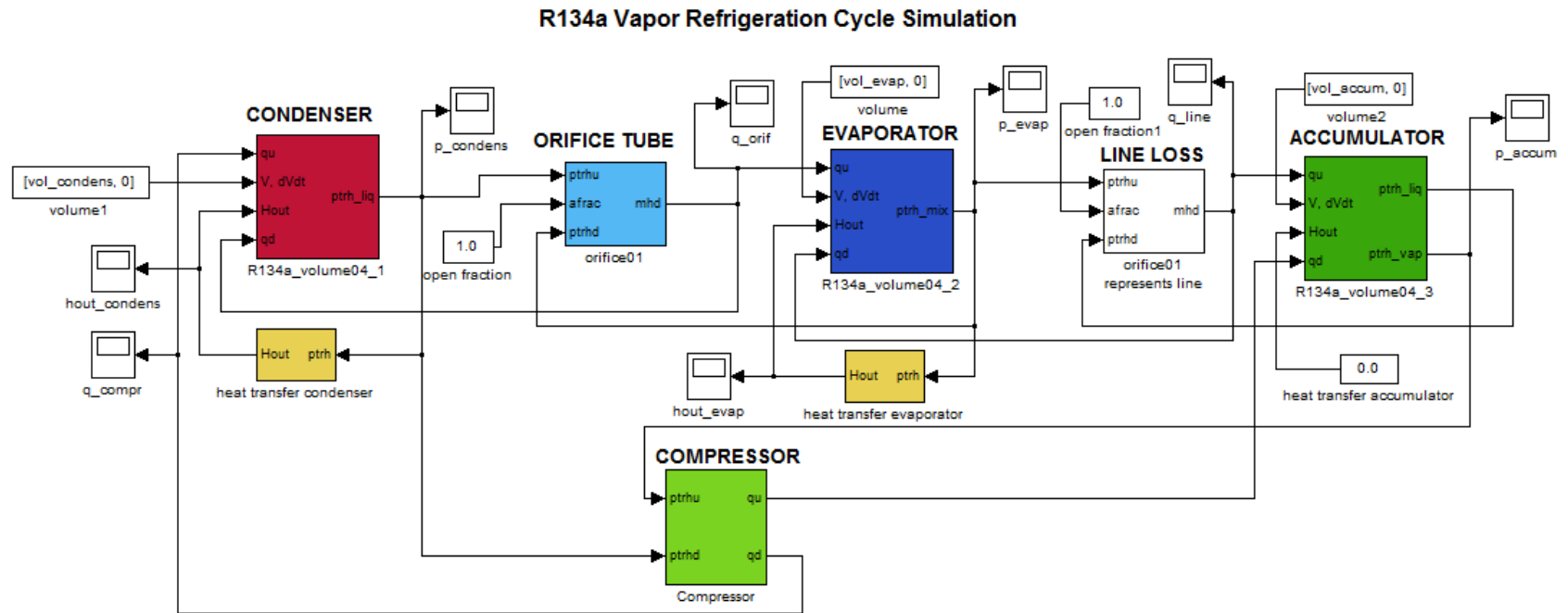
A/C Model - Accomplishments

- 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'



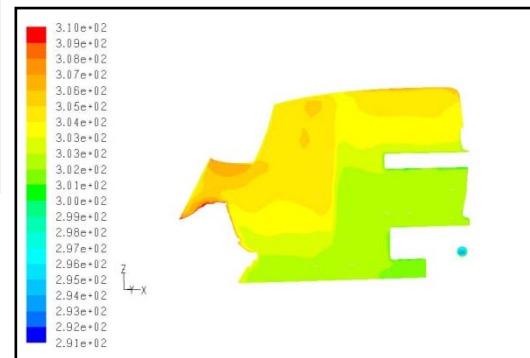
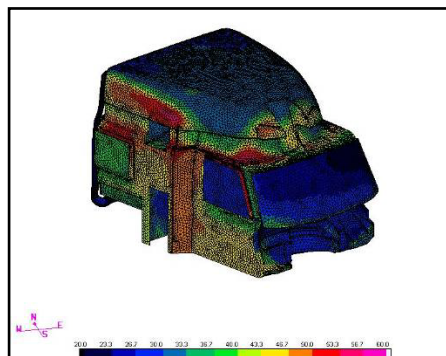
A/C Model - Accomplishments

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

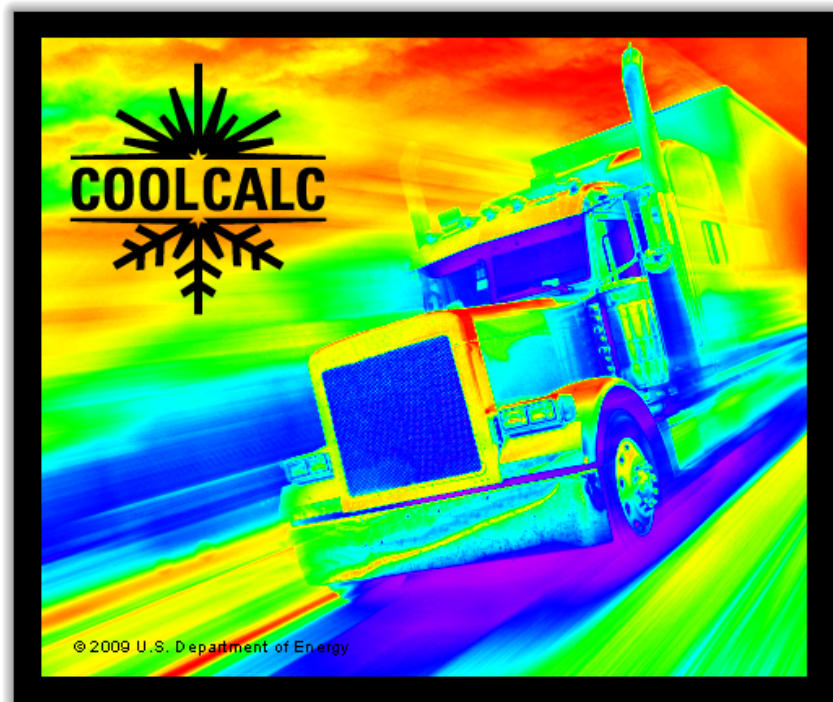
- Collaborating with industry partners
 - Kenworth (PACCAR)
 - Completed testing of truck, creating data for CoolCalc validation
 - Kenworth provided truck and vehicle information for model validation
 - Volvo
 - Started testing truck, will complete thermal testing this summer

Contacts

Special thanks to:

Lee Slezak

*Advanced Vehicle Technology
Analysis and Evaluation
Vehicle Technologies Program*



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