DOE’s Roof Savings Calculator (RSC)

http://rsc.ornl.gov
(www.roofcalc.com)

in collaboration with EPA, ORNL, LBNL, WBT, CEC

Joshua New, Ph.D.
Building Technologies Research & Integration Center (BTRIC)
Whole Building and Community Integration Group

for:
MCA Roofing Council
Clearwater Beach, FL
January 27, 2014
Presentation summary

- Context – US Energy and ORNL BTRIC
- Building Physics
- Roof Savings Calculator
- Empirical Validation of AtticSim
- Ongoing Validation
- Preliminary Cool Roofing Economics
- Previous Related Projects
- Recent Support Software Upgrades
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Buildings use a lot of energy

Update: 41% of all energy and 72% of all electricity used in the US; over $220 billion in annual energy costs

Source: US Department of Energy

Figure 1. U.S. Primary energy consumption, 2006

The Role of Renewable Energy in the Nation’s Energy Supply, 2009
Total = 64.578 Quadrillion Btu
Total = 7,744 Quadrillion Btu

Note: Sum of components may not add to 100% due to independent rounding
Figure 2. Residential energy loads attributed to envelope and windows


Figure 3. Commercial energy loads attributed to envelope and windows

Science to transform today's buildings into smart, responsive, and efficient structures

Experimental S&T Capabilities

Building Science

Materials Science

Neutron Science

Sensors, Controls, Grid

Modeling and Visualization R&D

Automated Model Calibration & GIS

Computational Science

Applied R&D

Innovative Products

Industry CRADAs

Better Buildings via Novel Tools and Technologies

Next Generation Commercial Buildings

Next Generation Residential Buildings

Data/Knowledge
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Facing our energy challenges

“We're using 19th and 20th century technologies to battle 21st century problems like climate change and energy security.”

Remarks of President Barack Obama, Signing of the American Recovery and Reinvestment Act, February 17, 2009

“Make it white,”
Former Secretary Steven Chu,
Daily Show, July 21, 2009
Cool roof context

Goal to address climate change, manage Earth’s heat budget
(amount of Earth’s heat from the sun minus amount reflected into space)

2 pillars of geo-engineering:

• Albedo engineering for solar radiation management – increasing Earth’s reflectance
  Examples: cloud whitening, stratoshield/stratospheric doping (SO₂, Pinatubo option), reflective aerosols in jet fuel

• Greenhouse gas remediation – primarily carbon sequestration (capture and storage)
  Examples: iron fertilization, artificial trees, biochar charcoal, ocean dissolution
Terms

- Thermodynamics
Terms

• Overview of attic physics
Camouflage invisible to night vision
Multifunctional steep slope roofing system research success

- Multifunctional roof reduces peak energy demand by 90% (PCM, ASV, RB)
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COMPUTER TOOL FOR SIMULATING COOL ROOFS

Roof Savings Calculator (RSC)

Chris Scruton
CEC

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H. Gilbert,
H. Akbari

Marc LaFrance
DOE BT

A. Desjarlais,
W. Miller,
J. New

WBT
Joe Huang,
Ender Erdem

LBNL
INDUSTRY

COLLABORATIVE R&D

ORNL
Roof Savings Calculator

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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1 Current version of the “Roof Savings Calculator” (RSC) as of 1/11/10
2 Based on March 6, 2008 Project Advisory Committee Meeting (PAC_inputs.ppt).
3 Based on January 21, 2009 Project Advisory Committee Quarterly Report (Qrpt-09Q4.pdf).
4 Based on http://www.roofcalc.com/RoofCalcBuildingInput.aspx
5 Based on http://www.ornl.gov/sci/roofs+walls/facts/CoolCalcEnergy.htm
Roof Savings Calculator
DOE-2.1E+AtticSim

- Building Details
- HVAC efficiency and utility prices
- Roof and Attic Information (base vs. comp)
- Reports energy and cost savings
Residential buildings
Commercial building types

Office

“Big Box” Retail

Warehouse

# Roof Savings Calculator

## Residential Roof Savings Calc (RSC)

Go to: Simple Mode

<table>
<thead>
<tr>
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<td>1. Closest location</td>
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<td>(ft²)</td>
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<td>per 1000 ft³): 11.65</td>
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<td>- High-efficiency (15)</td>
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<td></td>
<td></td>
<td></td>
<td>- Custom</td>
</tr>
</tbody>
</table>
Roof Savings Calculator

www.roofcalc.com

9. Roof type:
- Tile
- Metal
- Asphalt shingles

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
10. Solar reflectance (aged 3 yrs):
- 60%
- 50%
- 40%
- 30%
- 20%
- 10%
- Custom

**Solar Reflectance**

Increased reflectance saves energy by reflecting incoming solar radiation back towards space. Maximum reflectivity is achieved with white roof products. But don’t let looks fool you; there are also “cool color” roof products which look dark in the visible spectrum but still reflect most of the heat, giving homeowners the more traditional roof color options as well as the potential energy savings. This calculator models customizable aged reflectance of the outermost roofing product.

Aged (3-year) reflectance is recommended, as studies show most products stabilize their reflectivity within 3 years and are more indicative of lifetime performance. Aged (or weathered) reflectance values can be found on some product labels and the Cool Roof Rating Council (CRRC) lists aged reflectance values for many products. The aged reflectance can be estimated from the initial solar reflectance, based on the California Energy Commission’s Worksheet, using the following equation:

$$SR_{3yr} = 0.2 + 0.7(SR - 0.2)$$

**Cool Color Products**

![Cool Color Products Image]

11. Thermal emittance (aged 3 yrs):
- Acrylic Al-Zn coated steel (15%)
- Bare Al-Zn coated steel (20%)
- Metallic field-applied coating (50%)
- Painted steel (85%)
- Other materials (90%)
- Custom

**Thermal Emittance**

Roof products with a low thermal emittance save energy by radiating the absorbed heat toward space. Approximately 90% of materials have an emittance of 90%; low-emittance surfaces such as aluminum foil or a car’s sun shade, can have emittances of 5% and emit heat from the reflective side. Solar reflectance and emittance are the two radiative properties used to measure the “coolness” of a roof. This calculator models customizable emittance of the outermost roofing product.

Many organizations, such as the United States Green Building Council (USGBC) and its Leadership in Energy and Environmental Design (LEED) rating system, utilize a combined metric known as the Solar Reflectance Index (SRI).

**More info:**
- [LBNL SRI Excel]
- [ORNL SRI Calculator]
12. Above-sheathing ventilation:
- Yes
- No

**Above-Sheathing Ventilation**

Above-sheathing ventilation (ASV), also known as "roof on a roof", provides an air gap with thermally induced air flow patterns which has been shown to reduce heat flow penetrating the attic by at least 30% compared to a direct-to-deck nailed roof. This calculator models ASV using a 4" air gap.

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13. Pitch (rise:run):
- High (slope ≥ 8:12)
- Medium (2:12 < slope < 8:12)
- Low (slope ≤ 2:12)

**Roof Pitch**

The pitch of a roof, also known as angle or inclination, determines how much solar radiation impinges on a building throughout the day. The typical unitless metric is rise-in-run. This calculator supports pitches of 2:12, 4:12, and 8:12 (17, 32, and 59 angular degrees, respectively) for residential buildings; all commercial buildings are modeled as flat roofs with 0.25:12 for rainfall runoff.
14. Radiant barrier present:
- Yes
- No

**Radiant Barrier**

Radiant barriers (RB) save energy by reducing the heat radiated into the attic as the roof heats up during the day. RBs consist of a thin layer of highly reflective material, usually aluminum, and must have an emittance less than 0.1 as measured by ASTM C1371. This calculator models a RB in its most effective location, attached to the underside of the rafters with the reflective side facing the attic floor.

More info: [RB Calculator RB Fact Sheet](#)

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**Attic Insulation**

Attic insulation protects your home against unwanted heat gain/loss. It is measured by R-value which depends on the material, its thickness, and density with multiple layers added together. Insulation is often one of the most economical ways to make your home more energy efficient. The most common types of insulation are fiberglass batts (usu. pink), cellulose insulation, and spray foam insulation. This calculator supports a custom R-value of attic insulation.

More info: [Insulation Calculator Insulation Fact Sheet](#)
Duct Location

Heating, Ventilation, and Air Conditioning (HVAC) ducts are typically located in non-conditioned spaces, such as the attic, because it is easier and cheaper given the way US buildings are constructed; this is the worst location from an energy perspective. Locating ducts inside a conditioned space, such as between floors or in a conditioned basement, removes the losses from leaky ducts as well as exposure to adverse environmental conditions and can decrease your utility bills significantly. This calculator supports ducts located in a conditioned space or in the attic; simulations in conditioned spaces will run faster as the computationally intensive duct loss model is not invoked.

Duct Leakage

Leaky ducts in unconditioned spaces are effectively costing you money to condition the planet, not your house. Commercial buildings have typical leakage rate of 10-20%; likewise, residential buildings typically have duct leakage rates near 14%. The CEC’s Title 24 target leakage rate for inspected ducts is 4% and requires no greater than 5%. This calculator supports duct leakage rates of 4% and 14%.

16. Duct location:
- Conditioned space
- Attic

17. Duct leakage:
- Inspected (4%)
- Uninspected (14%)
Roof Savings Calculator

www.roofcalc.com

Simulation Results

You save $117/year!

Energy Savings

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Monthly Savings

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White-Rooftop Utility Usage

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Base-Case Utility Usage

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RoofCalc.com Impact

Dashboard

24,100 web simulations, 156 users/feedback, 3+ million runs

Average: ~80 visitors/day

30,752 visits came from 112 countries/territories

This country/territory sent 28,498 visits via 52 regions

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Presentation summary

• Context – US Energy and ORNL BTRIC
• Building Physics
• Roof Savings Calculator
• **Empirical Validation of AtticSim**
• Ongoing Validation
• Preliminary Cool Roofing Economics
• Previous Related Projects
• Recent Support Software Upgrades
Each bay width ~ 11 ft

2         3     4    5       6         1      7

Weather station

15 lb

15 lb

15 lb

Deck Armor

Fascia

1/300

1/150

Triflex Non breathable

Cool shingles

Sealed Non-Breathable – Cool color

ASV

RB
AtticSim (Attic Simulation) Model

CEC PIER: Demonstrations
Ft Irwin, US Army

Roof & Attic Energy Balance

ASTM C 1340 Standard For Estimating Heat Gain or Loss Through Ceilings Under Attics


AtticSim Benchmark of Ft Irwin House (South-facing Roof Deck)

Cool Color Tile Direct-to-deck

Miller, W. 2010. Field experiments to evaluate cool-colored roofing. Task 2.5.7 CEC milestone report.
AtticSim and DOE-2.1E/AtticSim Benchmark of Ft Irwin House “Attic Air Temperature”

Field Data for House N5 (IRR Tile DtD)

Time (hrs) for Week 080108
Presentation summary

- Context – US Energy and ORNL BTRIC
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- Roof Savings Calculator
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Presentation summary

- Context – US Energy and ORNL BTRIC
- Physical Properties
- Roof Savings Calculator
- Software Design
- Ongoing Projects
## Current Results

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<th>Austin</th>
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Expected Results

Fargo

\[ y = 0.0001x^4 - 0.0312x^3 + 2.184x^2 - 72.376x + 239.17 \]
\[ R^2 = 0.7391 \]

Houston

\[ y = 2.05x^4 - 0.0043x^3 + 0.3318x^2 - 2.9666x + 44.346 \]
\[ R^2 = 0.9058 \]
Unusual Results

**Baltimore**

\[ y = 0.0001x^4 - 0.0288x^3 + 2.065x^2 - 63.285x + 221.89 \]

\[ R^2 = 0.4277 \]

**Chicago**

\[ y = 8E-05x^4 - 0.0167x^3 + 1.2494x^2 - 40.338x + 150.68 \]

\[ R^2 = 0.2626 \]
Surprising Results

**Atlanta**

\[
y = 0.0001x^4 - 0.0267x^3 + 1.8258x^2 - 53.853x + 184.58
\]

\[
R^2 = 0.3785
\]

**San Francisco**

\[
y = 0.0001x^4 - 0.03x^3 + 1.8506x^2 - 48.045x + 127.63
\]

\[
R^2 = 0.8706
\]
Summer Operation of HVAC Duct in ASHRAE Climate Zone 3

Q - Assumes Heat Transfer to Duct
TMY2 for Atlanta, GA

Heat Transfer [Btu/hr] vs Attic Air Temperature [°F]

- Total Duct Heat Transfer
- Duct Leakage
- Radiation
- Convection
- Duct Storage
- Attic Air Temperature

August 1 to 72 hours

Graph shows the heat transfer and attic air temperature over a period from August 1 to 72 hours.
Summary
## Optimal Roofing Systems

<table>
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<th>Location</th>
<th>Observed Condition</th>
<th>Trend Desired SRI</th>
<th>Maximum Observed Savings, $</th>
<th>Best Observed System</th>
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- Context – US Energy and ORNL BTRIC
- Building Physics
- Roof Savings Calculator
- Empirical Validation of AtticSim
- Ongoing Validation
- Preliminary Cool Roofing Economics
- Previous Related Projects
- Recent Support Software Upgrades
Outliers (Heating)

• Selection of heating outliers
• Find all are from Miami, have box building type, and heat pump
HPC used to verify building simulation engine of tool enabling industry promotion of energy efficiency

Leveraging HPC resources to facilitate deployment of building energy efficiency technologies

Engine (AtticSim/DOE-2) debugged using HPC Science assets enabling visual analytics on $3 \times 10^6$ simulations

Roof Savings Calculator (RSC) website/service developed and validated [estimates energy cost savings of improvements to flat or sloped roofs for any existing condition or climate]

Industry partners install 2000+ roofs/mo, is integrating RSC into their proposal generating system (others expected to follow)

Potential cumulative savings 117.2 GWh/yr ($1.6 billion/yr)
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Current RSC Site

http://www.roofcalc.com

Parameter Entry

Building
1. Closest location (similar weather):
   Select location
2. Building Type:
   Office
3. Conditioned floor area (ft²):
   10000
4. Number of floors:
5. Year of construction:
   - post-1990
   - 1980-1990
   - pre-1980

Heating/Cooling
6. Heating equipment:
   - Electric heat pump
   - Natural gas furnace
   - Pl. Electricity price (cents per kWh):
   - 10.27
   - Pl. Natural gas price (dollars per 1000 ft³):
   - 8.59
7. Heating system efficiency (AFUE):
   - High-efficiency (90%)
   - Mid-efficiency (85%)
   - Low-efficiency (70%)
   - None
   - Custom
8. Cooling system efficiency (SEER):
   - High-efficiency (15)
   - Mid-efficiency (13)
   - Low-efficiency (10)
   - None

Result Output

Simulation Results

You save S-332/year!

Energy Savings

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<th>Heating</th>
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2017 kWh
- 65 MBtu

Monthly Savings

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White-Roof Utility Usage

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<td>768.1</td>
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</tbody>
</table>

Base-Case Utility Usage

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling (kWh)</td>
<td>0.0</td>
<td>0.0</td>
<td>17.2</td>
<td>7.7</td>
<td>77.8</td>
<td>597.4</td>
<td>994.6</td>
<td>1017.2</td>
<td>1287.1</td>
<td>459.2</td>
<td>5.6</td>
<td>0.0</td>
<td>4616.1</td>
</tr>
<tr>
<td>Heating (kWh)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Heating (MBtu)</td>
<td>119.3</td>
<td>95.3</td>
<td>79.4</td>
<td>59.8</td>
<td>30.3</td>
<td>11.3</td>
<td>6.6</td>
<td>8.0</td>
<td>24.3</td>
<td>65.5</td>
<td>94.5</td>
<td>109.2</td>
<td>703.6</td>
</tr>
</tbody>
</table>
Enhanced RSC Site

Input Parameter GUI

- Intro
- Building Location
- Building Details
- WWR
- HVAC Type
- Heating/Cooling
- Cool Roof
- Roof Pitch
- Radiant Barrier
- Ceiling Insulation
- Duct Location
- Duct Leak
- Roof Type

Result Output

- Total Savings: $-178

Database

These numbers represent our estimate of your energy costs. You can specify new values and re-calculate.

- Electricity price (cents per kWh):
  - 11.68
- Natural gas price (dollars per 1000 ft³):
  - 11.65

Learn More

Previous | Next

Calculate Savings

User

Hyperion

Savings

Results

Exists?

Simulation

RSC Engine
RSC Web Service

• SoapResults = simulate(SoapModel)
  – Accepts a model and returns the RSC results

• ZipString = test(SoapModel)
  – Forces the model to be evaluated by the engine (rather than checking the database) and returns a zip (as a base64-encoded string) of the DOE2/AtticSim output files

• ScenarioID = upload(SoapModel, SoapResults)
  – Uploads the model and results to the database, bypassing the engine

• (SoapModel, SoapResults) = download(ScenarioID, VersionNumber)
  – Downloads a model/result pair for the scenario ID and version number
RSC Service Example (Python)

```python
client = suds.client.Client('URL/TO/SERVICE/rsc.wsdl')
print(client)

sm = client.factory.create('schema:soapmodel')
load_soap_model_from_xml('../examplemodel.xml', sm)
sr = client.service.simulate(sm)
print(sr)

sm = client.factory.create('schema:soapmodel')
load_soap_model_from_xml('../examplemodel.xml', sm)
print(sm)
contents = client.service.test(sm)
with open('pytest.zip', 'wb') as outfile:
    outfile.write(base64.b64decode(contents))

sm = client.factory.create('schema:soapmodel')
load_soap_model_from_xml('../examplemodel.xml', sm)
sr = client.factory.create('schema:soapresults')
load_soap_results_from_xml('../exampleresults.xml', sr)
sid = client.service.upload(sm, sr)
print(sid)

modres = client.service.download(83356208, '0.9')
print(modres['soapmodel'])
print(modres['soapresults'])
```
RSC Web Service XML

Soap Model
- buildingLocation
- buildingType
- buildingArea
- buildingFloors
- buildingWwr
- buildingVintage
- heatingType
- heatingEfficiency
- coolingEfficiency
- atticVent
- atticInsulation
- atticRadiantBarrier
- ductLocation
- ductInspection
- roofType
- roofReflectance
- roofEmittance
- roofPitch

Soap Result
- source
- executionTime
- scenarioId
- versionNumber
- heatingGas01
- heatingGas02...
- heatingGas12
- heatingElectricity01
- heatingElectricity02...
- heatingElectricity12
- coolingElectricity01
- coolingElectricity02...
- coolingElectricity12
- fanElectricity01
- fanElectricity02...
- fanElectricity12
def calculate_error(self, scenario_id, version):
    download = self.client.service.download(scenario_id, version)
    old_results = self._convert_to_dict(download['soapresults'])
    new_results = self._run_engine(download['soapmodel'])
    error = self._calc_result_error(old_results, new_results)
    if error > 0.0001:
        raise AssertionError('Error is {} > 0.0001'.format(error))

***Settings***
Library rsctests.RSCTestLibrary

***Test Cases***
www.roofcalc.com 1 Calculate Error 83342208 0.9
www.roofcalc.com 2 Calculate Error 83336950 0.9
www.roofcalc.com 3 Calculate Error 83325075 0.9
Testing RSC – Python Robot Framework

Roofcalc Tests Test Report

Summary Information

- Status: 1 critical test failed
- Start Time: 20130725 14:19:52.537
- End Time: 20130725 14:20:19.059
- Elapsed Time: 00:00:26.522
- Log File: log.html

Test Statistics

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Pass</th>
<th>Fail</th>
<th>Elapsed</th>
<th>Pass / Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Tests</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>00:00:26</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>All Tests</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>00:00:26</td>
<td>Pass / Fail</td>
</tr>
</tbody>
</table>

Statistics by Tag

No Tags

Test Details

Name: Roofcalc Tests
Status: 3 critical test, 2 passed, 1 failed
3 test total, 2 passed, 1 failed
Start / End Time: 20130725 14:19:52.537 / 20130725 14:20:19.059
Elapsed Time: 00:00:26.522
Log File: log.html#s1

<table>
<thead>
<tr>
<th>Name</th>
<th>Documentation</th>
<th>Tags</th>
<th>Crit.</th>
<th>Status</th>
<th>Message</th>
<th>Elapsed</th>
<th>Start / End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofcalc Tests</td>
<td><a href="http://www.roofcalc.com">www.roofcalc.com</a></td>
<td></td>
<td>yes</td>
<td>PASS</td>
<td></td>
<td>00:00:20.589</td>
<td>20130725 14:19:52.856, 20130725 14:20:13.475</td>
</tr>
<tr>
<td>Roofcalc Tests</td>
<td><a href="http://www.roofcalc.com">www.roofcalc.com</a></td>
<td></td>
<td></td>
<td>FAIL</td>
<td>Error is 31.241959519 &gt; 0.0001</td>
<td>00:00:01.228</td>
<td>20130725 14:20:13.476, 20130725 14:20:14.704</td>
</tr>
</tbody>
</table>
Discussion