National Renewable Energy Laboratory
Innovation for Our Energy Future

CoolCab Truck Thermal Load Reduction

Project ID: vssp_09_proc

DOE Vehicle Technologies Program Merit Review

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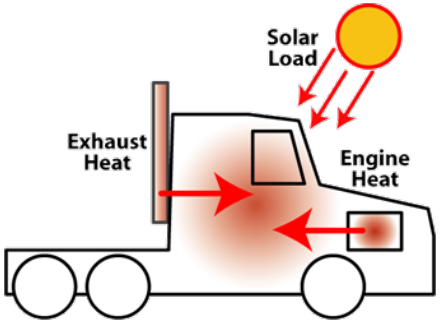
NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy operated by the Alliance for Sustainable Energy, LLC

Project Description

THE CHALLENGE

Trucks idle for driver comfort. Idling consumes more than $3 billion in fuel per year for long-haul trucks.

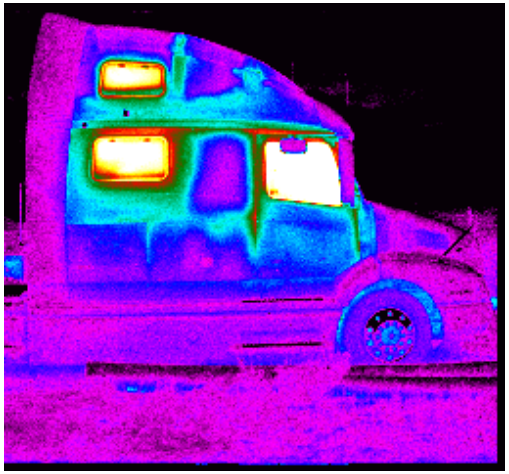


Varying thermal conditions inhibit the use of idle reduction technologies.

THE SOLUTION

Design efficient thermal management systems that keep the cab comfortable without the need for engine idling.

Solar Reflective Glazings



Thermal Comfort Evaluation

NREL infrared testing identified potential to reduce heating and cooling loads with improved insulation.

- 1500W for typical heating – 20% improvement over baseline
- Reducing the load will enable idle reduction technologies
- 838 million gallon savings potential with no idling

Timeline

Project	Dates
Light-Duty Vehicle A/C Systems	1998-2007
Idle Reduction Technology Validations	2003-2006
Infrared Image Testing – Freightliner	2005
Truck Cabin Test – Volvo	2006
Truck Cabin Test – International	2007
Thermal Modeling	2008
HVAC Load Estimation Tool Development	2009

Budget

- Funding
  - FY09 DOE funding: $500,000
  - FY08 DOE funding: $410,000
  - Prior funding (FY05-07) total: $240,000

Objectives

- Objectives
  - Investigate the potential to reduce truck cabin thermal load through testing and analysis
  - Develop a tool to help predict HVAC load reduction in truck tractor sleeper cabins

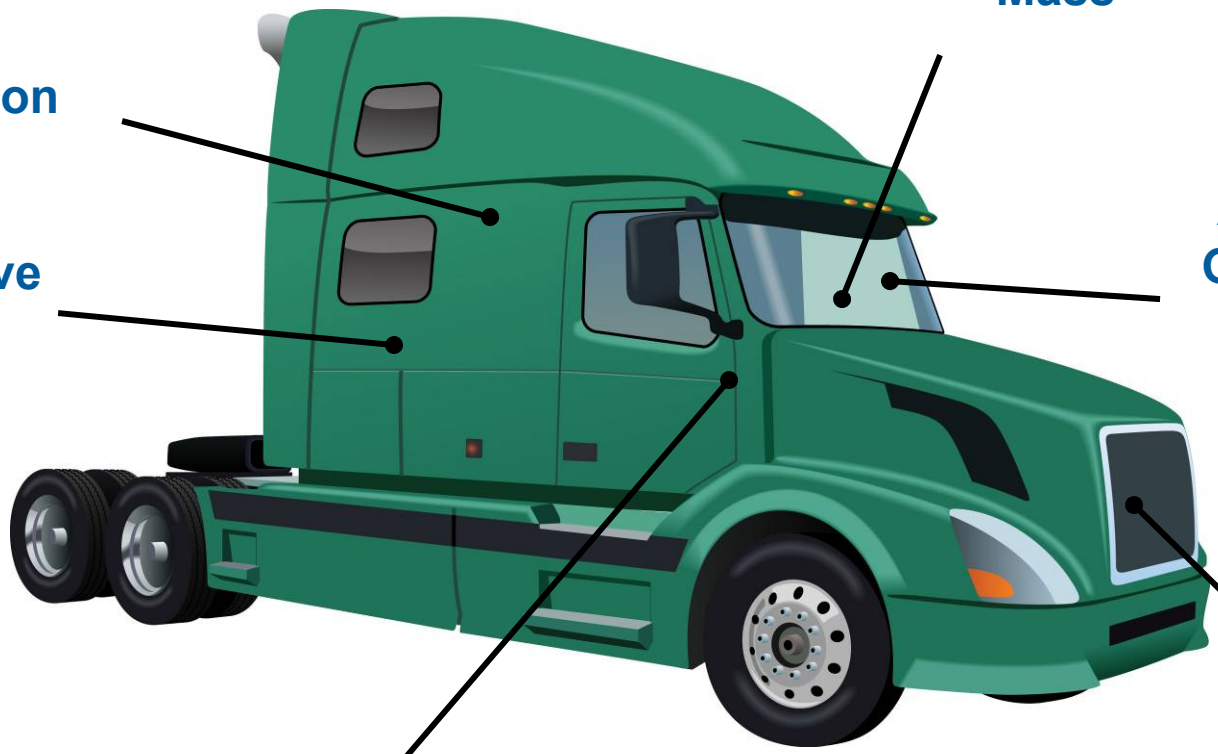
Milestones

- Key Milestones
  - Engineering test report: Infrared image field test at Schneider National, July 2005
  - Status report: CoolCab Testing with Volvo Truck, September 2006
  - Interim report on CoolCab activity, August 2007
  - Presentation of results of industry meetings and tool specifications, September 2008
  - SAE Paper: Thermal Load Reduction of Truck Tractor Sleeper Cabins, October 2008

Barriers and Approach

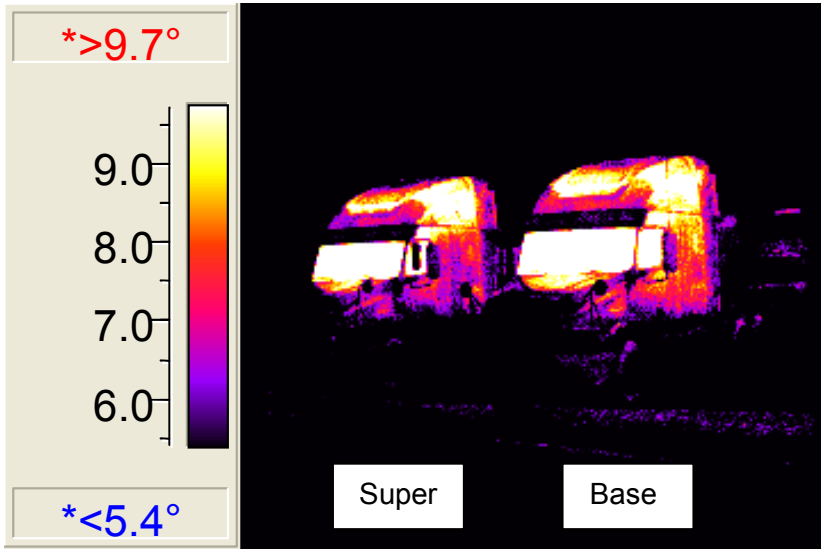
- Barriers
  - Industry lacks key performance data on HVAC loads and truck cabin insulation
  - Truck fleets operate on small profit margins and are sensitive to purchase costs for equipment
- Approach
  - Work with industry to identify specific needs and development projects

CoolCab Advanced Technologies



Infrared Image Test

- Freightliner Trucks at Schneider National
- Investigate potential for improving cab efficiency
- Qualitative comparison
  - Identify high heat loss areas
  - Note areas with greatest potential for improvement



Accomplishments

CoolCab Testing with Volvo

- Volvo truck at NREL for testing
  - 77-inch sleeper cab
  - On-board technologies
- Objectives
  - Quantify truck cabin heat transfer
  - Identify potential improvements
- Approach
  - Co-heat tests to determine UA
  - Measure air exchange rate
  - Solar soak tests
  - Infrared imaging

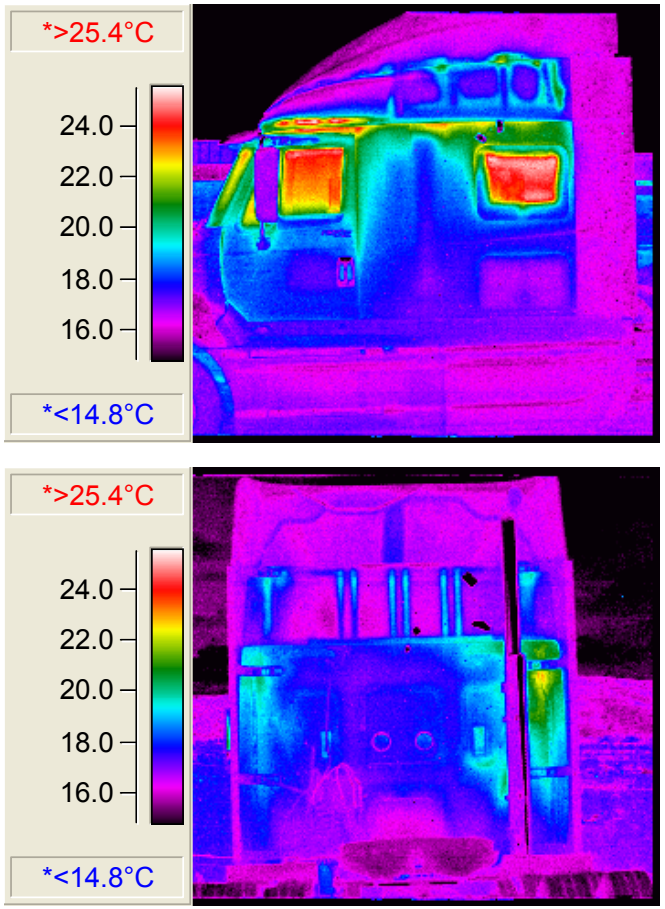
CoolCab Testing with International

- International truck at NREL
  - ProStar sleeper cab tractor
  - Electric HVAC system with battery APU
- Objectives
  - Quantify truck cabin heat transfer
  - Predict HVAC system load requirements

Accomplishments

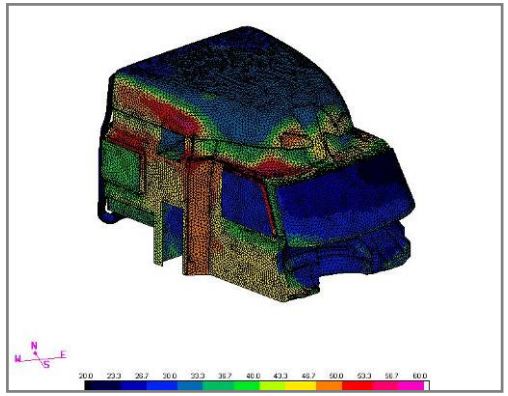
Summary of UA Test Results

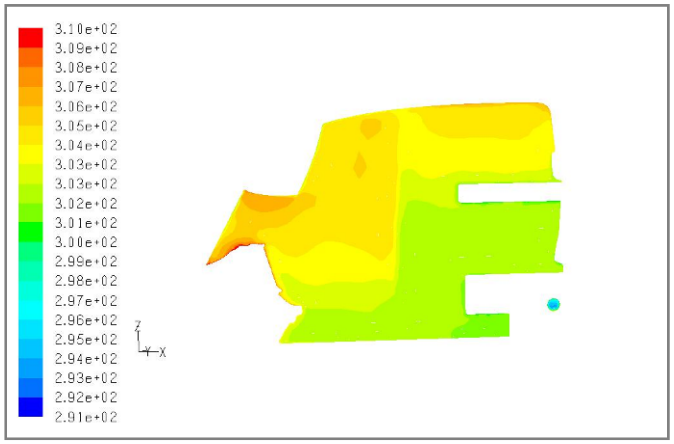
	Base or Unmodified Case	Sleeper Curtain Closed	Arctic Curtain Closed	Windows Insulated
UA Test Truck 1	65 W/K	-16%	N/A	-16%
UA Test Truck 2	51 W/K	-21%	-26%	-14%



Thermal Modeling

- CFD Model
  - Fluent CFD
  - Radtherm
- Validate with test data
  - Solar soak air temperatures predicted within 3ºC
  - Apply multiple configurations
- Model impact of enhanced thermal technologies
  - Baseline A/C case
  - Increased cab insulation





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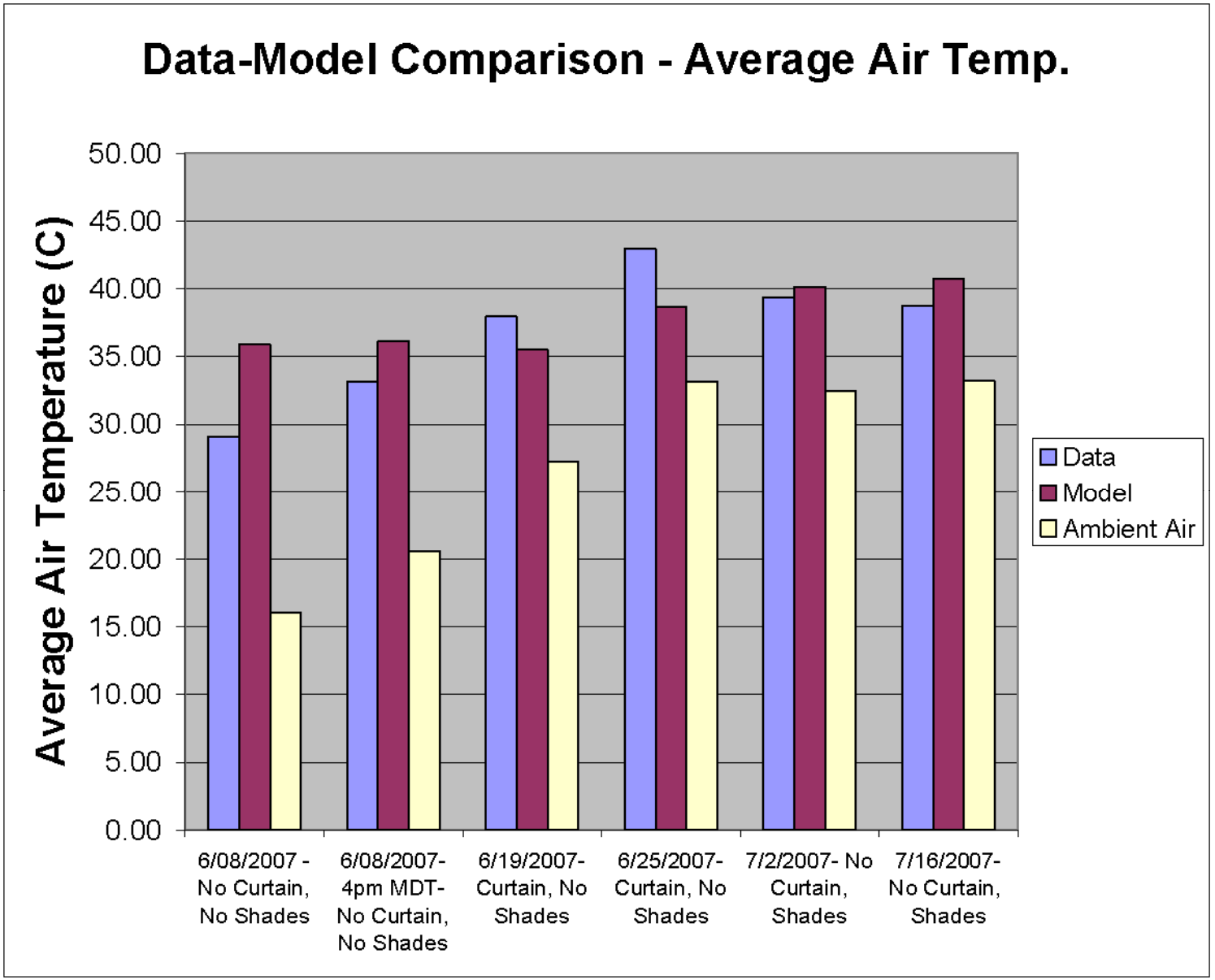

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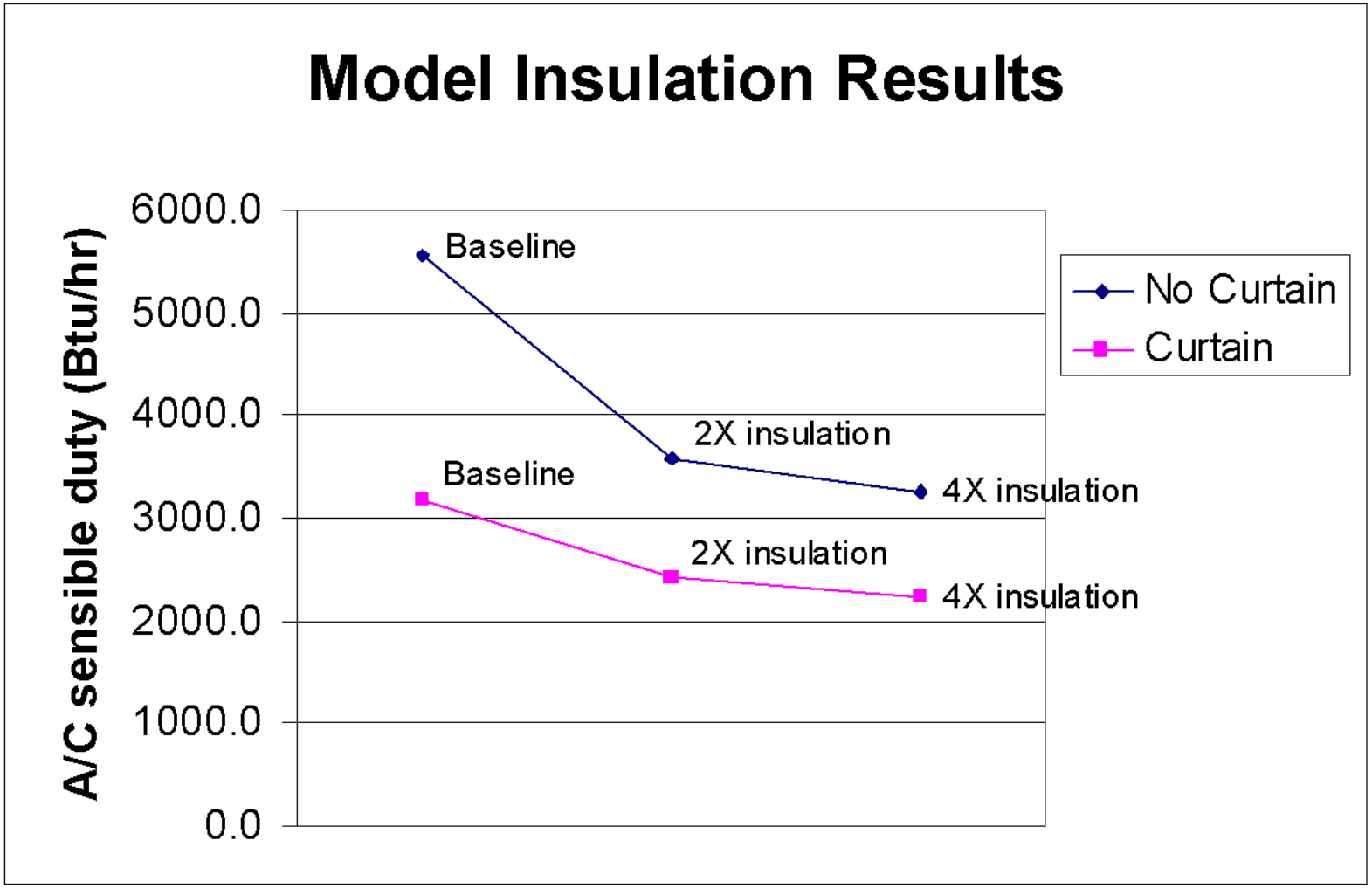
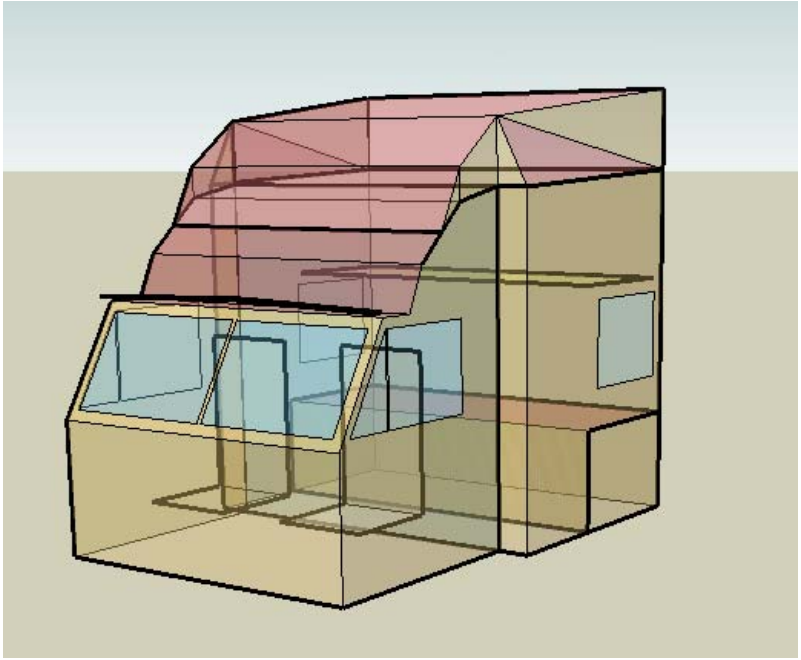


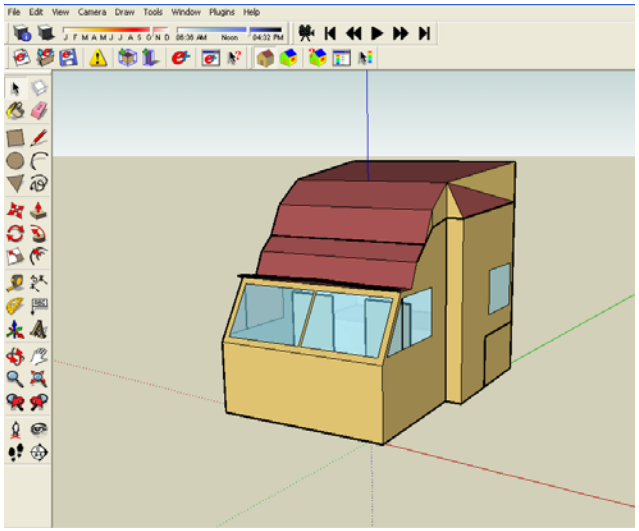
HVAC Load Calculation Tool Concept

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



HVAC Load Calculation Tool – CoolCalc

- Key input parameters
  - Truck cab geometry
  - Material properties
  - Climatic conditions
- Outputs
  - Calculate loads
  - Estimate potential load reduction



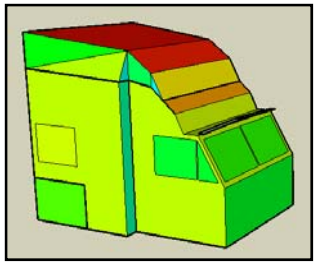
- Industry input to define requirements
  - Truck OEMs
  - Idle reduction technology manufacturers
  - 21st Century Truck

CoolCalc Development

- Truck testing and modeling data
- Industry Input
  - Feedback from 21CT partners
  - Future industry partner for validation
- Grow capabilities
  - Apply a suite of tools
    - Load estimation: CoolCalc
    - Detailed flow analysis: CFD
    - Vehicle fuel consumption: PSAT
    - In-use validation: Fleet Test & Evaluation

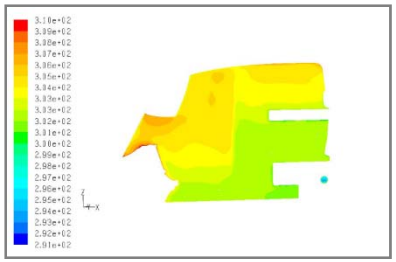
Accomplishments

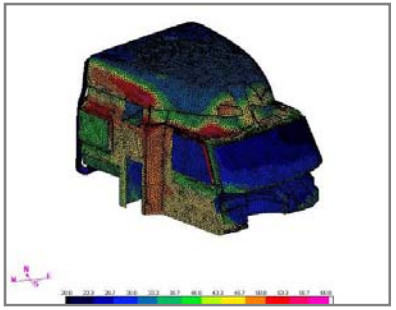
CoolCalc



Load Estimation

CFD



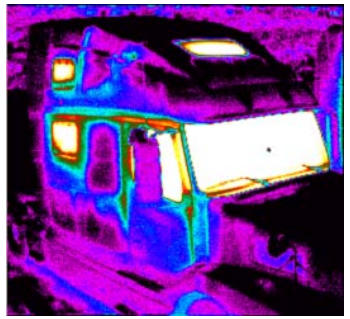


Detailed Flow Analysis

Fuel Consumption

In-Use Validation

Testing



Vehicle Modeling

CoolCalc Heat Transfer Solver – EnergyPlus

- DOE/EERE buildings energy analysis/thermal load simulation program
- Released 1999 but dates back to BLAST and DOE-2, programs developed in the 70s and 80s
- Sixteen developers from national labs, industry, and universities
- Received a 2003 R&D 100 award
- Capabilities
  - Simultaneously solves building, HVAC system, and plant equipment
  - Sub-hourly, user-defined time steps
  - Heat balance based solution
  - Transient heat conduction
- No GUI – text-file based

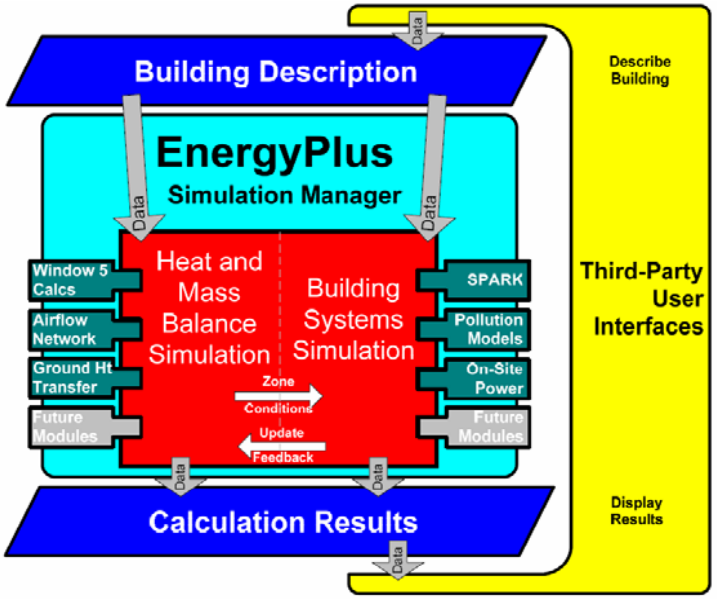
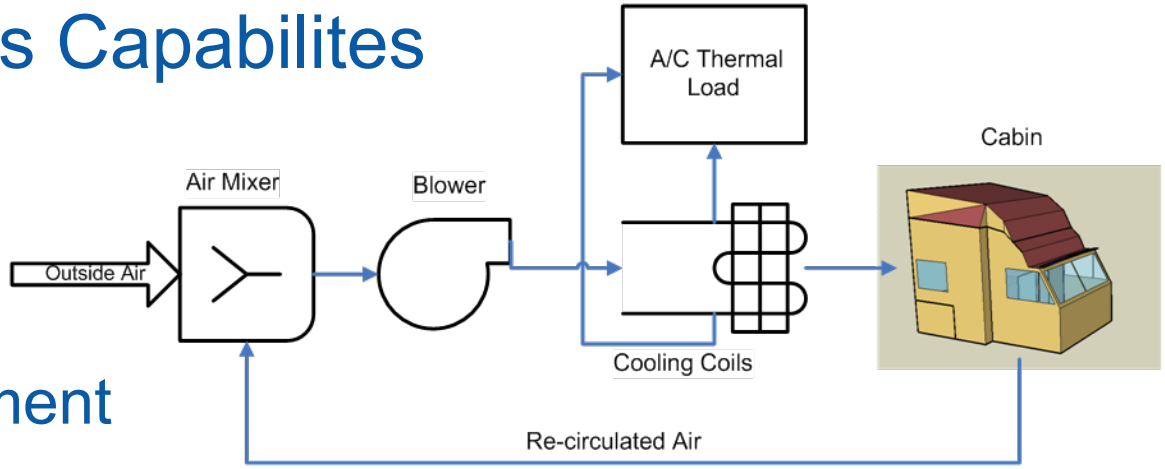


Figure 1. EnergyPlus -- the big picture

Other EnergyPlus Capabilites

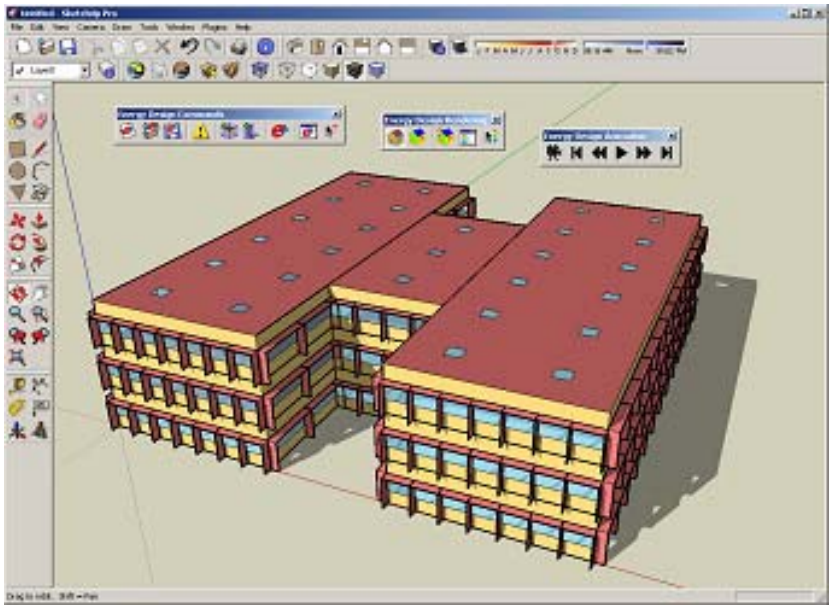
- A/C models
- Controls
- Scheduling loads and equipment
- Weather database
  - 1,300 locations, many with typical mean year data
  - Limited real-time (hourly) data available
- Thermal comfort



Sensation	Description
3	Hot
2	Warm
1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

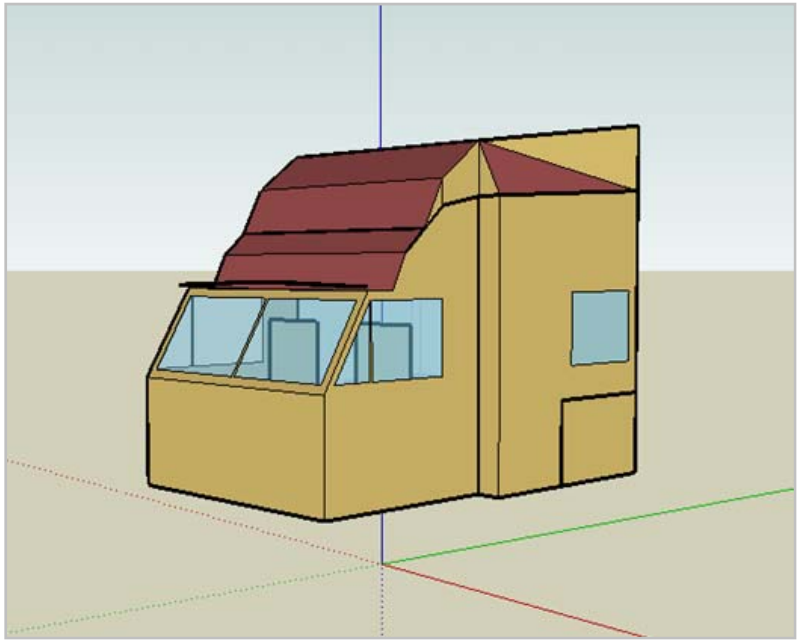
CoolCalc Graphical User Interface (GUI)

- SketchUp
  - "3D for everyone"
  - Designed to be "intuitive, flexible, and easier to use"
  - Developed in 1998, acquired by Google in 2006
- Energy Design Plug-In (2008)
  - Developed at NREL
  - Creates EnergyPlus input files
  - Provides user interface for EnergyPlus
    - Geometry
    - Material assignment
    - Run simulation
    - Result visualization

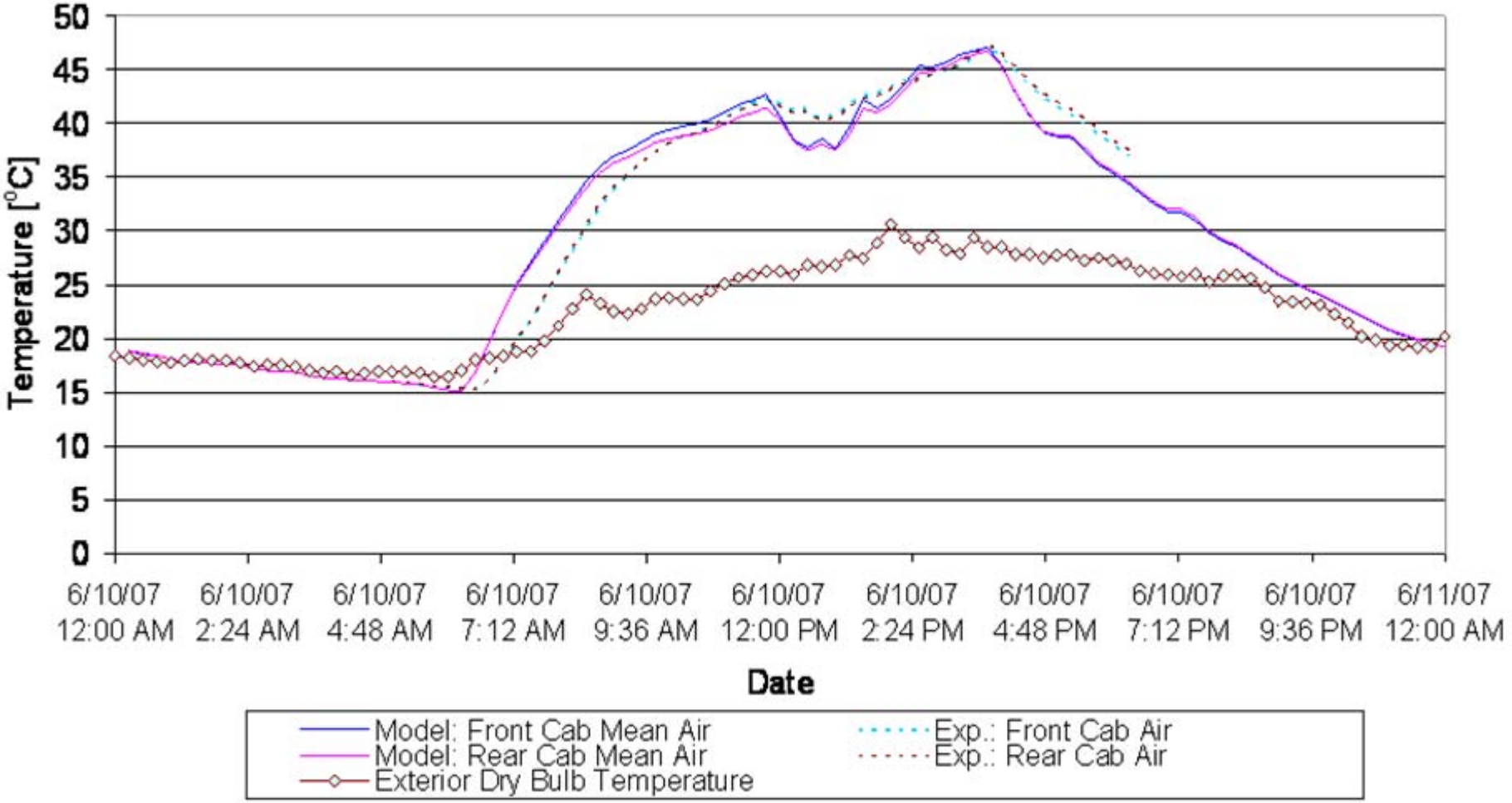


Concept Validation – Initial Test Case

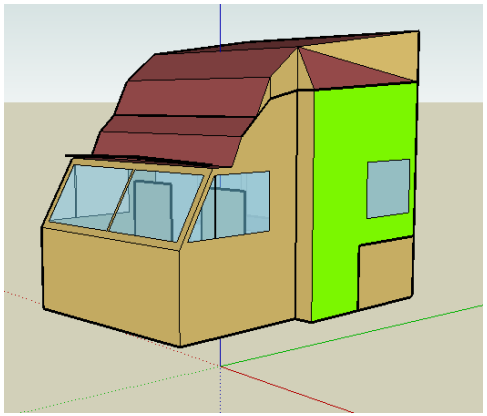
- Comparison to soak testing (2007)
  - Geometry created using rough dimensions
  - Best guess assumptions
  - On site weather data used
  - Compared to experimental data

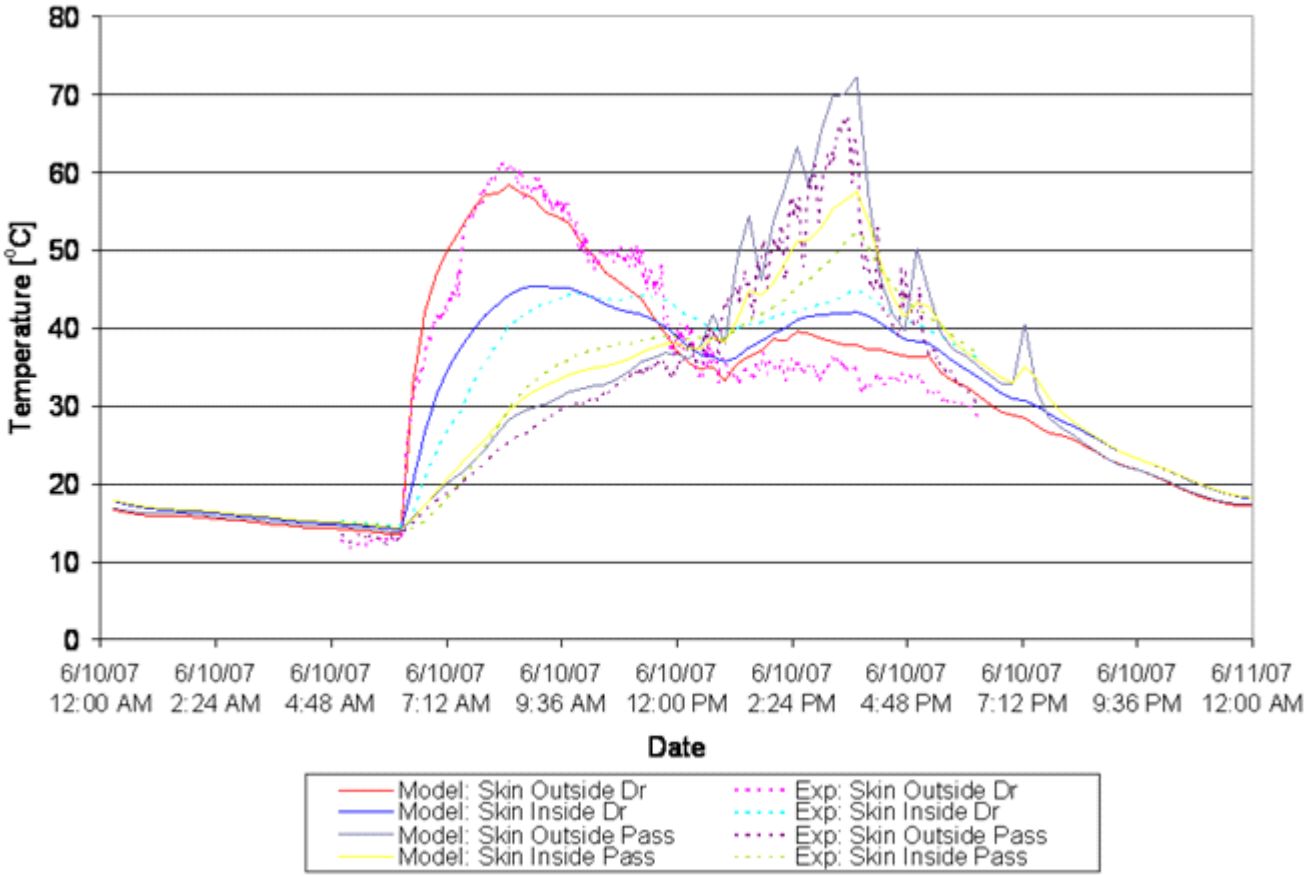


Concept Validation – Air Temp. Comparison

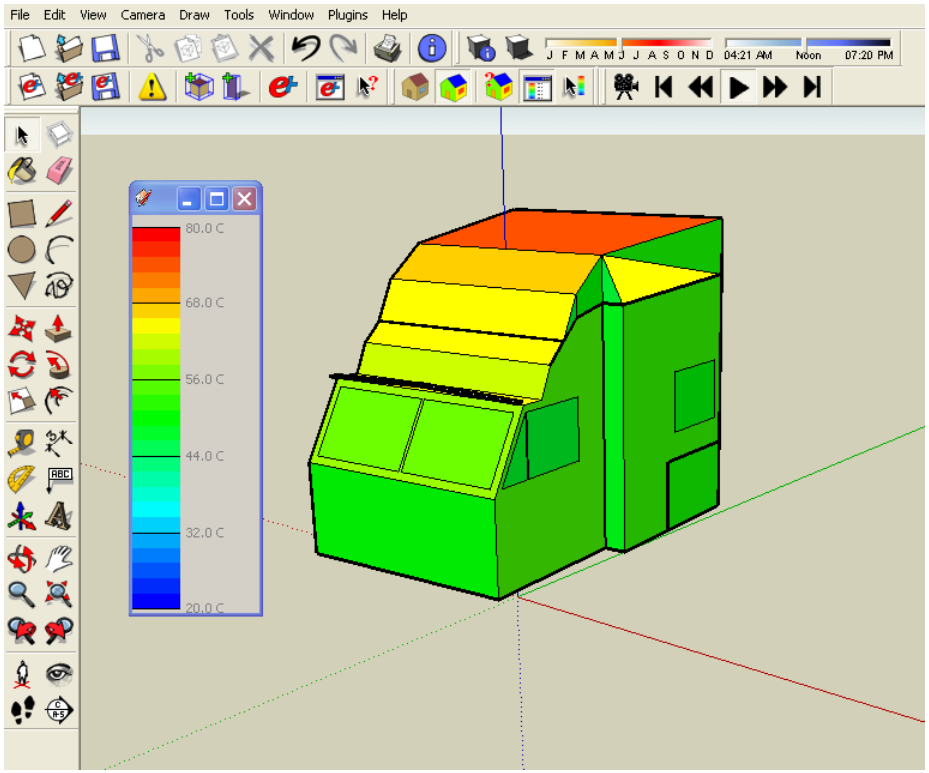


Concept Validation – Surface Temp. Comparison

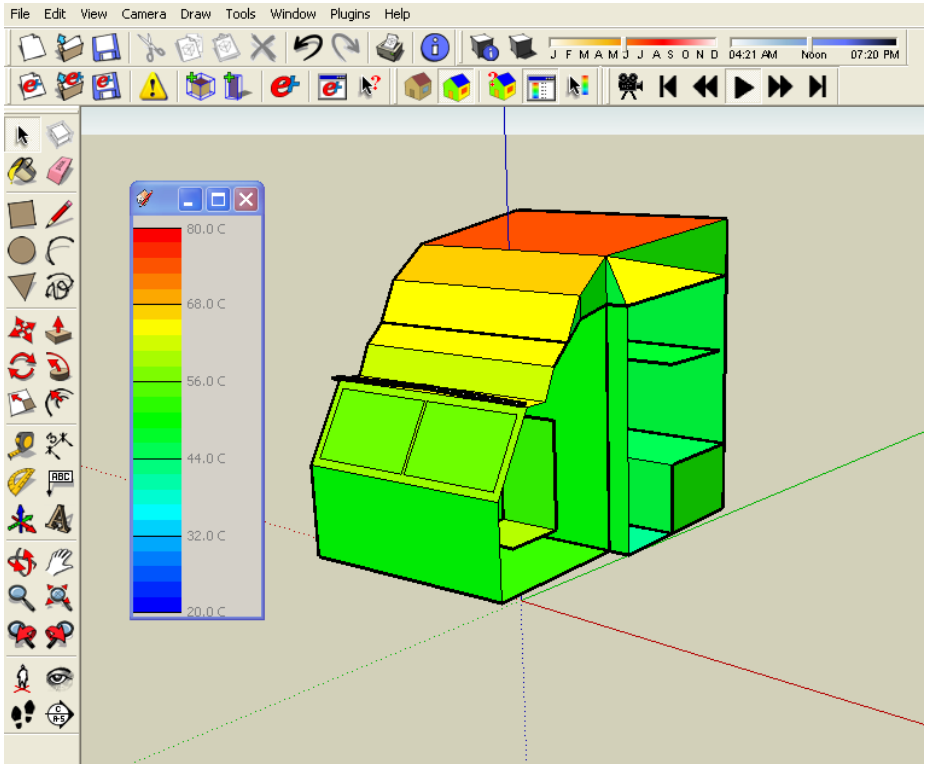




Concept Validation – Surface Temp. Comparison



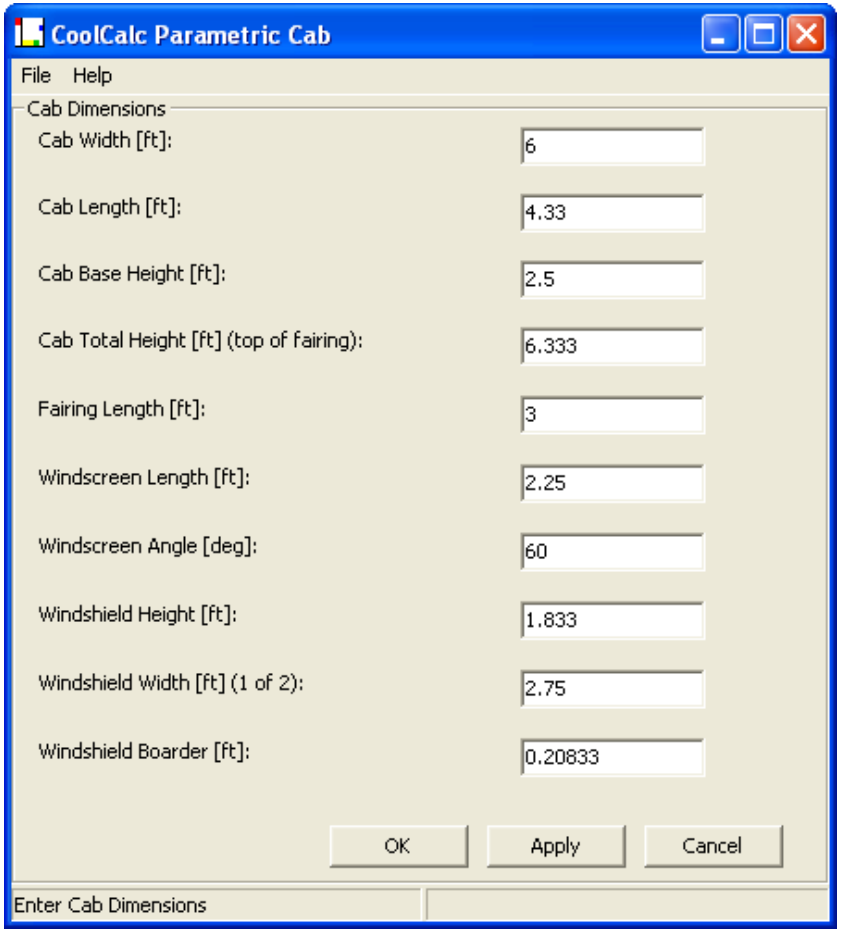
Outside temperature



Inside temperatures
(hidden side wall)

CoolCalc Development

- Geometry
  - Parametric cab creation
  - Manual modification
- Material property assignment
  - Thermal mass
  - Conductivity
  - Layered structures
  - LW and SW radiation properties
- A/C Settings
  - Thermostat
  - Percent recirculation
- Other
  - Air infiltration
  - Internal loads
  - Internal mass
- Link to vehicle fuel use model



Partners

Government

- 21st Century Truck Partnership

Industry

- Volvo
- International
- Freightliner
- Schneider National
- Caterpillar
- Cummins
- Webasto
- Espar

Future Work

- Continue Development of CoolCalc
  - Working prototype of tool in FY09
  - Vehicle specific interface
    - Toolbar interface
    - Base cab generation
    - A/C thermal calculation
    - Construction and material properties
- Application of prototype tool FY10
  - Model and predict HVAC thermal loads
  - Truck testing to measure HVAC loads
  - Validation of tool with truck data
  - Industry collaboration

Contacts

Special thanks to:

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