DEVELOPMENT OF A ROOF SAVINGS CALCULATOR

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ABSTRACT
A web-based Roof Savings Calculator (RSC) has been deployed for the Department of Energy as an industry-consensus tool to help building owners, manufacturers, distributors, contractors and researchers easily run complex roof and attic simulations. This tool employs the latest web technologies and usability design to provide an easy input interface to an annual simulation of hour-by-hour, whole-building performance using the world-class simulation tools *DOE-2.1E* and *AtticSim*. Building defaults were assigned and can provide annual energy and cost savings after the user selects nothing more than building location.

In addition to cool reflective roofs, the RSC tool can simulate multiple roof types at arbitrary inclinations. There are options for above sheathing ventilation, radiant barriers and low-emittance surfaces. The tool also accommodates HVAC ducts either in the conditioned space or in the attic with custom air leakage rates. Multiple layers of thermal mass, ceiling insulation and other parameters can be compared side-by-side to generate energy/cost savings between two buildings. The RSC tool was benchmarked against field data for demonstration homes in Ft Irwin, CA.

1. INTRODUCTION
The Roof Savings Calculator (RSC) was developed through collaboration between Oak Ridge National Laboratory (ORNL) and Lawrence Berkeley National Laboratory (LBNL) in the context of a California Energy Commission (CEC) Public Interest Energy Research (PIER) project to make cool colored roofing materials a market reality in all roof products. The RSC website [17] and a simulation engine validated against demonstration homes was developed to replace the liberal DOE Roofing Calculator [15] and the conservative EPA Energy Star Roofing Calculator [16] which reported different roof savings estimates.

The primary objective with this calculator was to develop a web-based tool with which users can easily, and yet realistically, estimate the cooling energy savings achieved by installing cool roofing products on the most common residential and commercial building types in the US stock. Several goals included development of a fast simulation engine benchmarked against cool-colored roofing materials, educating the public with regard to cool roofing options and savings, helping manufacturers of cool-colored materials deploy their products, and assist utilities and public interest organizations refine incentive programs for cool roofs. Recent emphasis on domestic building energy use, market penetration for cool roofing products and job creation has made the work a top priority by the Department of Energy's (DOE) Building Technologies Program.

In the remainder of this paper, we first describe the background of the software programs in Section 2. In Section 3, we discuss the integration of the software programs. In Section 4 we describe the ground-truth validation process using demonstration homes in Ft. Irwin, followed by the development of the web interface in Section 5. Finally, we conclude in Section 6.

2. BACKGROUND

The Roof Savings Calculator (RSC) is a web-accessible tool which leverages *AtticSim* for advanced modeling of modern attic and cool roofing technologies in combination with hour-by-hour building energy performance provided by *DOE-2.1E* to provide simulations which quantify annual energy and cost savings between a standard building and an cool-roof building. We discuss some history and the motivation to use each of these software codes in more detail below.

2.1 DOE-2.1E

DOE-2.1E [1] is a whole-building energy simulation program that was originally developed by Lawrence Berkeley National Laboratory in the early 1980's (Version 2.1A) [2] , with continued development through 1993 (Ver. 2.1B through 2.1E) [3]. *DOE-2.1E* is the most current version of *DOE-2* that is in the public domain, although there are later efforts and user-interfaces developed by private companies. Counting its many versions and user interfaces, *DOE-2* is the most widely used building energy simulation program in the world today. It has been the basis of most performance-based building energy standards in the U.S. and at least ten other countries, as well as being used for voluntary "Green Building" rating systems such as the US Green Building Council's Leadership in Energy and Environmental Design (LEED).

DOE-2 itself is an engineering program, with a text-based input and output procedure. The program takes as input a description of the physical building and its space conditioning system, its internal conditions, e.g., schedules for occupancy and lighting, and operations, e.g., thermostat schedules, and the hourly weather conditions, e.g., temperature, humidity, wind speed, and solar radiation, and produces as output the energy consumption, as well as the indoor conditions, of the building. Using the program is difficult because it requires in-depth knowledge both of how *DOE-2* works and how buildings are constructed and operated. Although there are numerous papers attesting to the fundamental soundness of the *DOE-2* program, the fact remains that a computer

model is only as good as are the inputs. The multiplicity of inputs can cause confounding results.

DOE-2 operates on an hourly time-step, and uses *response factors* to model the dynamic heat flows through the building envelope. At the zone level, *DOE-2* uses *weighting factors* (also called *zone response factors*) to model the dynamic response of the space, taking into account its thermal mass or capacitance, heat loss through radiation and or convection. *DOE-2* is made up of two programs, an input processing program called **doebdl** and a simulation program called **doesim**, which is composed of four separate modules called sequentially by *DOE-2.1*E.The LOADS module simulates the heat flows in and out of the building and calculates the net balance at a fixed reference temperature, negative being interpreted as a heating load and positive as a cooling load. The SYSTEMS module takes the results from LOADS, simulates the operation of the HVAC system, and derives the actual zone temperatures, amount of heating and cooling provided by the system, and the energy consumed. If the building has a central plant, the heating and cooling demands from SYSTEMS are passed to the PLANT module that simulates the energy consumed by the plant to meet the SYSTEMS demands. The ECONOMICS module computes energy costs and is not used in this application.

Although DOE stopped all support for *DOE-2* in 1999, White Box Technologies and others have continued to maintain and even add features to *DOE-2.1E*. For example, Huang [4] added an improved foundation model to the code at the request of the California Energy Commission (CEC). Most recently, LBNL approved making *DOE-2.1E* open source code and White Box technologies announced the creation of an Open Source Center for Building Simulations to maintain the *DOE-2.1E* software for the community of building scientists and practitioners.

2.2 AtticSim

AtticSim is a computer tool for predicting the thermal performance of residential attics. The code is publicly available as an ASTM protocol [7]. It mathematically describes the conduction through the gables, eaves, roof deck and ceiling; the convection at the exterior and interior surfaces; the radiosity heat exchange between surfaces within the attic enclosure; the heat transfer to the ventilation air stream; and the latent heat effects due to sorption and desorption of moisture at the wood surfaces. Solar reflectance, thermal emittance and water vapor permeance of the sundry surfaces are input. The model can account for different insulation R-values and/or radiant barriers attached to the various attic surfaces. It also has an algorithm for predicting the effect of air-conditioning ducts placed in the attic [8].

Typical construction places ductwork within the attic, which can literally triple the loads for the attic assembly for moderately leaky ducts [8][9]. Petrie [10] validated the duct algorithm in ASTM C 1340 against experimental data for an attic assembly tested first without and then with a radiant barrier attached to the underside of the roof deck. Validations showed the duct algorithm predicted the duct air change (inlet-to-outlet of the supply duct) within ±0.3°F (±0.2°C) over all tests housing an insulated duct system.

AtticSim was the subject of an extensive field validation conducted by Ober and Wilkes for ASHRAE [11], which provides mathematical documentation of the code and validation results for low-slope and steep-slope field data collected from seven different field sites. The code was later validated for steep-slope asphalt shingle and stone-coated metal roofs [12]. *AtticSim* was also benchmarked against clay and concrete tile and painted metal roof and attic assemblies that exhibit above-sheathing ventilation to predict the heat transfer crossing the air space [13].

3. INTEGRATION OF DOE-2/AtticSim

DOE-2.1E and *AtticSim* are both written in FORTRAN and the method of integration primarily relies upon the idea of using the attic floor as a boundary condition for interaction between the two codes. For all simulations the attic floor is assumed sealed with no air leakage crossing from the conditioned space into the attic. The heat flows at the attic's roof, gables, eaves and floor are calculated using the thermal response factor technique by Mitalas and Stephenson [14]. This method requires the thermal conductivity, specific heat, density and thickness of each attic section for calculating conduction transfer functions. *DOE-2.1E* uses a similar technique of response factors (RF) to calculate heat flows through the building envelope, but uses weighting factors (WF) to model the heat gain.

The compatibility of the two sets of procedures and their setup for computing parallel path heat flows was a key hurdle for making *AtticSim* work seamlessly within the "Systems" framework of the *DOE-2.1E* program. White Box Technology made a comparison of the response factors generated by DOE-2 to those used by *AtticSim*. It was found that the two routines computed about the same values the only difference is that DOE-2 starts using the common ratio earlier than does that used by *AtticSim*. Table 1 displays results for the west facing gable roof. The ratio of two consecutive response factors is termed the common ratio and it becomes constant after a sufficient number of terms.

Table 1. Sample Output from *DOE-2.1E* and *AtticSim* for the conduction transfer functions computed through the insulation path in the gable end of an attic.

Attic Surface	DOE2.1E Response Factors		
West_facing_gable_insulation_path			
0	0.0659029186	0.0304230750	0.0659029186
1	-0.0236259736	0.0117719891	-0.0236259736
2	-0.0000408221	0.0000408221	-0.0000408221
3	-0.0000001163	0.0000001163	-0.0000001163
COMMON_RATIO	0.0028485756		
Attic Surface	AtticSim Response Factors		
West_facing_gable_insulation_path			
0	0.0659029161	0.0304230732	0.0659029161
1	-0.0236259750	0.0117719903	-0.0236259750
2	-0.0000408222	0.0000408222	-0.0000408222
3	-0.0000001163	0.0000001163	-0.0000001163
COMMON_RATIO	0.0028485769		
	Differences between DOE2.1E and AtticSim		
0	-0.0000000025	-0.0000000018	-0.0000000025
1	-0.0000000014	0.0000000012	-0.0000000014
2	-0.0000000001	0.0000000001	-0.0000000001
3	0.0000000000	0.0000000000	0.0000000000
4	0.0000000013		

In the linkage to *DOE-2.1E, AtticSim* has been converted to a subroutine that is called in the SYSTEMS module, in effect replacing the TEMDEV subroutine that solves for the zone temperature and calculates the heat gain or extraction provided by the HVAC system. As SYSTEMS loops through the zones, it starts first with the attic, where it will invoke *AtticSim*, and pass to it inputs for the ambient conditions, thermal properties, i.e., response factors, of the surfaces, as well as temperature of the space below and the on-time of the HVAC system from the previous time step. *AtticSim* then returns to **doesim** the attic temperature, the heat flow through the ceiling, and the heat gain or loss to the ducts, which are used by **doesim** to solve for the temperature of the zone below, the heat addition or extraction and finally energy consumption of the HVAC system. To ensure these changes didn't significantly affect the output of the integrated DOE-2/AtticSim program, comparison studies found the differences to be negligible as shown in Table 1.
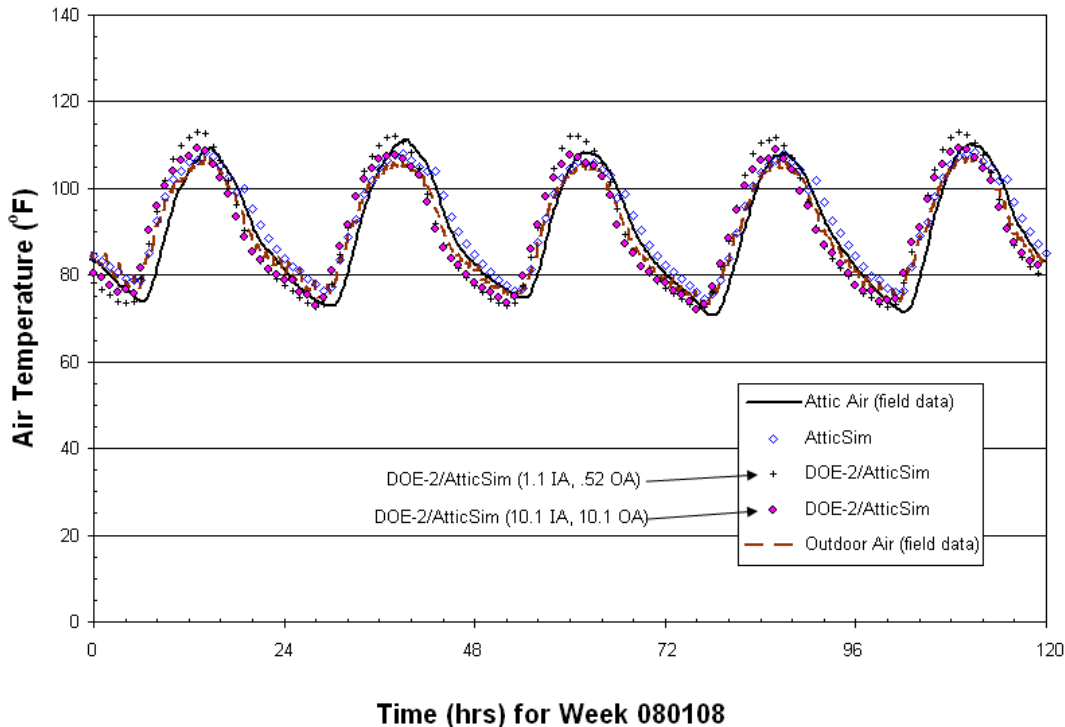
Time (hrs) for Week 080108

Figure 1. Comparison of AtticSim before and after integration with DOE-2

To affect this linkage, numerous changes were also necessary to the input processing **doebdl** program in order to pass the input data from the building model described in *DOE-2*'s Building Description Language (BDL) to *AtticSim*. Some 20 new keywords have been added, in addition to the "data mining" of the existing *DOE-2* inputs.

As stated *AtticSim* is an ASTM protocol [7] and is publicly available. It has been extensively peered reviewed and benchmarked against field data, and therefore was an excellent candidate for use with the whole building model. *DOE-2.1E* does not adequately describe the radiation exchanges occurring in attics. *AtticSim* does not predict whole building performance. Combined, the two tools offer a powerful feature that can translate reduced heat flux from cool roof and attic technologies to annual energy and cost savings in a way that can be bechmarked against demonstration homes.

4. DEMONSTRATION HOMES

The 2003 F.W. Dodge [26] report shows tile roofs comprise 30% of the new and retrofit roof markets in CA. We therefore conducted field experiments in Southern California to benchmark both *AtticSim* as a standalone tool and the new RSC tool. *AtticSim* has a history of validations against several different profiles of tile, stone-coated metal, asphalt shingle and standing seam metal roofs, all of which were field tested at ORNL. However, *AtticSim* was also benchmarked against two of the Ft Irwin homes to assist White Box Technology with its benchmark of the RSC tool.

The four demonstration homes were setup for making two bases of comparison: 1) concrete tile applied directly to the deck, one coated with a cool color coating the other not coated, and 2) concrete tile elevated 1½-in (0.038-m) above the deck, one roof coated with a cool color coating the other not coated. *AtticSim* was benchmarked against House N5 for summer data (Aug. 2008) and House N8 for winter data (Feb 2008). During these periods tenants were paid a $200 per month incentive to keep their thermostats at 72°F (22.2^{o}C). House N5 has the tile attached directly to the deck (labeled D-t-D) with the tile painted with COOLTILE IR COATINGS™ by American RoofTile Coatings. House N8 had conventionally painted the tile placed on double battens (labeled DB).

4.1 AtticSim Benchmark of House N5

The solar irradiance from pyranometers fixed to the sloped roof surfaces, and the weather data were used by *AtticSim* to compute the surface temperature of the tile, the air temperature in the inclined air space made by the tile, the heat flux crossing the roof decks, the attic air temperature and the heat flow crossing the attic floor. Measured temperature at the thermostat was also used by *AtticSim* to estimate convection effects from the ceiling into the conditioned space.

Estimates had to be made of the airflow induced by a solar fan installed on the south facing roof. All homes had these fans which energized whenever the photovoltaic panel generated enough current to drive the fan. However, results show that *AtticSim* simulated the attic air temperature within about ± 2°F (0.6°C) as shown in Figure 2a.

The heat flux crossing the south facing roof deck was accurately computed by *AtticSim* as measured by heat flux transducers (installed on underside of roof deck). Figure 2b shows that *AtticSim* was also able to follow the diurnal trends in heat flows crossing the attic floor having R_{US} 38 (R_{SI} 6.7) fiberglass batt insulation. The peak day values between *AtticSim* and measured ceiling heat flows are within about 5% of measure; however, measured data lags *AtticSim* predictions and is believed due to the truss system in the attic. Additional simulation work will be conducted to check whether the truss system affects the predictions.
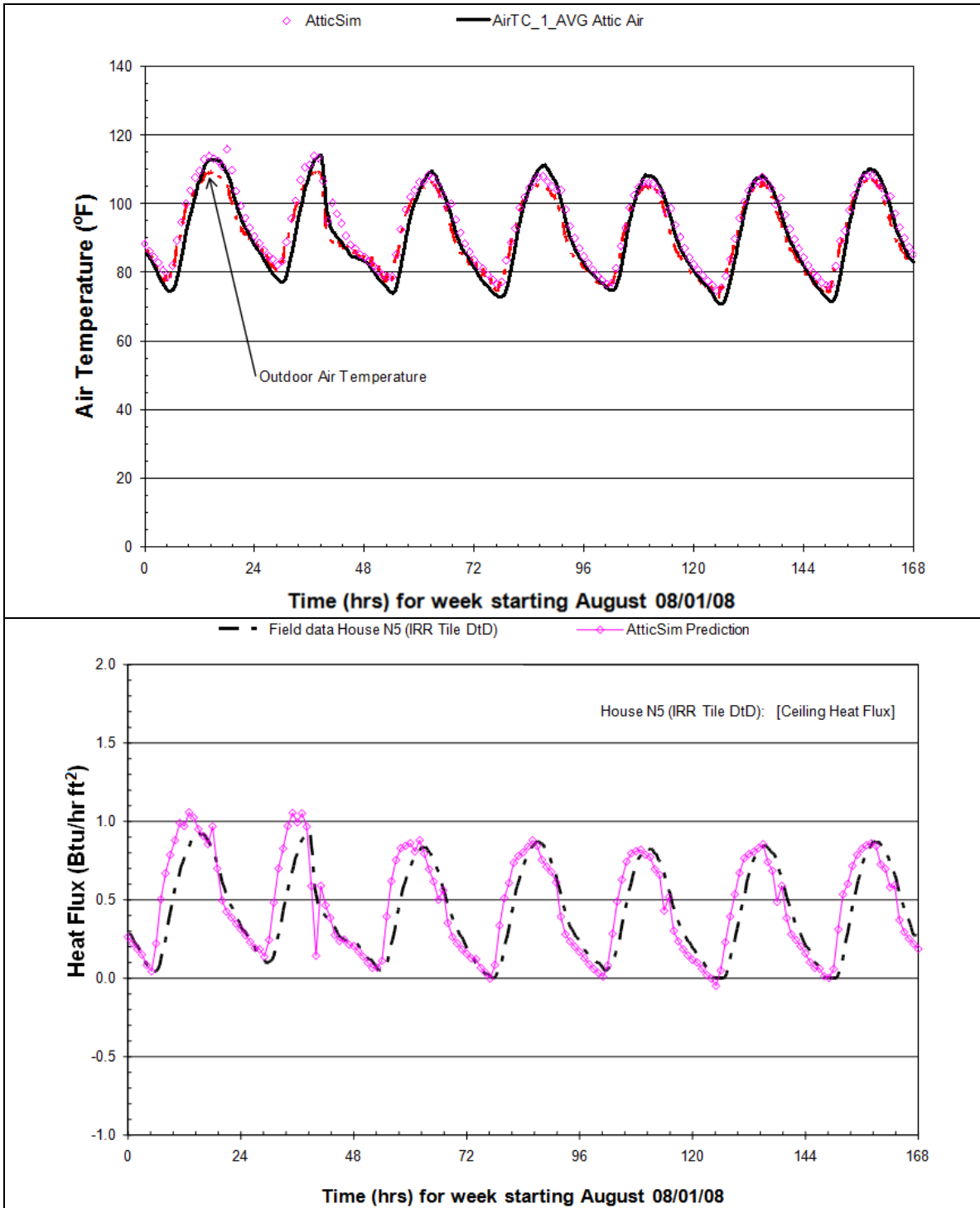
Figure 2. The attic air temperature (2a) and the heat flows through the south-facing roof deck (2b) for House N5 having cool color tile laid directly to the deck.

4.2 AtticSim Benchmark of House N8

The air temperature in the inclined air space formed by the double batten arrangement of the concrete tile is shown in Figure 3 for data collected during February 2008. Again the solar irradiance was input *AtticSim* from pyranometers fixed to the sloped roof surfaces, and the weather data were used in *AtticSim* to compute the thermal performance of the roof and attic. The code well replicated the measured air temperature in the ventilated space under the tile. Miller et al. [12] provide details of the energy balance for interior duct flow that is used to compute the air temperature in the air space.
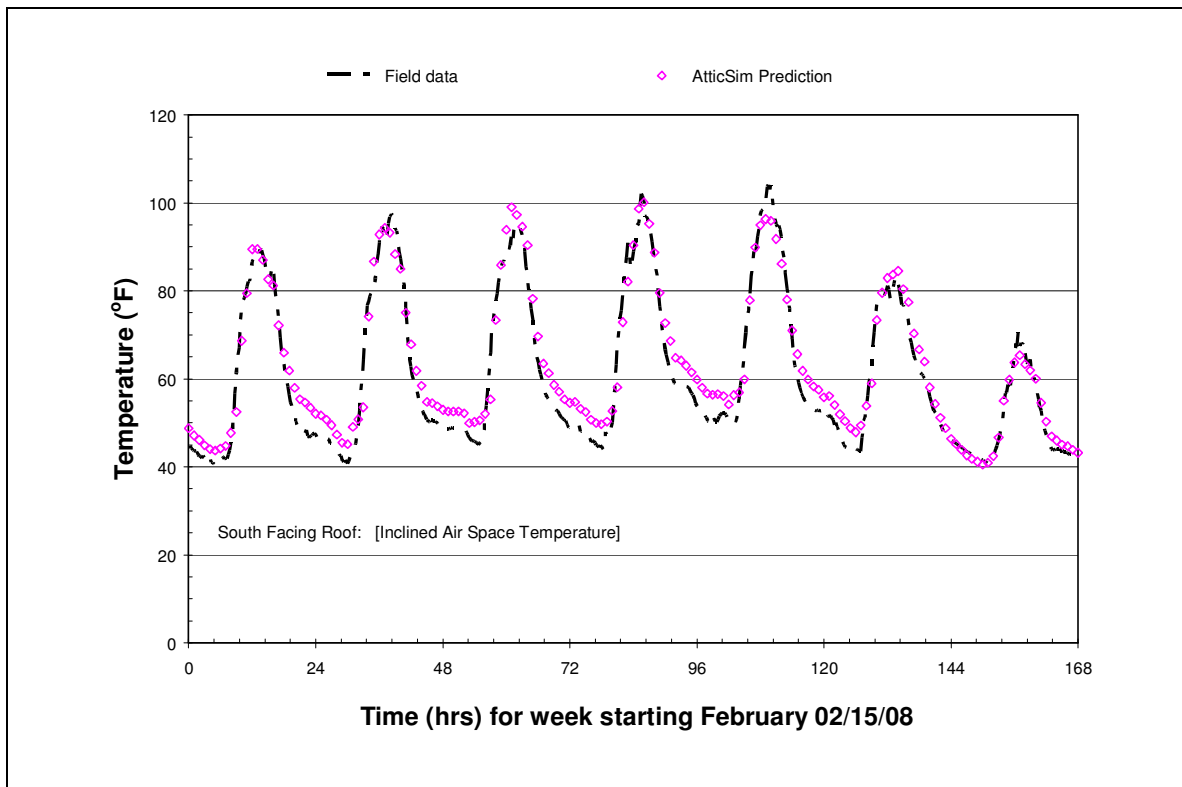
Figure 3. The air temperature in the inclined air space under the concrete tile is predicted to within ± 2°F (0.6°C) of the field data for House N8 having conventionally painted tile placed on double battens.

For this February week of data, the outdoor air temperature peaks at about 68°F (20°C) during the day and drops to about 50 to 40 °F (10 to 4.4°C) at night. Therefore the ceiling heat loads are relatively small and did not exceed ± 0.5 Btu/(hr ft^2) [0.16 W/m^2]. Yet results show that *AtticSim* simulated the daily trends in ceiling heat flux relatively well in Figure 4. During the daytime the predicted and measured flux are not accurate and differ by about 0.25 Btu/(hr ft^2) [0.08 W/m^2] as shown in Figure 4. This occurs because the temperature difference across the R_{US} 38 (R_{SI} 6.7) batt insulation is at best only 3.6°F (2°C), while at night the temperature drop across the ceiling insulation is about 14.4°F

(8°C). Therefore the error is primarily due to the uncertainty of the temperature measurements.
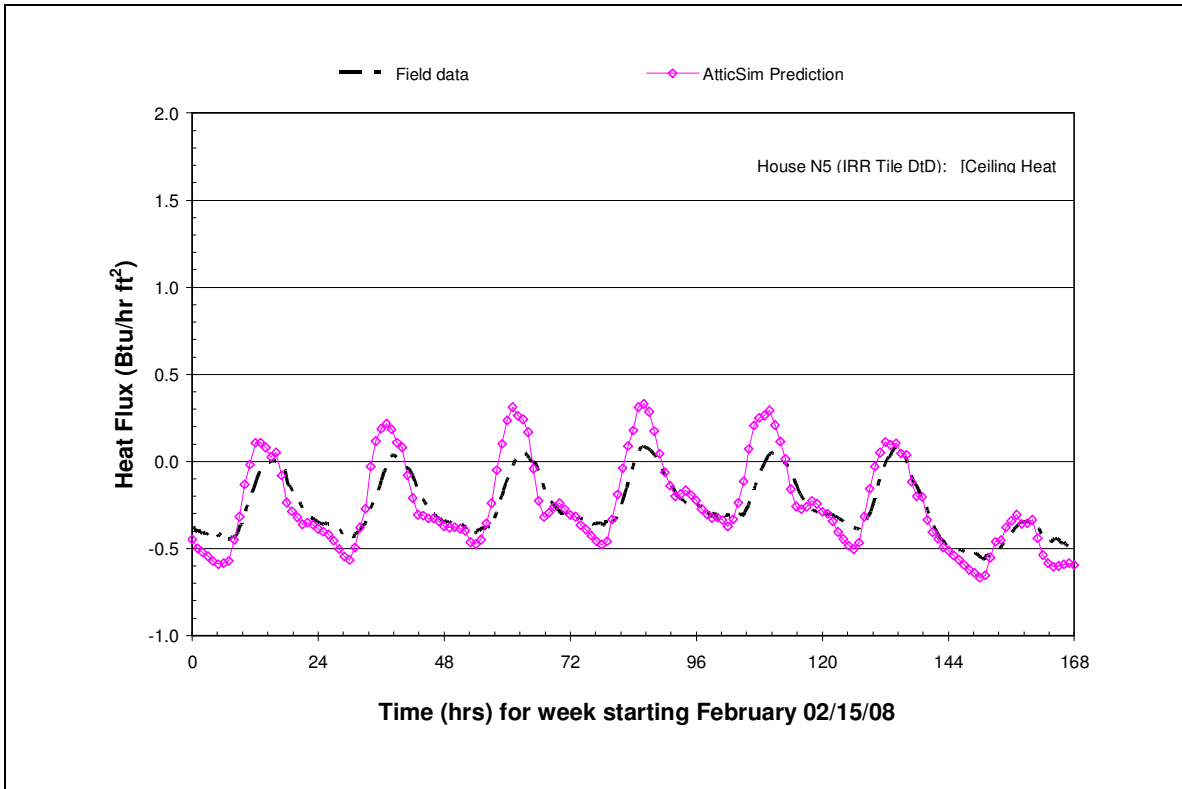

Figure 4. The ceiling heat flux computed by *AtticSim* and benchmarked against the field data for House N8 having conventionally painted tile placed on double battens.

4.3 *DOE-2.1E/AtticSim* Benchmark Houses

We repeated the simulations described above for House N5 using the August 08 week of field data and for House N8 using the February 08 data with the combined *DOE-2.1E/AtticSim* code. Testing determined whether *AtticSim* worked properly within *DOE-2.1E* for the thermal exchange through the attic floor (i.e., house ceiling) and for the data exchange about HVAC operations and duct losses. Both of these issues are complex, since they are nonlinear as well as interrelated. The heat flows through the attic floor, which are critical for determining the energy savings from attic conservation measures, are further complicated by the fact that *DOE-2* uses several sequential steps to derive net zone heat flows, so that in coupling *DOE-2* with *AtticSim* it has been necessary to disable some of these steps to prevent double counting. To calculate the duct losses, *AtticSim* needs to know the on-time for the HVAC system, but that is not known until further into the simulation process. Ultimately, it was found necessary to model the attic twice, once with *DOE-2* and then again with *AtticSim*.

Figure 5 is similar to Figure 2a, but this time showing the attic air temperatures modeled with the combined *DOE-2/AtticSim* program rather than with the standalone *AtticSim* program.
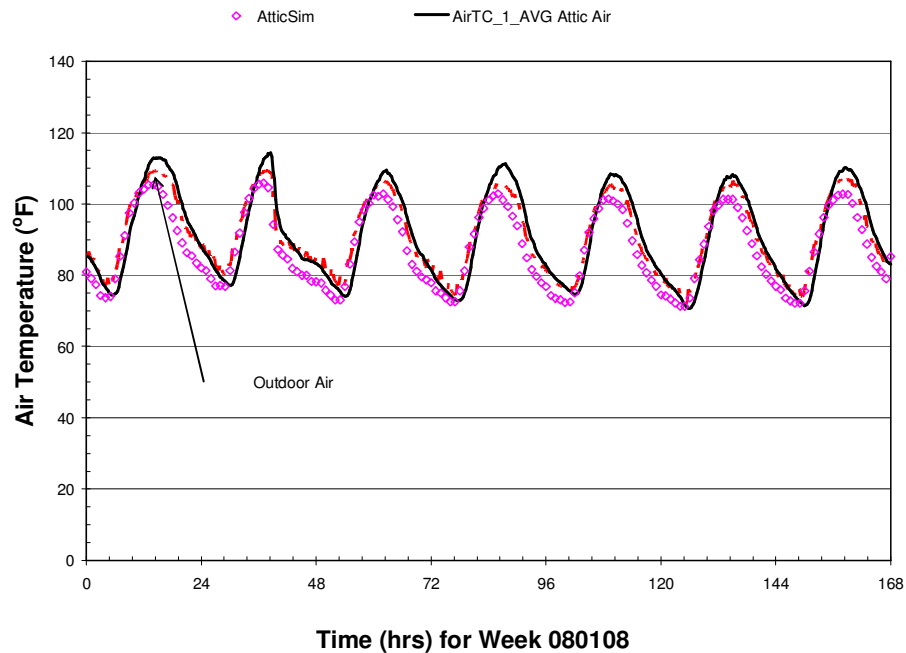

Figure 5. Comparison of *DOE-2.1E/AtticSim* to measured attic temperature for House N5 collected August 08

In comparison to Figure 2a, the attic temperatures shown by the combined *DOE-2.1E/AtticSim* code are lower. This may be due to either differences in how the attic is being modeled as compared to the standalone *AtticSim* simulation, or to double-counting of ceiling heat flows in the draft version of the DOE-2.1E/*AtticSim* program.

Figure 5 shows the attic air temperatures modeled with the combined *DOE-2/AtticSim* program for House N8 as compared to measured data field data for February 08. Here again the attic temperatures shown by the combined *DOE-2.1E/AtticSim* program matches the measured minima, but are consistently several degrees lower than the daily maxima. This again may be due to double-counting of ceiling heat flows in the draft version of the *DOE-2.1E/AtticSim* program.

5. WEB INTERFACE

5.1 Building Templates

For the Web-based Roofing Calculator, four template files have been created for four building input types – residential, medium-sized office, warehouse, and big box retail store. These building types are the four largest by square foot of conditioned area in the United States. The residential file is adapted from the template file developed by Huang [5] for the *RESFEN* program, a similar easy-to-use program for calculating window

energy performance using *DOE-2* as the simulation engine. The three commercial files are adapted from a set of commercial building prototypes first developed in 1990 [5] that later served as the basis for DOE's commercial building benchmark models [6].

These are called template files because they contain numerous *macros,* a feature available in *DOE-2* since the early 1990s that allow the file to be altered based on high-level user inputs set in a Graphical User Interface (GUI). These high-level inputs include building location, vintage, floor area, number of floors, window-to-floor (residential) or window-to-wall (commercial) ratio, and HVAC equipment. For the RSC, the user inputs are much more specific for the attic/roof assembly, including the roof construction, cover material, pitch, solar reflectance, thermal emittance, inclusion of radiant barrier, duct location and characteristics, and ceiling R-value. Once these user inputs have been defined, the *macro* statements allow the template file to be modified accordingly.

5.2 Web Deployment

An important objective identified early in development was to maximize the impact of this project by providing a publicly accessible website for comparative simulations of traditional and energy-saving roofing options. This web portal is designed to serve as an industry-consensus roof savings calculator for commercial and residential buildings using whole-building energy simulations; the managers for the DOE and EPA calculators [15][16] have agreed to take down their web-based calculators prior to full deployment of the Roof Savings Calculator (RSC). Below we discuss in further detail how objectives of the Project Advisory Committee (PAC) were met, the modern web technologies employed in the development of the calculator, usability considerations, and current functionality.

5.2.1 Traceability

The PAC defined a set of questions and answers that the calculator was to support both in meeting slides as well as in a quarterly report. In addition, the calculator was to support all relevant capabilities from other calculators while minimizing the number of questions a user must answer. The summary of comparative analysis between these calculators, documents, and the current version of the calculator are listed in Table 2.

Subsequent alpha versions of RSC were refined by suggestions from teleconference meetings. These included the simplification of input by removing days of operation per week, internal load, and HVAC schedule since it was believed that we have fairly accurate data regarding prevalent parameters for these properties as a function of building type and that their presence would allow biased users to report unrealistic savings estimates. *AtticSim* does not support conditioned space under a roof so there is currently no modeling support for an attic-less cathedral roof. The RSC tool is initialized to default answers selected from the best available statistics offered by the DOE's Energy Information Administration (EIA) [18], EPA's Energy Star [19] Program, and iterative expert review.

5.2.2 Technologies

Many current web technologies were employed in the development of the deployed calculator. The use of dynamic hypertext markup language (DHTML) includes technologies such as HTML and the HTML Document Object Model (HTML DOM) [20], cascading style sheets (CSS) [30], asynchronous JavaScript and XML (AJAX), and the Personal Home Page language (PHP) [22], as well as the jQuery [23] and jQuery User Interface (jQueryUI) Javascript library. The reasoning for employment of these technologies and their relevance to calculator capabilities, visibility, and maintenance are detailed below.

Table 2. Input Comparison Chart

	RSC[17]	PAC Slides	PAC QRpt	DOE[15]	EPA[16]
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	✓				

DHTML is the art of making dynamic and interactive web pages. It typically combines HTML, JavaScript, the HTML DOM, and CSS. HTML and the HTML DOM are defined via specifications from the World Wide Web Consortium (W3C). HTML is

the predominant markup language for web pages. It allows the use of "tags" (keywords surrounded by angle brackets) to denote structural semantics for a document. The HTML DOM is a cross-platform language-independent convention for interacting with HTML objects and thereby allows all computer types to interact via the internet. HTML DOM allows retrieval and operations on specific elements within the body of a page and is often used closely in combination with CSS.

CSS is a simple mechanism for adding style (e.g. fonts, colors, spacing) to Web documents. This logical separation of content and form through CSS offers several advantages: editing a single CSS file can make site-wide changes in seconds; logical handles (such as the class, name and id properties of div and span tags) allow precise simultaneous control of particular elements or group of elements; load times are improved due to browser caching and reduction in amount of formatting tags necessary; maintenance capabilities are improved due to cleaner code and separation of concerns; and better search engine placement due to proper HTML structure.

AJAX, coined by Jesse Garret in late 2005, is actually a group of interrelated web development techniques and technologies involving execution on the client-side to create interactive web applications. It allows program-level code to operate within web applications while retrieving data asynchronously from the server without interfering with the display or behavior of the existing page. AJAX was used extensively to provide an interactive web application that shows and hides relevant questions/answers based upon recent selections, updates default values between residential/commercial building types, and allows interactive switching between basic/advanced modes. The JavaScript Object Notation (JSON) lightweight data-interchange format [27] was used for transferring data between server and client. The drawbacks of AJAX include more complex code and thus longer development and maintenance efforts, often improper operation with the "back" button, reduced security, and the ~5% [24] of people who do not have JavaScript enabled for security reasons will be unable to use the dynamic content.

PHP is a general-purpose scripting language typically used to provide dynamic web content. PHP code is used in the calculator to dynamically generate a custom HTML response to the posted user selections and generate the server response which displays energy and cost savings.

jQuery, initially released in 2006 and currently in active development, is a lightweight JavaScript library that facilitates interaction with HTML. It is the most popular JavaScript library in use as of the time of this writing and is used in 20% of the 10,000 largest websites [29]. jQuery allows efficient programming and reduced development times by providing a powerful application programming interface (API) which abstracts away many of the lower-level calls necessary in pure JavaScript. jQueryUI provides access to jQuery's visual controls and includes several core interaction plugins as well as many UI widgets. jQueryUI's Accordion widget was used to provide logical groupings of calculator form questions in a way that could be minimized when completed. Additional mouseover tooltips using jQueryUI's BeautyTips is also planned for future calculator versions. The entire look-and-feel of the calculator was designed using jQueryUI's ThemeRoller [23] which allows "skinning" by providing

a mechanism for immediately changing the calculator's look-and-feel based upon a custom, downloaded theme.

5.2.3 Interface Design

The calculator tool was designed to address several web usability issues [21][25][28]; domain-specific terms included in these references are used throughout the remainder of this subsection. Consistency is achieved through similar actions and wording required. User selection of radio buttons and text box entry aligns with common user mental models. Words for building technologies were chosen based upon popularity according to Google search hits which also serves to increase visibility in the relevant domain. The input page is designed to yield closure by dividing the questions into logical groups related to building properties, heating/cooling, and roof comparison which constitute the beginning, middle, and end of the input process. Simple error handling is provided. Short-term memory load is reduced by simplified questions, answers, and page organization. Items are made visible only when relevant (ie. clicking the custom radio button makes the text box visible and also places the cursor in the box for the user to begin typing). Radio buttons, rather than drop-down boxes, were utilized heavily at the expense of screen space since they allow less cognitive overhead (the user is immediately aware of all available choices), label options for radio buttons are clickable to reduce selection time, and radio buttons require fewer and less accurate clicks than drop-down boxes.

The "7 plus/minus 2" principle was followed by organizing the page into essentially three levels: high-level groupings of building, utility cost, and roof system; less than 7 questions in each of these sections, and relevant subproperties of these questions indented under the appropriate material. The Pareto principle was used to focus users on the subset of options which require input while assigning defaults all others. Fitt's Law was leveraged by providing immediate accessibility to all options as radio buttons and also making radio button labels clickable. The baby-duck syndrome was utilized by providing simple form input in the form of a short, multiple-choice test.

The Gestalt principle of proximity and similarity are evidenced in the logical grouping of questions; the law of symmetry was the basis for the black roof and white roof comparisons being symmetric across the page center. The calculator was not divided into multiple pages, but collapsible sections, since fold area is important but not crucial. Gloss is provided through mouse-over hints of where question helper links will take the user when clicked. Granularity has been addressed through collaborative reduction of input options. Readability has been enhanced by using web rank determination for question and answer phrasing. Walk-up-and-use design was implemented through page organization to allow a first-time user to quickly and easily run complex simulations. Defaults were set according to the best available statistics for every question except building location, allowing the calculator to be run simply after answering a single question.

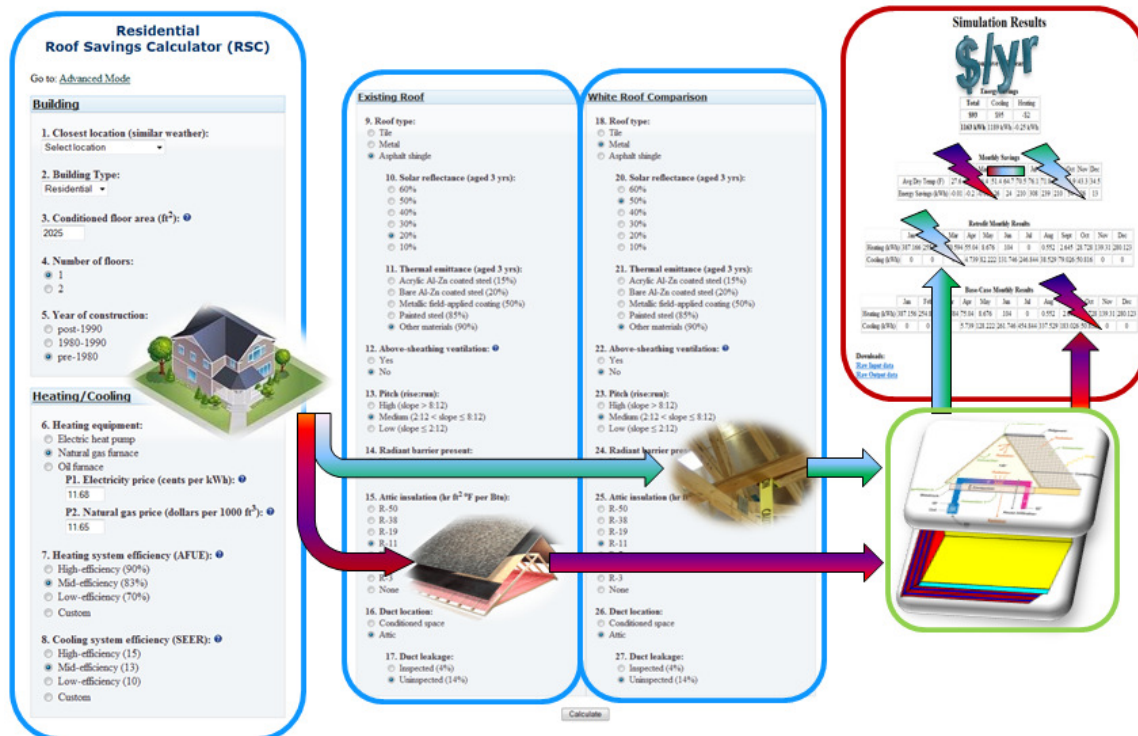**Figure 6. Roof Savings Calculator (RSC) Main Page: www.roofcalc.com**

Figure 7. Screenshots and System Diagram of the Roof Savings Calculator

6. CONCLUSIONS

In conclusion, the RSC [17] provides an approachable portal for both industry experts and residential homeowners to leverage the best available whole-building energy simulation packages and determine energy and cost savings for modern roof technologies and related retrofits. The tool uses the *DOE-2.1E* whole-building energy simulation program and calls *AtticSim* from the SYSTEMS module where *AtticSim* computes the temperatures and heat flows of all surfaces in the attic and passes back to *DOE-2.1E* the attic air temperature, the duct gains and losses and the ceiling heat flow. Combined, the two codes, benchmarked against field data including CA demonstration homes at Ft. Irwin, was shown to yield credible results and is now available online.

DISCLAIMERS

Mention of the trade names, instrument model and model number, and any commercial products in the manuscript does not represent the endorsement of the authors nor their employer, the Oak Ridge National Laboratory or the US Department of Energy.

NOMENCLATURE

AJAX	Asynchronous JavaScript and XML
API	application programming interface
CSS	Cascading Style Sheets
DHTML	Dynamic HyperText Markup Language
DOE	Department of Energy
DOM	Document Object Model
EPA	Environmental Protection Agency
HVAC	Heating Ventilation and Air Conditioning
JSON	JavaScript Object Notation
PHP	Personal Home Page
PVC	PolyVinylChloride thermoplastic membranes
PIER	Public Interest Energy Research
RSC	Roof Savings Calculator
SR	solar reflectance
TE	thermal emittance
R_{US}	Thermal resistance (hr ft^2 ^{o}F) per Btu
R_{SI}	Thermal resistance (m^2 K) per Watt

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