A WEB-BASED SIMULATION TOOL ON THE PERFORMANCE OF DIFFERENT ROOFING SYSTEMS

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INTRODUCTION

• The Roof Savings Calculator (RSC) provides the general public with a web-based program for calculating the energy and cost savings of different roofing and attic systems on four different building types (residential, office, retail, and warehouse) in 239 US TMY2 locations.

• The core simulation engine of the RSC is doe2 attic, which couples the AtticSim program developed by ORNL with the DOE-2.1E whole-building simulation program developed by LBNL.

• The paper focuses only on the development of doe2 attic and its validation against measured data, but in this presentation I have also asked co-author Joshua New to provide a brief overview of the RSC.
CONTENTS OF PRESENTATION

• Description of *AtticSim*
• Description of *DOE-2.1E*
• Combining *AtticSim* with *DOE-2.1E* to create *doe2attic*
• Duct modeling in *doe2attic*
• Validation of *doe2attic* against one year’s measured data for two houses in California
  – Attic air temperatures
  – Ceiling heat fluxes
  – A/C electricity consumption
• Overview of the *Roof Savings Calculator (RSC)*
ATTICSIM

- Specialized stand-alone program developed by ORNL for predicting the thermal performance of residential attics, first released in 1998 and continuously upgraded.


- Conduction calculated using Conduction Transfer Functions (CTF), convection using correlations to literature data, radiative exchange using First Principles equations, latent heat effects due to sorption and desorption considered.

- Radiant heat exchange calculated using Heat Balance equations, with fixed view factors between seven attic surfaces (2 roofs, 2 gables, 2 eaves, and 1 attic floor/ceiling).

- A finite-element duct model was added in 2004 that simulates conduction, surface convection, and radiative exchange between the ducts and the attic surfaces, even when the HVAC system is off to account for thermal storage and lag in the duct system.
**DOE-2.1E**

- *DOE-2* is a whole-building simulation program originally developed by LBNL in the early 1980s and continuously maintained until 1996.
- *DOE-2.1E* is the most recent version in the public domain released in 1993.
- *DOE-2* development after 1996 is being done by private companies, in particular *DOE-2.2/2.3* used as the simulation engine for *eQUEST*.
- *DOE-2.1E* was chosen as the core engine for *RSC* because of its stability, robustness, computational speed, and the authors’ accessibility and familiarity with the source code.
COMBINING ATTICSIM WITH DOE-2.1E TO CREATE DOE2ATTIC (1)

• The integration of AtticSim with DOE-2.1E was dictated by the structure of DOE-2.

• The integration was made easier because both programs were written in Fortran 77.

• A new subroutine ATI has been added to doe2atticbdl to read the attic description (including the ducts) in the input file and pass it to AtticSim.

• AtticSim has been restructured as a large subroutine ats that is called in the SYSTEM module of doe2atticsim.
COMBINING ATTICSIM WITH DOE-2.1E TO CREATE DOE2ATTIC (2)

• **DOE-2** takes a two-step approach in calculating the zone loads; In LOADS, the heat gains and losses are calculated at a fixed reference temperature; in SYSTEMS the actual zone temperature is calculated based on those heat gains and losses, the thermostat setting, and HVAC capacity.

• In LOADS, **doe2attic** uses the same reference temperature for the attic and space below, so that LOADS will show no heat flow across the attic floor/ceiling.

• In SYSTEMS, **doe2attic** passes to **AtticSim** the previous hour’s room air temperature, HVAC fractional on-time, and duct supply air temperature. **AtticSim** then simulates the attic and duct system (if any) and sends back to **doe2attic**
  - heat flow through the ceiling to zone below
  - attic air temperature
  - heat gains or losses of the duct system (if there are any)
DUCT MODELING IN DOE2ATTIC

• Major addition to AtticSim in 2004.
• Finite-element solution tightly coupled with the attic model.
• Energy losses from attic duct systems are frequently greater than that from conduction through the ceiling, especially during the summer.
• Improvements to the AtticSim duct model in doe2attic
  ➢ Correction to the HVAC loads due to ducts (mass balance)
  ➢ Correction to the HVAC “on-time” fraction (integer cycles)
  ➢ Change in duct length for large buildings. Instead of a fixed element length, a “growth factor” was used to progressively increase the element length for longer ducts
• Improvements to the AtticSim data exchange in doe2attic
  ➢ Differentiate Supply Air Temperatures and “on-time” fractions between A/C and economizer modes
VALIDATION OF DOE2ATTIC AGAINST ONE YEAR’S MEASURED DATA FOR TWO HOUSES IN CALIFORNIA

• Detailed monitoring of attic conditions and electricity use in two houses in Fresno, one with a standard roof and the other with a “cool roof” from May 2012 through April 2013.

• Monitored data include:
  - weather conditions (temperature, humidity, wind speed, and global horizontal solar radiation)
  - Attic air temperature and heat flow through the ceiling
  - Room air temperature
  - Total house and air-conditioning electricity use
COMPARISON OF \textit{DOE2ATTIC} TO MEASURED ATTIC AIR TEMPERATURES

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\textbf{Standard Home Attic Air Temperatures Aug 1-7, 2012} \\
\begin{tikzpicture}
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\addplot [red,mark=square*,mark options={scale=0.5},thick] table [x=x,y=doe2attic] {data1.csv};
\legend{measured, doe2attic}
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\begin{center}
\textbf{Cool Home Attic Air Temperatures Aug 1-7, 2012} \\
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    ymax=70,
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]
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\begin{center}
\textbf{Standard Home Attic Air Temperatures Dec 15-21, 2012} \\
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\begin{center}
\textbf{Cool Home Attic Air Temps Dec 15-21, 2012} \\
\begin{tikzpicture}
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\end{center}
COMPARISON OF DOE2ATTIC TO MEASURED CEILING HEAT FLUXES


Cool Roof Ceiling Heat Flux Aug 1-7, 2012


COMPARISON OF *DOE2ATTIC* TO MEASURED ROOM AIR TEMPERATURES

**Standard Home Room Air Temperatures Aug 1-7, 2012**

**Cool Roof House Room Air Temps Aug 1-7, 2012**

**Standard Home Room Air Temperatures May 1-7, 2012**

**Cool Home Room Air Temperatures May 1-7, 2012**
COMPARISON OF DOE2ATTIC TO MEASURED COOLING ELECTRICITY USE

IBPSA Building Simulation Conference, Hyderabad, India, Dec. 7-9, 2015
COMPARISON OF DOE2ATTIC TO MEASURED HOURLY COOLING ELECTRICITY USE

Standard House

\[ y = 0.9215x \]
\[ R^2 = 0.7825 \]

Cool House

\[ y = 0.8698x \]
\[ R^2 = 0.7355 \]
COMPARISON OF DOE2ATTIC TO MEASURED MONTHLY COOLING ELECTRICITY USE

Measured monthly A/C Elec Usage

Simulated monthly A/C Elec Usage
CONCLUSIONS

• The wealth of monitored data permitted an unusually high level of detail in the validation.

• Although the close correlation in attic air temperatures suggests that AtticSim is modeling correctly attic heat transfer, the discrepancy in the Standard Home ceiling heat fluxes remains unexplained.

• The comparison of simulated to measured cooling electricity use indicates an underprediction of 8-13%.

• Ongoing work found that cooling energy losses due to ducts was being incorrectly reported by doe2attic, which may explain this underprediction.

• The thermal modeling of attics appears to be working well, but further work is still needed on the duct modeling.
OVERVIEW OF THE \textit{ROOF SAVINGS CALCULATOR (RSC)}

Chris Scruton CEC

R. Levinson, H. Gilbert, H. Akbari

INDUSTRY

COLLABORATIVE R&D

Marc LaFrance DOE BT

A. Desjarlais, W. Miller, J. New

LBNL

ORNL

WBT

Joe Huang, Ender Erdem
COMPARISON OF RSC TO PREVIOUS CALCULATORS

• Replaces:
  – EPA Roof Comparison Calc
  – DOE Cool Roof Calculator

• Minimal questions (<20)
  – Only location is required
  – Building America defaults
  – Help links for unknown information

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### Calculator Input Comparison Chart

<table>
<thead>
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<th>Feature</th>
<th>RSC°</th>
<th>PAC Slides²</th>
<th>PAC QRpt³</th>
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<th>DOE⁵</th>
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BUILDING TYPES IN THE RSC

Residential

Office

“Big Box” Retail

Warehouse


RSC INPUT SCREENS
(http://www.roofcalc.com)
RSC ROOF TYPES
( http://www.roofcalc.com )

Residential Roof Types
Roofs can be created with many material types involving different durability and thermal properties. This calculator supports the most common residential roof types for the US:

- Asphalt Shingles
- Metal Roof
- Tile Roof

Commercial Roof Types
Roofs can be created with many material types which have varying durability and thermal properties. This calculator supports the most common commercial roof types for the US building stock including:

- Built-Up
- Metal
- Modified Bitumen
- Concrete Pavers
- Single-Ply Membranes

9. Roof type:
- Single-ply membranes
- Concrete pavers
- Modified bitumen
- Metal
- Built up
RSC OUTPUT RESULTS
(http://www.roofcalc.com)

Simulation Results

You save $117/year!

Energy Savings

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<th>Total</th>
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<td>$117</td>
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<td>$21</td>
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933 kWh 0 kWh 3 MBtus

Monthly Savings

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<th>Mar</th>
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<th>May</th>
<th>Jun</th>
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<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<td>-2.6</td>
<td>48.1</td>
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<td>208.6</td>
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<td>181.9</td>
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White-Roof Utility Usage

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<td>597.5</td>
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Base-Case Utility Usage

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