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

Joe Huang[1], Joshua New[2], William Miller[2], Ken Childs[2], Ronnen Levinson[3]

[1]White Box Technologies, United States of America;

[2]Oak Ridge National Laboratory, United States of America;

[3]Lawrence Berkeley National Laboratory, United States of America

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 *doe2attic*, 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 *doe2attic* 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

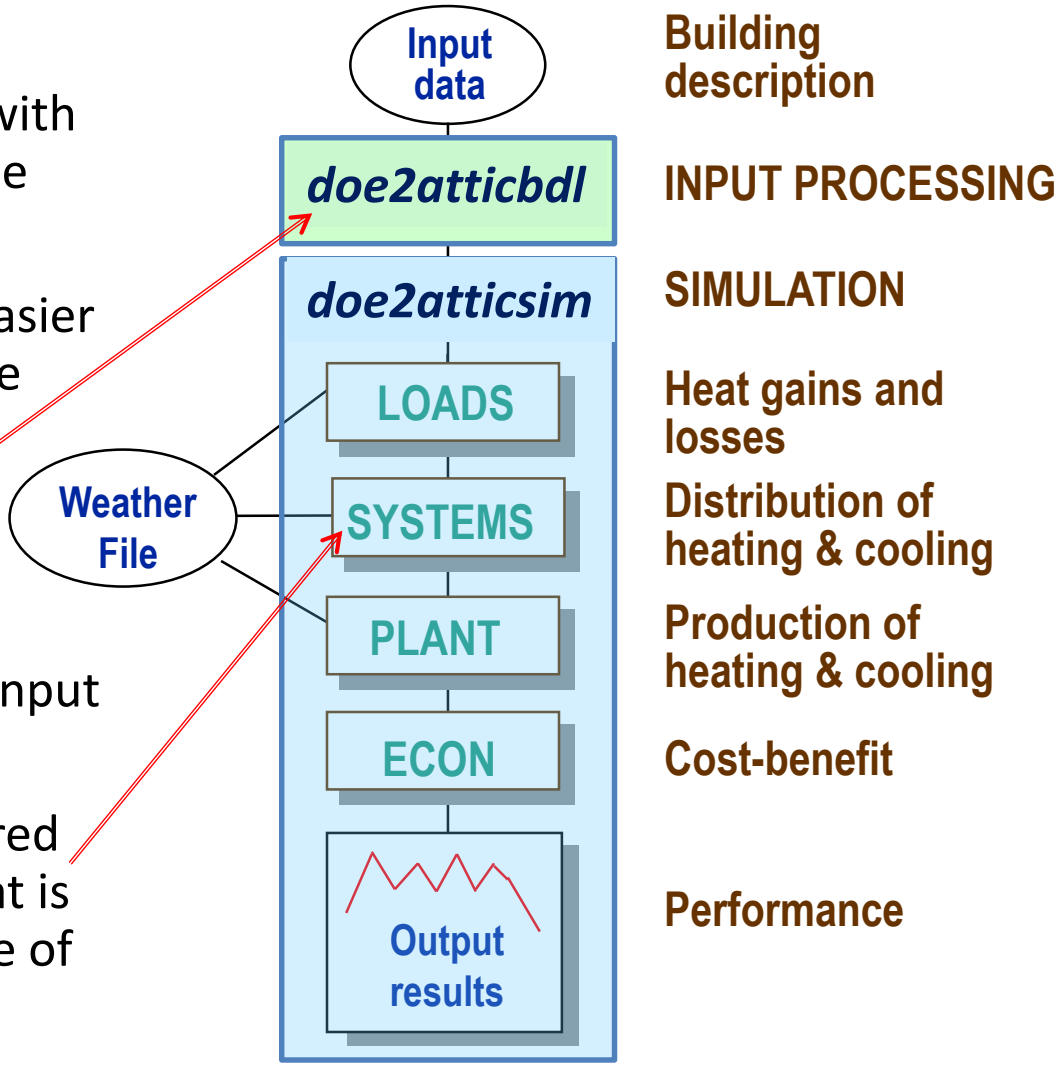
- Specialized stand-alone program developed by ORNL for predicting the thermal performance of residential attics, first released in 1998 and continuously upgraded.
- Adopted by ASTM in 2004 as Standard C1340, "Standard practice for estimation of heat gain or loss through ceilings…"
- Conduction calculated 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)

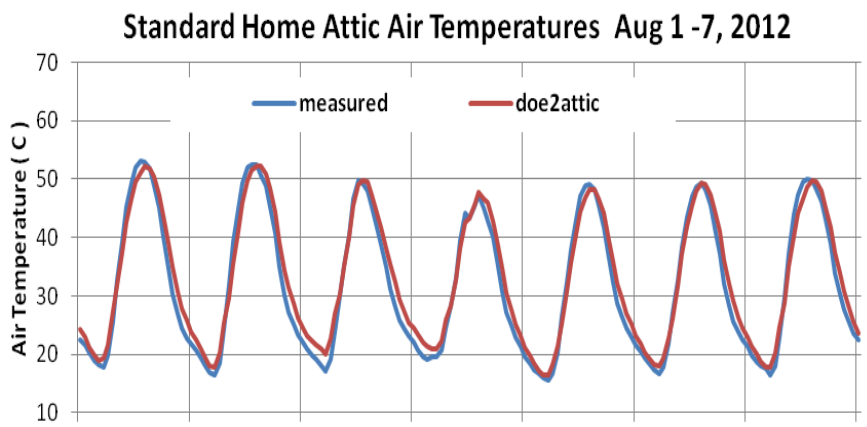
DUCT MODELING IN *DOE2ATTIC*

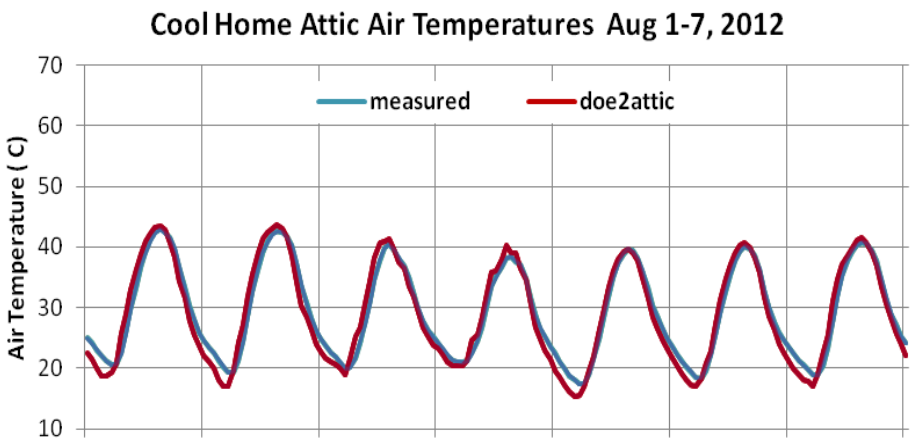
- Major addition to *AtticSim* in 2004.
- Finite-element solution tightly coupled with the attic model.
- Energy losses from attic duct systems are frequently greater than that from conduction through the ceiling, especially during the summer.
- Improvements to the *AtticSim* duct model in *doe2attic*
  - 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

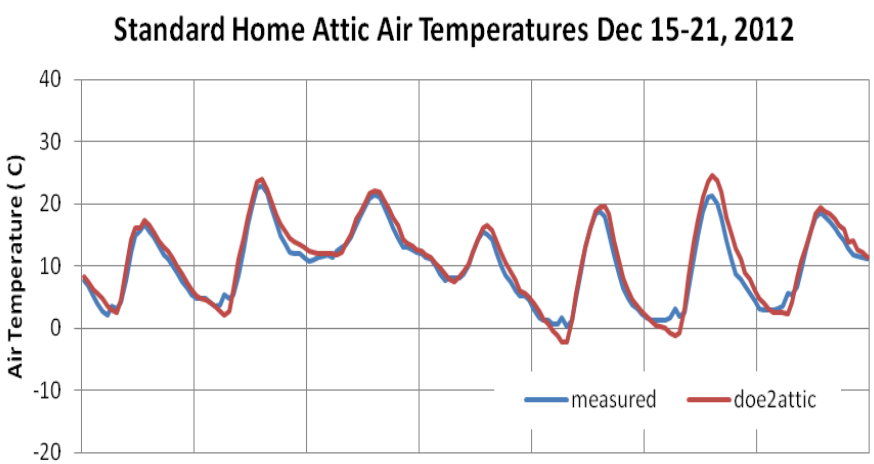
VALIDATION OF *DOE2ATTIC* AGAINST ONE YEAR'S MEASURED DATA FOR TWO HOUSES IN CALIFORNIA

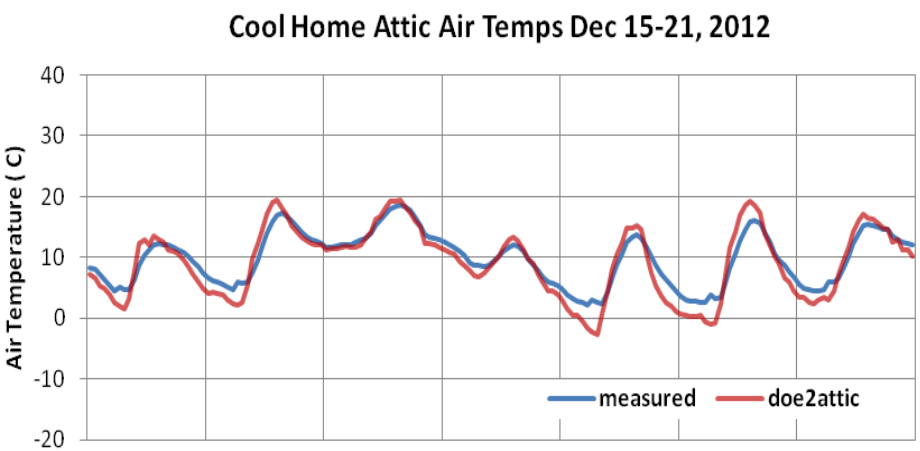
- Detailed monitoring of attic conditions and electricity use in two houses in Fresno, one with a standard roof and the other with a "cool roof" from May 2012 through April 2013.
- Monitored data include:
  - weather conditions (temperature, humidity, wind speed, and global horizontal solar radiation
  - Attic air temperature and heat flow through the ceiling
  - Room air temperature
  - Total house and air-conditioning electricity use

COMPARISON OF *DOE2ATTIC* TO MEASURED ATTIC AIR TEMPERATURES

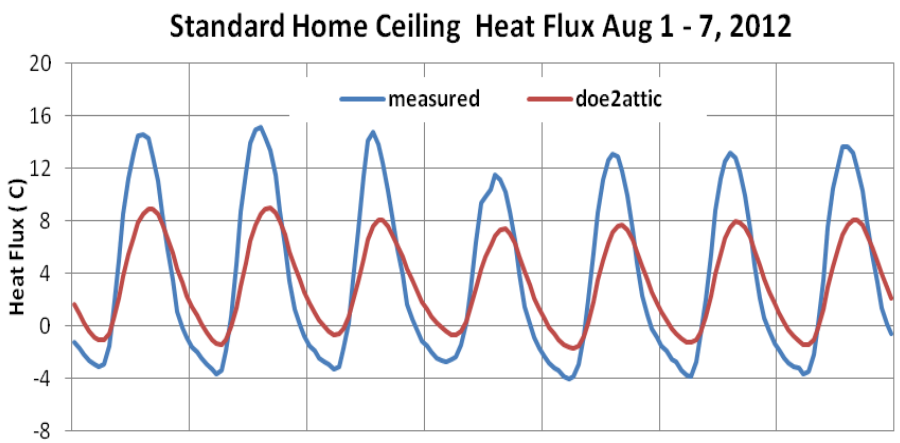


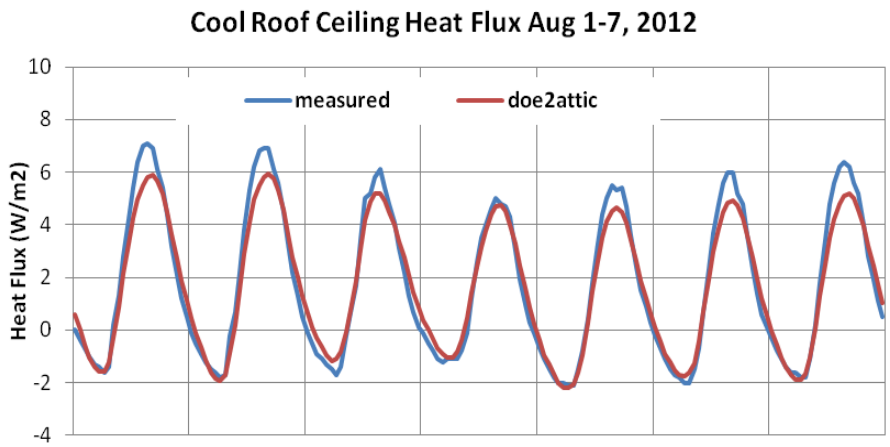


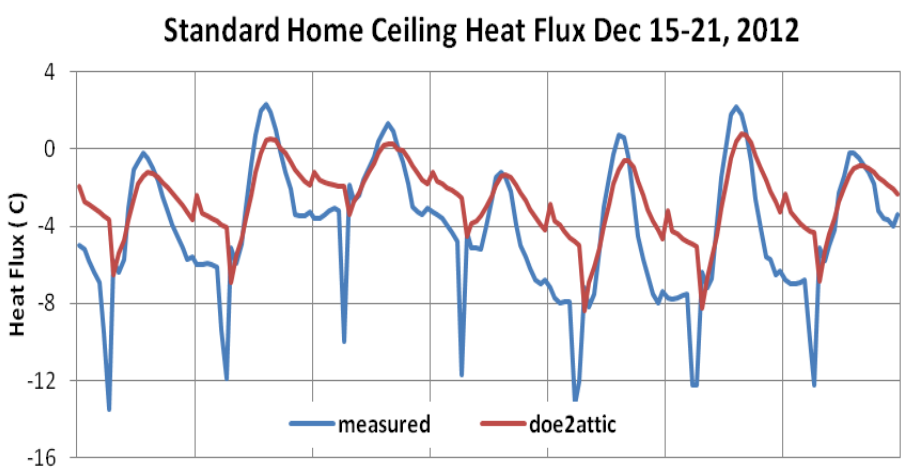


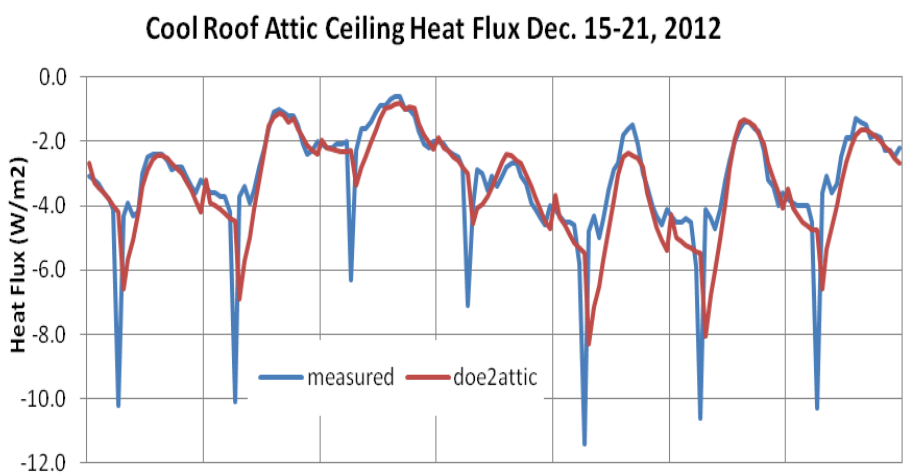


COMPARISON OF *DOE2ATTIC* TO MEASURED CEILING HEAT FLUXES

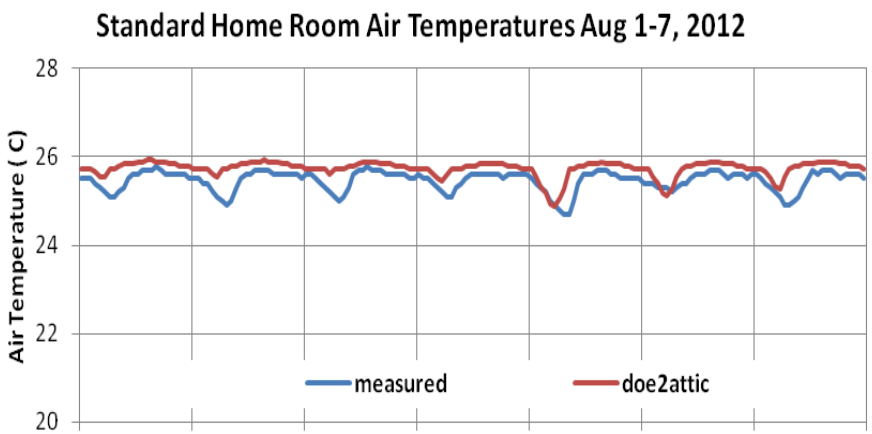


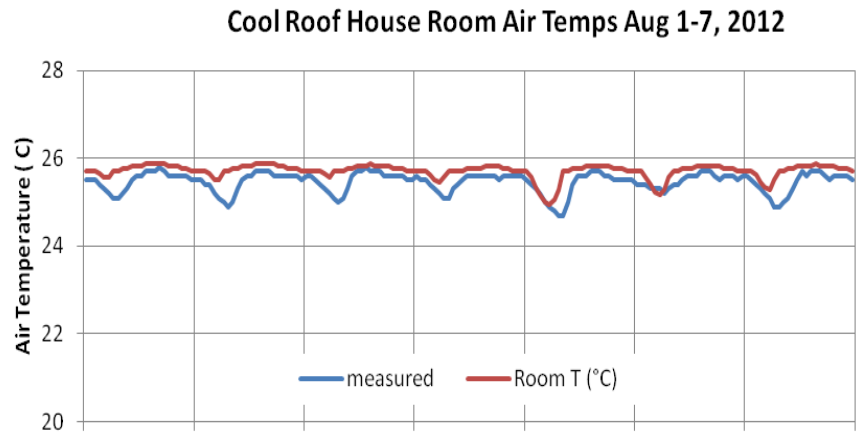


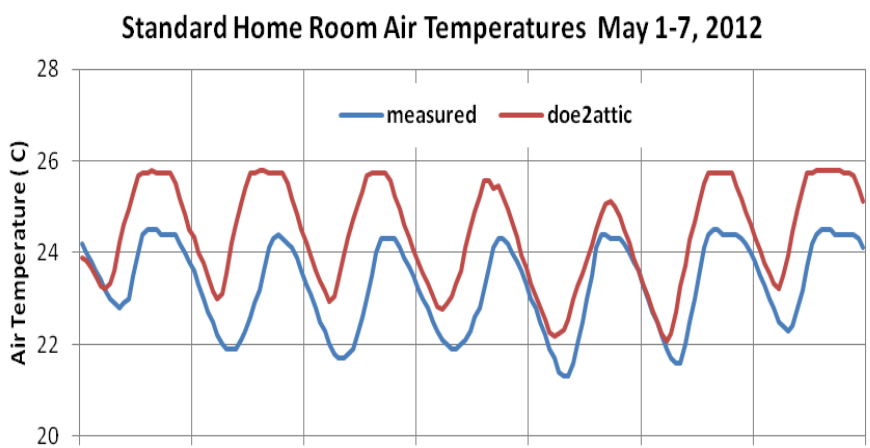


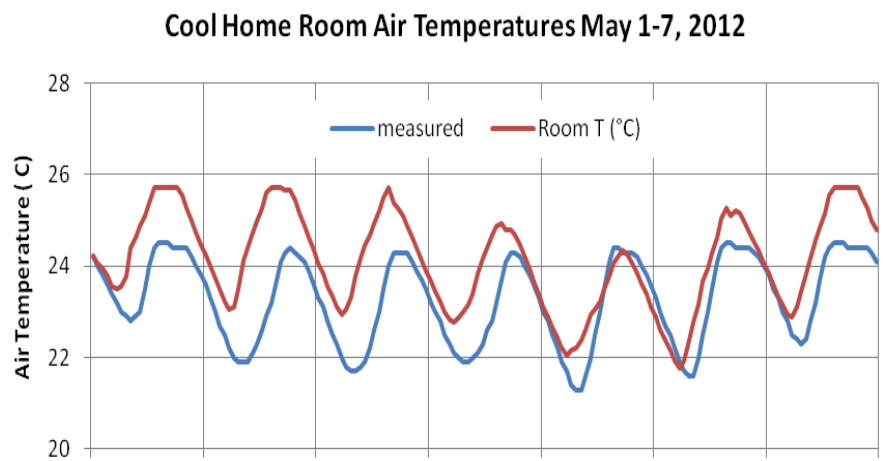


COMPARISON OF *DOE2ATTIC* TO MEASURED ROOM AIR TEMPERATURES

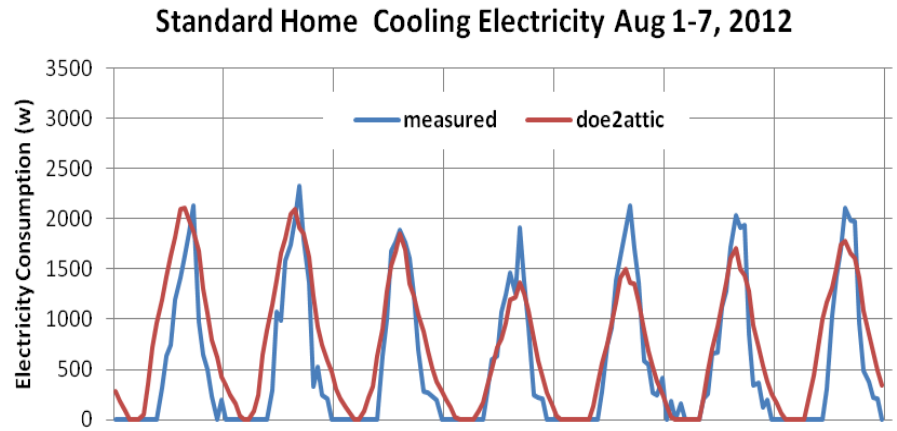


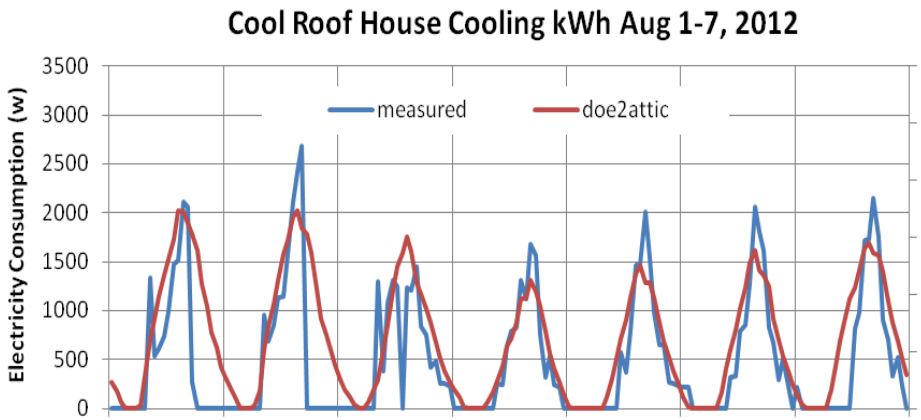


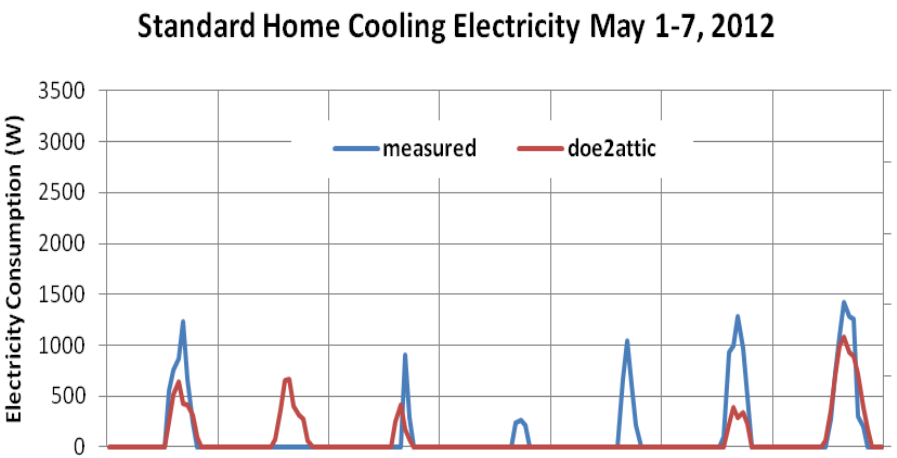


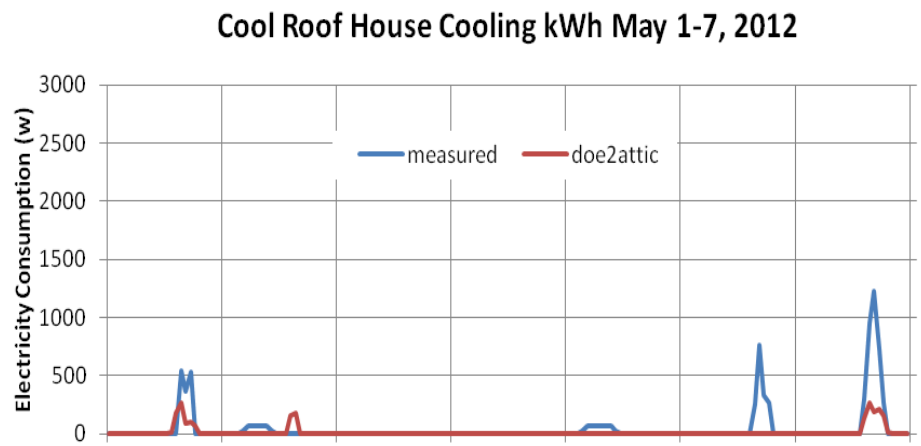


COMPARISON OF *DOE2ATTIC* TO MEASURED COOLING ELECTRICITY USE

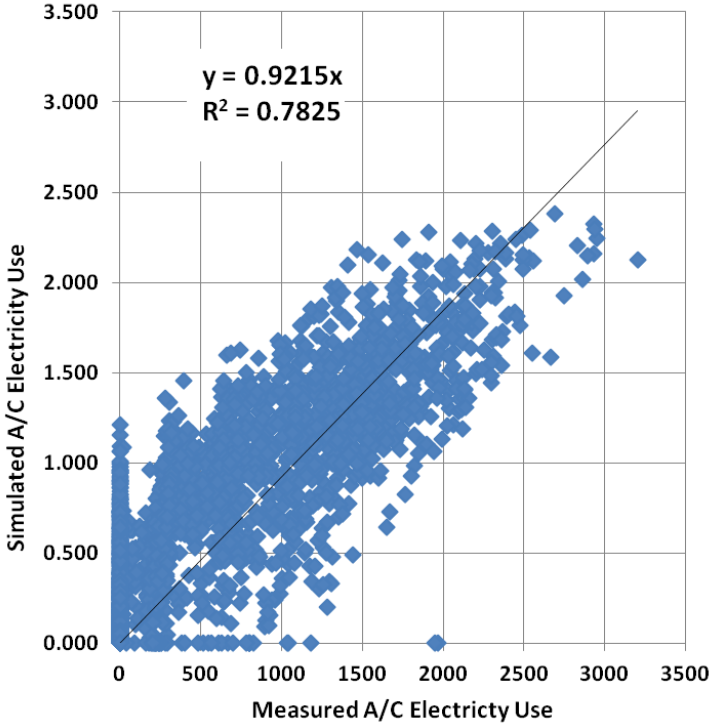




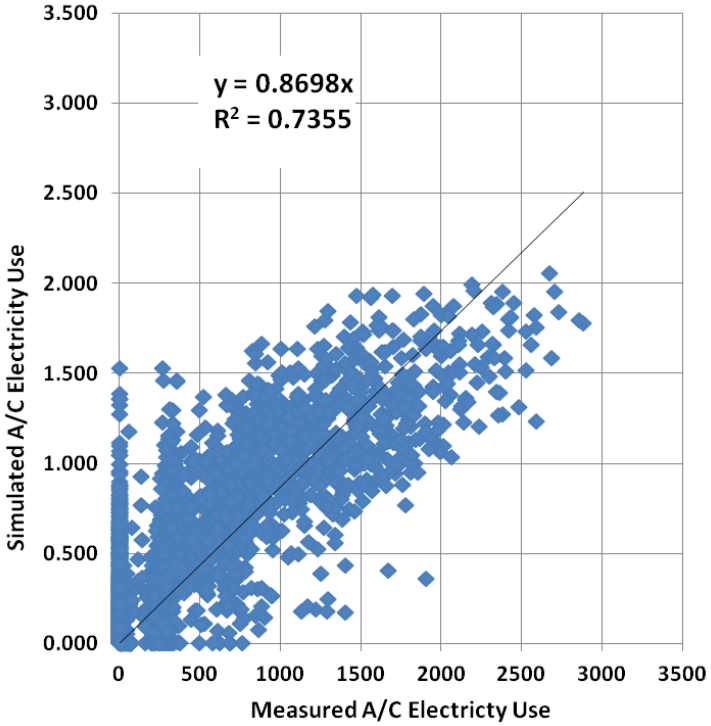




COMPARISON OF *DOE2ATTIC* TO MEASURED HOURLY COOLING ELECTRICITY USE

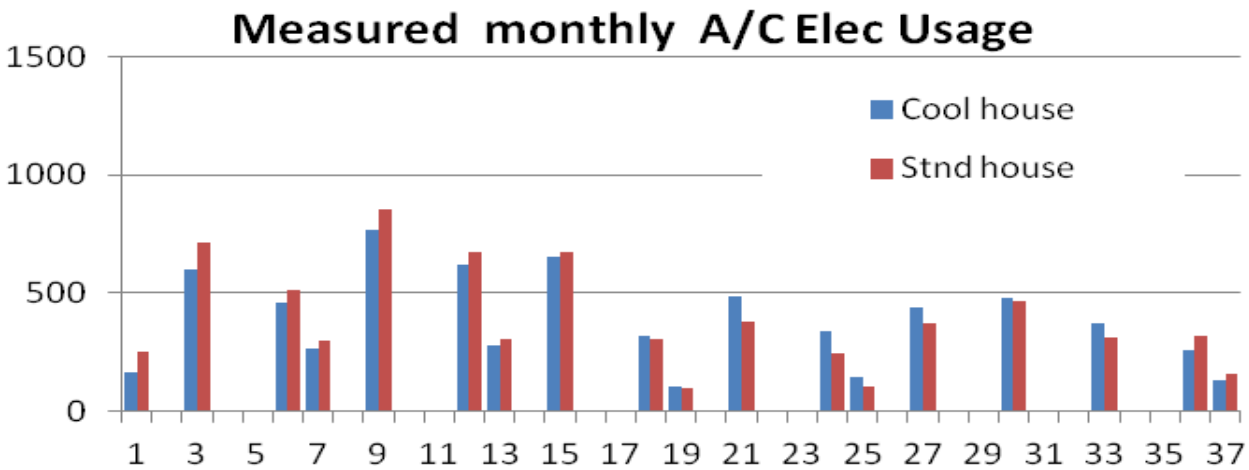


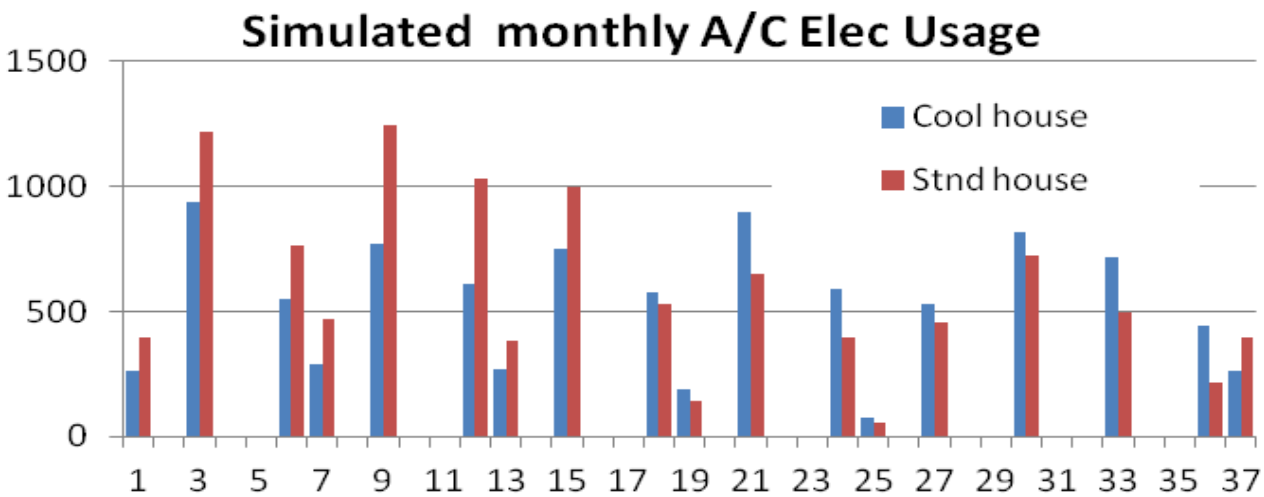
Standard House



Cool House

COMPARISON OF *DOE2ATTIC* TO MEASURED MONTHLY COOLING ELECTRICITY USE

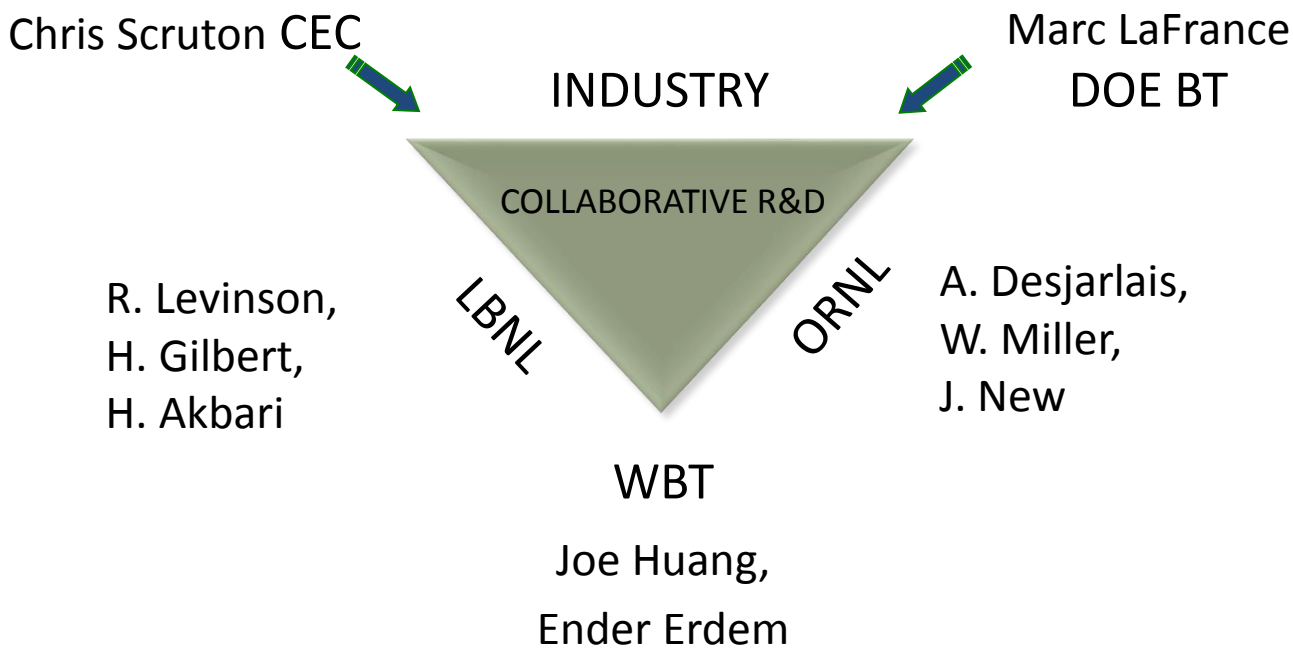




CONCLUSIONS

- 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 *ROOF SAVINGS CALCULATOR (RSC)*



COMPARISON OF *RSC* TO PREVIOUS CALCULATORS

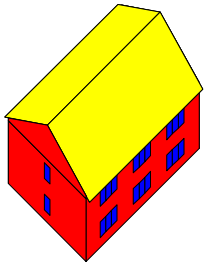
- Replaces:
  - EPA Roof Comparison Calc
  - DOE Cool Roof Calculator
- Minimal questions (<20)
  - Only location is required
  - Building America defaults
  - Help links for unknown information

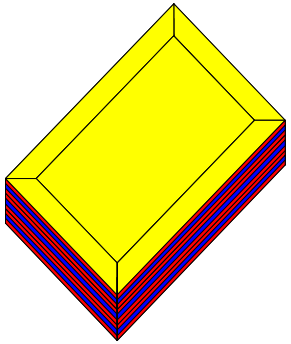
Calculator Input Comparison Chart

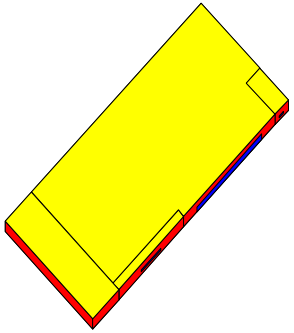
	RSC[1]	PAC Slides[2]	PAC QRpt[3]	EPA[4]	DOE[5]
Building Type	✓	✓	✓	✓	
Location	✓	✓		✓	✓
Days of Operation per week		✓	✓	✓	
Building stock	✓	✓		✓	
Cooling system efficiency (SEER)	✓	✓	✓	✓	✓
Type of heating	✓	✓	✓	✓	✓
Heating system efficiency	✓	✓	✓	✓	✓
Duct location	✓	✓	✓		
Level of roof/ceiling insulation	✓	✓	✓	✓	✓
Above-sheathing ventilation	✓	✓			
Radiant barrier	✓	✓			
Roof thermal mass	✓	✓			
Roof solar reflectance	✓	✓	✓	✓	✓
Roof solar reflectance (black compare)	✓		✓	✓	
Roof thermal emittance	✓	✓	✓		✓
Roof thermal emittance (black compare)	✓		✓		
Internal load		✓			
Conditioned space under roof		✓			
Gas and electricity costs	✓	✓	✓	✓	✓
Inclination / Roof Area	✓			✓	
HVAC Schedule			✓		
Conditioned space (ft^2)	✓			✓	
Number of floors	✓				
Window-to-wall ratio	✓				

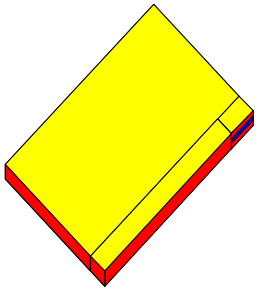
BUILDING TYPES IN THE *RSC*

Residential	Office	“Big Box” Retail	Warehouse







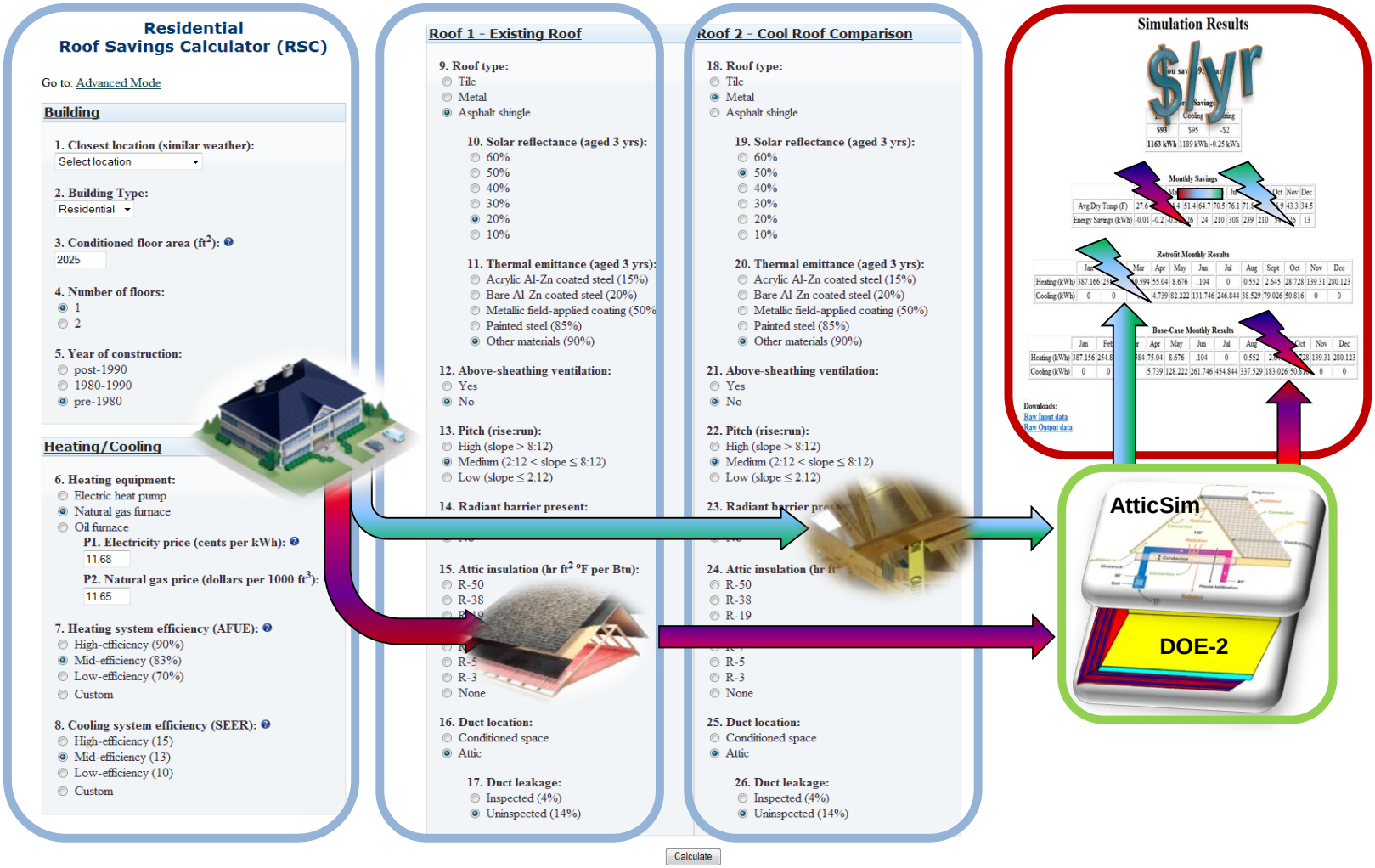


Huang et al. 1987, “Methodology and Assumptions for Evaluating Heating and Cooling Energy Requirements in New Single-family Residential Buildings”, LBL-19128, Lawrence Berkeley National Laboratory, Berkeley CA.

Torcellini et al. 2008, “DOE Commercial Building Benchmark Models”, NREL/CP-550-43291, National Renewable Energy Laboratory, Golden CO.

RSC INPUT SCREENS

(http://www.roofcalc.com)



RSC ROOF TYPES

(http://www.roofcalc.com)

9. Roof type:

- ○ Tile
- ○ Metal
- ◉ Asphalt sl

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

Total	Cooling	Heating
$117	$96	$21
	933 kWh	0 kWh 3 MBtus

Monthly Savings

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	**Total**
Cooling Savings (kWh)	-4.9	-19.1	-2.6	48.1	123.4	208.6	210.4	181.9	143.7	51.3	-5.1	-2.9	**932.7**
Heating Savings (kWh)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Heating Savings (MBtus)	1.9	0.4	-0.4	-0.3	-0.0	0.0	0.0	-0.0	-0.0	-0.4	0.1	1.3	**2.5**

White-Roof Utility Usage

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	**Total**
Cooling (kWh)	25.4	140.5	597.5	1978.1	3969.2	6145.9	7027.0	6442.0	4476.9	1785.4	595.9	4.7	**33188.5**
Heating (kWh)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Heating (MBtus)	62.4	27.1	13.9	2.9	0.7	0.6	0.6	0.6	0.6	2.7	15.6	38.3	**166.1**

Base-Case Utility Usage

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	**Total**
Cooling (kWh)	20.5	121.4	594.9	2026.2	4092.6	6354.5	7237.4	6623.9	4620.6	1836.7	590.8	1.8	**34121.2**
Heating (kWh)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Heating (MBtus)	64.3	27.6	13.5	2.7	0.7	0.6	0.6	0.6	0.6	2.3	15.6	39.6	**168.7**