Building America Technical Systems Project Description

1. Project Title: Cool Roofs and Nightcool System

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3. Other participating organizations: Building Science Corp. (BSC) is developing further information on sealed attic construction which is being shared between BAIHP and BSC.

4. Project:

1. Schedule
   a) Initiation Date: 1999
   b) Phase Completions: Reports on evaluated configurations issued annually
   c) Original expected completion date: 2006
2. Funding Status: competitive award
3. Project/technology maturity: Applied research and evaluation. Deployment

5. Statement of the Problem: Building America now has very aggressive energy reduction goals for the energy related performance in new residential buildings by 2020. Previous research has shown that the roof attic and duct heat gains can represent up to 25-30% of total residential cooling load. Cool roofing materials have been found to drastically reduce these heat gains. However, realistic data on performance is critical. Given the emerging importance of reducing attic ventilation to improve storm resistance (sheathing uplift and rainwater intrusion), we have identified this as a critical area within Building America research.

Secondly, we are working on a new concept, called Nightcool, which seeks to change the roof from an energy penalty into a system that can be used to produce high efficiency cooling for the home. Using a building's roof to take advantage of long-wave radiation to the night sky has been long identified as a potentially productive means to reduce space cooling in buildings– a major objective within the EERE mission. This is because a typical roof at 75EF will radiate at about 55-60 W/m^2 to clear night sky and about 25 W/m^2 to a cloudy sky. For a typical roof (2500 ft^2 or 250 square meters), this represents a cooling potential of 6,000 - 14,000 Watts or about 1.5 - 4.0 tons of cooling potential on summer nights with favorable conditions.

6. Project Objectives:

Cool Roofs: The fundamental project objectives are to evaluate differing roofing materials and configurations which can reduce cooling and heating needs in residences. Work over the last two years has evaluated spectrally selective paints, highly reflective surfaces, sealed attic construction in a test facility. Recently it has become apparent that attic ventilation impacts on cooling and attic moisture are not adequately known. Therefore, evaluating attic ventilation interactions remains an important objective. Additional attic ventilation is a commonly advocated method to reduce ceiling summertime heat gains in residential buildings. Increasing passive attic ventilation (wind and buoyancy driven ventilation) can be obtained by increasing the free inlet and outlet areas or by adding a ridge vent to take advantage of the stack effect. Although various means of augmenting passive ventilation may useful for new construction, this must be balanced from the emerging concerns of the impact of attic ventilation on attic and household moisture rates in very humid climates. Recent concerns associated with roof storm resistance against wind damage and water intrusion suggests the great importance of critical examination of roof/attic ventilation elements and their resistance to impact from storm events. Moreover, evaluation of roof systems after hurricanes show that where attic ventilation is used, effective ridge ventilation that retards rain intrusion is an important factor in reducing sheathing uplift damage and corresponding structural roof failure. Rain water intrusion is another critical and large unquantified area.

NightCool System: Within the effort to produce advanced building integrated technologies, another objective is to design a simple and productive residential roof integrated night cooling system. We also seek to simulate performance parameters and used to develop a viable system. Finally, we intend to test the system concept in a scaled down buildings under real weather condition and prove and refine the concept.

7. Project History: Florida Solar Energy Center has been involved for attic related research for over twenty years. This work has included projects with U.S. DOE, Florida utilities and the Florida Energy Office. This work has included numerous reports and evaluation with wide publication around the U.S. Building Science Corporation has been working on sealed attic technology for over five years.

8. Technical Approach:

Cool Roofs: To address these research needs, FSEC constructed the flexible roof facility (FRF) in Cocoa, Florida, ten miles west of the Atlantic Ocean on mainland Florida (Figure 1). The FRF is a 24 ft by 48 ft frame building with its long axis oriented east-west. The roof and attic are partitioned to allow simultaneous testing of multiple roof configurations. The attic is sectioned into six individual six foot test bays spanning three 2 ft. trusses thermally separated by partition walls insulated to R-21 ft^2-hr-EF/Btu. The A-framed roof has a 5/12 pitch (22.6E) covered by 3/4th inch plywood decking. On the attic floor, R-19 un-faced batt insulation was installed between the trusses in all of the test bays in a consistent fashion. One half inch gypsum board separates the attic from the conditioned interior. The roof lends itself to easy reconfiguration with different roof products and has been used in the past to examine different levels of ventilation and installation configurations for tile roofing. A black asphalt shingle roof was one of the test bays to serve as a reference case for all of the other roofing types. The project has developed copious data on comparative attic system performance over the last ten years. Figure 2 illustrates the measured average attic air temperatures in the test cells over the summer of 2003 that strongly influence cooling needs.

Figure 1. FSEC's Flexible Roof Facility

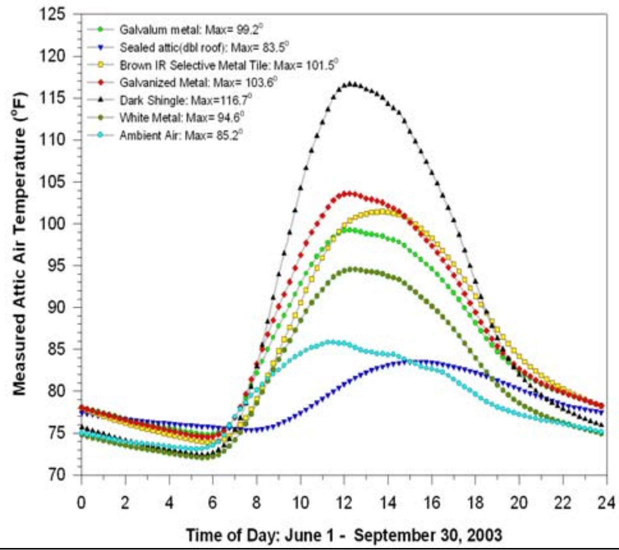

Figure 2. Average measured attic air temperature in the summer of 2003 in FRF test cells.

NightCool System: The operation of the system is detailed in Figure 3. Fundamentally, it utilizes a metal roof over a sealed attic with an integrated dehumidification system. During the day, the building is de-coupled from the roof and heat gain to the attic space is minimized by the white reflective metal roof. During this time the space is conventionally cooled with a small air conditioner. However, at night as the interior surface of the metal roof in the attic space falls two degrees below the desired interior thermostat set-point, the return air for the air conditioner is channeled through the attic space by way of electrically controlled louvers with the variable speed fan set to low. The warm air from the interior then goes to the attic and warms the interior side of the metal roof which then radiates the heat away to the night sky. As increased cooling is required, the air handler fan speed is increased. If the interior air temperature does not cool sufficiently or the relative humidity is not kept within bounds (<55% RH) the compressor is energized to supplement the sky radiation cooling. The massive construction of interior tile floors and concrete walls) will store sensible cooling to reduce daytime space conditioning needs. The concept may also be able to help with daytime heating needs in very cold climates as well by using a darker roof as a solar collector.

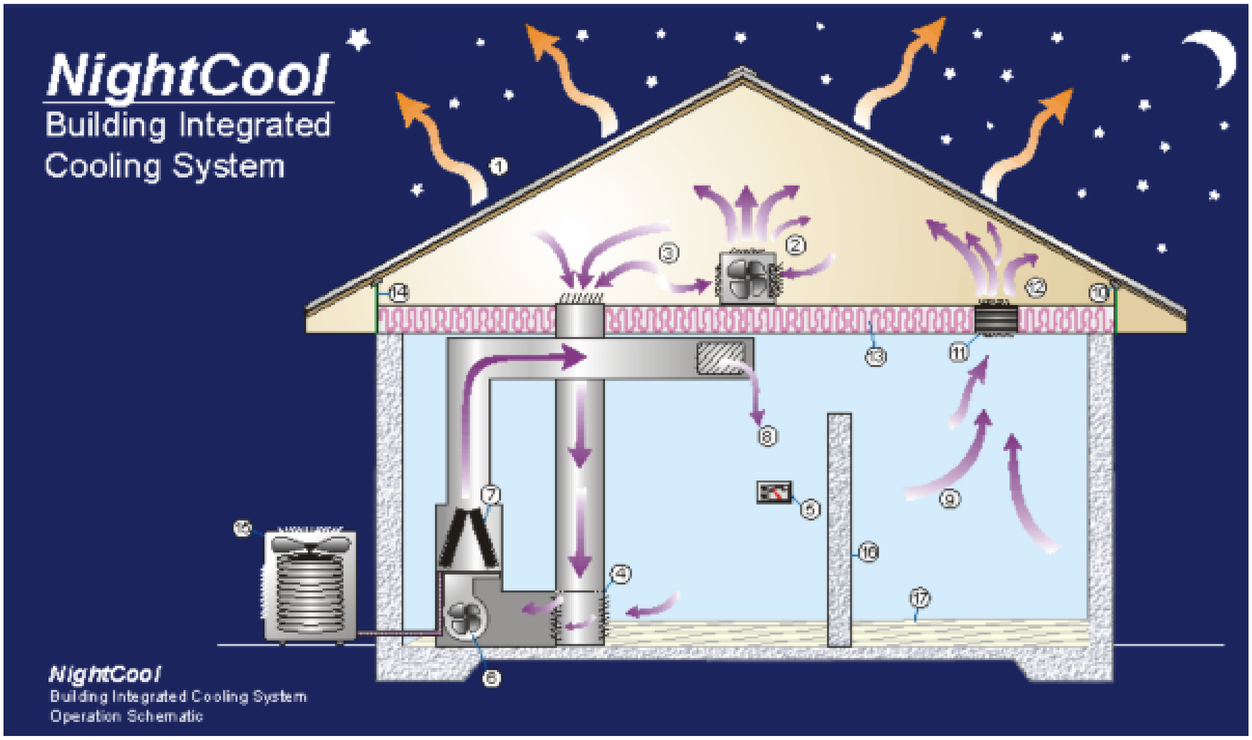

Figure 3. Schematic of *NightCool* concept.

1. White metal roof on metal battens (no decking). Both sides are surfaced for high emissivity. A temperature probe measures roof underside temperature. 2. Small capacity dehumidifer (such as *Whirlpool AD40DBK*); operates only during evening hours when thermostat and roof temperature monitor calls for cooling and attic relative humidity is greater than 55%. 3. Baffled inlet frill from attic for nighttime operation. 4. Room return inlet (for daytime operation). Closed by damper at night when temperature conditions are met. 5. Thermostat (compares roof surface temperature and setting to determine vapor compression vs. nighttime cooling operation). 6. Variable speed air handler fan with electronically commutated motor.	7. Vapor compression air conditioner cooling coil. 8. Interior duct system with supply outlet. 9. Interior room air return to attic during evening hours when Night Cool is activated. 10. Roofline drip collection system with drain. 11. Ceiling return for NightCool operation mode. 12. Attic air connects to cool roof for nocturnal cooling. 13. R-20 ceiling insulation. 14. Sealed attic construction with top plate baffles (tested and sealed system). 15. Air conditioner outdoor unit (condenser). 16. Concrete interior walls (thermal mass for sensible cool storage). 17. Tile floor (add thermal mass).

9. Technical Work Plan for 2005:

Cool Roofs: Due to the fundamental influence of attic ventilation on attic thermal performance, and the poor availability of long-term comparative data, we recommend that priority research for the summer of 2005 use FSEC's Flexible Roof Facility (FRF) to examine attic ventilation influences. The FRF would be set up in the following configuration to establish relative performance. All cells would have black shingles save for Test 6 six with the white metal roof which has served for years as the best performing roofing system. All test cells would have R-30 insulation installed on the attic floor with the ventilation areas carefully verified.

Cell No	Description of Experiment	Research Justification
6	White metal roof, 1:300 ventilation	Best performing roofing system
5	Reference, 1:300 ventilation area	Standard requirement for building codes
4	Black shingles, 1:150 vent area	Added attic ventilation area per codes
3	Black shingles, Sealed	New ASHRAE option for humid climates
2	Black shingles, 1:150, soffit vs. ridge	Evaluation impact of soffit vs. ridge venting
1	Black shingles, open soffit with PV vents	Evaluate PV ventilators

Test cell #2 would alternately have the ridge vents opened and closed midway through the summer season to examine influences on performance. Relative humidity sensors would be used to evaluate how the different attic ventilation strategies influence attic moisture conditions. In addition, moisture sensors would be placed in the areas surrounding the ridge vents to see if wind blown moisture is introduced to the attics during weather events. Monitoring would continue for an entire year to examine both cooling and heating related performance.

NightCool System: The theoretical concept has been recently evaluated in a project report which evaluates how the system operates against various parameters and under typical Florida weather condtitions. In 2005, two side by side small scale test facilities will be used to evaluate actual system performance under realistic conditions.

The concept will be evaluated by two approaches. Firstly, a detailed computer simulation will be developed of the night cooling concept. Secondly, two instrumented test buildings will be used in to evaluate the concept under realistic weather conditions.

The computer simulation of the concept will be developed is based on other work by Givoni and others. This work evaluates the concept potential by a series of calculations based on physical principles. Once validated against similar calculation procedures, the simulation was used to evaluate the impact of various physical system parameters (roof conductivity, view factors, system air flow rate etc) as well as various system values (return air temperatures and flow rates) as well as weather conditions. In this way, it is possible to determine the critical system parameters to make the concept viable as well as potentially superior in performance. The model was exercised using a sample of real weather data. Figure 4 shows the current *NightCool* model sensitivity to the system air flow rates.

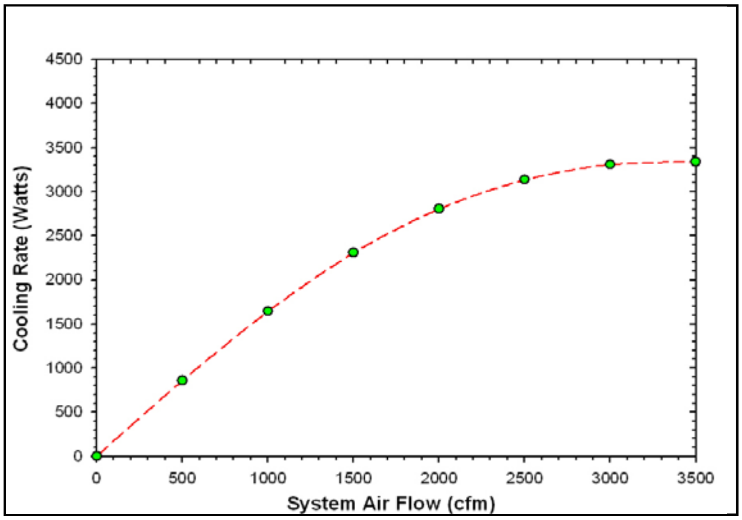

Figure 4. Sensitivity of *NightCool* performance to system air flow rate.

The empirical evaluation of the concept will be done by using two highly instrumented side-by-side 10 x 16' test sheds located at the Florida Solar Energy Center. One of the test sheds will be configured like a conventional home with a dark shingle roof and insulated ceiling under a ventilated attic. The experimental shed will feature a white reflective roof on battens with a sealed attic where the air from the shed interior can be linked to the sealed attic and roof radiator when the roof temperature drops below the room target cooling temperature. A detailed instrumentation plan has been developed so that appropriate data can be obtained to thoroughly evaluate performance.

10. Technical Barriers:

Cool Roofs: Facilities are now available to evaluate roofing system impact on cooling performance. Realistic data on thermal and rain water intrusion performance of various roofing systems with lower ventilation rates is largely unknown. For recommendations for alteration of building practice and code bodies, scientifically defensible data is vital. A realistic test structure to assess the energy and rain water intrusion impacts of roofing systems is critical within this process.

NightCool System: Various physical limitations (differential approach temperature, fan power, convection and conductance) constrain what can be actually achieved, however, so that perhaps half of this rate of cooling can be practically obtained. Even so, careful examination of vapor compression space cooling in many homes in Florida shows that roughly 9.2 kWh (28%) of this air conditioning is required between the hours of 9 PM and 7 AM when night sky radiation could greatly reduce space cooling. The big problem with night sky radiation cooling concepts have been that they have typically required exotic building configurations. These have included very expensive "roof ponds" or movable roof insulation with massive roofs so that heat is not gained during daytime hours. A key element of this novel configuration is that rather than using movable insulation with a massive roof, the insulation is installed conventionally on the ceiling.

11. Status of Research Projects:

Cool Roofs: In the summer of 2004 Test Cell #3 was configured with a spectrally selective panelized metal roofing system. The test cell arrangement emphasized data collection from three types of metal roofs. We are looking at unsurfaced metal roofs due to their low cost and popularity. We further examine two types of unsurfaced metal roofs - galvanized and galvalum, which should have very different long-term reflectance properties. Testing in 2004 evaluates three years of exposure.

- Unsurfaced galvanized metal (Cell #4)
- Unsurfaced galvalum metal (Cell #1)
- White standing seam metal (cleaned) (Cell #6)
- Spectrally selective metal panel roofing system (Cell #3) [reconfigured]

Cell #5 remains the control test cell with dark shingles and 1:300 attic ventilation. Cell #3 has a new metal roofing product with spectrally selective solar reflective properties (*Classic Metals: Timbercreek Shake* on galvanized steel). Analysis of the FRF data for 2003 has been completed showing that unfinished galvalum roofing offers about half the advantages of a white reflective roof surface and similar performance to IR reflective pigments. As described earlier, the test protocol for 2005 will comprehensively evaluate the impact of varying levels of attic ventilation.

NightCool System: The project work plan first created a simulation model of the *NightCool* cooling system to examine the fundamental relationships that affect the function of the system. The simulation would then be used to develop the concept functionality. The plan is then to develop a scaled down version of the concept that could be tested in two small side-by-side test sheds. Data will then be obtained from the test sheds as operated in

Central Florida. Currently, the simulation has been completed and is functional as an Excel spreadsheet, and the results have been used to create the anticipated configuration. A report has been completed describing parametric results from the simulations with evaluation of the various characteristics that were found to be critical to performance. Among these, uncertainty in the underside surface convective heat transfer coefficient looks important as well as air flow rate and radiator entering air temperature. The simulation shows that in Tampa, Florida from June - September, the system can produce an average of 15 kWh of cooling per day at a use in fan power of about 1.4 kWh for a system SEER of approximately 37 Btu/Wh. Performance during more mild swing seasons show EERs greater than 50 Btu/Wh. Performance was also evaluated in other climate locations: Phoenix, AZ; Baltimore, MD and Atlanta, GA. In each location, June-September performance was superior to that in Tampa, FL – with greater absolute cooling and efficiencies of 71-88 Btu/Wh. The detailed simulation report is currently available.

Figure 5. Site location of side-by-side *NightCool* and basecase test sheds.

Construction is also just beginning on the two instrumented test sheds which will be erected at FSEC's facilities and will be used to collect data on comparative system performance in the summer of 2005. The two 10 x 16' side by side test structures are shown under construction at the Florida Solar Energy Center (Figure 5).

12. Commercialization Plans:

Cool Roofs: The FRF cool roofs experiments provides detailed data on the real world thermal performance of roofing systems that has not been heretofore available. Results from this research have directly lead to development and marketing of IR selective pigments by BASF Corporation, Ferro Corporation and the Shepherd Paint Company. Our research on unsurfaced metal roofing is beginning to be noticed by building code bodies around the U.S. and to market the superior performance of these products by metal roofing manufacturers.

NightCool System: As this is a cutting-edge technology, commercialization would have to wait for favorable research results as well as full-scale testing in homes. Results would also have to be obtained in varying climates. No commercialization programs are anticipated until this building technology is successfully demonstrated in the FSEC test structures and in full scale buildings. Larger scale deployment of the technology would depend on favorable results from such evaluations.

13. Efficiency Improvement Metrics: Include in Technical Approach.

14. Project Output:

Cool Roofs: Reports for FRF performance provided in 2001, 2002 and 2003. Report on 2004 performance is in preparation. Detailed literature review of seal attic technology recently completed for Florida Department of Community Affairs which has relevance to the project.

Parker, D.S, Sonne, J.K, Sherwin, J.R, 2001. Flexible Roofing Facility: 2001 Summer Test Results, FSEC-CR-1336-02. Florida Solar Energy Center, Cocoa, FL. Available online at http://www.fsec.ucf.edu/bldg/pubs/cr1336/cr1336.htm

Parker, D.S., J.K. Sonne, J.R. Sherwin, and N. Moyer, August 2002. "Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida." Proceedings of ACEEE 2002 summer study, Asilomar Ca. Available online at http://www.fsec.ucf.edu/bldg/pubs/impact_roof/index.htm

Parker, D.S., Sonne, J.K., Sherwin, J.R., 2002. Flexible Roofing Facility: 2002 Summer Test Results, Prepared for: U.S. Department of Energy Building Technologies Program, July 2003. Available online at http://www.fsec.ucf.edu/bldg/pubs/frf2002/index.htm

Parker, D.S., Sonne, J.K, Sherwin, J.R., 2003. Flexible Roofing Facility: 2003 Summer Test Results, Prepared for U.S. Department of Energy Building Technologies Program, July 2004. Available online at http://www.fsec.ucf.edu/bldg/pubs/flexible/index.htm

NightCool: Report on Theoretical Performance of system recently completed and in draft form.

Parker, D.S., 2005. Theoretical Evaluation of the *NightCool* Nocturnal Radiation Cooling Concept, FSEC-CR-1502-05, Prepared for U.S. Department of Energy, Building Technologies Program, April 2005. Available online at http://www.fsec.ucf.edu/bldg/baihp/pubs/nightcool/index.htm

15. Budget:

The approximate budgets for these tasks since 2000 is provided below. Please note that these figures are very approximate as at FSEC accounts are NOT maintained by tasks, only at project levels. All numbers are in K$

	2000	2001	2002	2003	2004	2005	Totals
Coolroof -DOE	60	60	60	60	60	60	360
Coolroof- Costshare	15	15	15	15	15	15	90
Nightcool-DOE	0	0	0	0	40	80	120
Nightcool-Costshare	0	0	0	0	10	20	30

16. Principal Project Personnel:

Danny Parker serves as the task leader for both tasks and devotes approximately 25% of his time to them. John Sherwin and Stephen Barkaszi devote about 40% of their times and David Beal about 20% of his time to the tasks as indicated below.

Danny Parker:	Florida Solar Energy Center, 1679 Clearlake Road, Cocoa, FL 32922, Phone: 321-638-1405, FAX: 321-638-1439, email: dparker@fsec.ucf.edu
John Sherwin:	john@fsec.ucf.edu (FRF configuration and instrumentation)
Stephen Barkaszi:	barkaszi@fsec.ucf.edu (NightCool experiments)
David Beal:	david@fsec.ucf.edu (NightCool experiments)

Researcher bios are provided starting from next page.

17. Other Information Sources:
Publications related to these tasks are available online as indicated in item 14 above.

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Danny S. Parker
Principal Research Scientist

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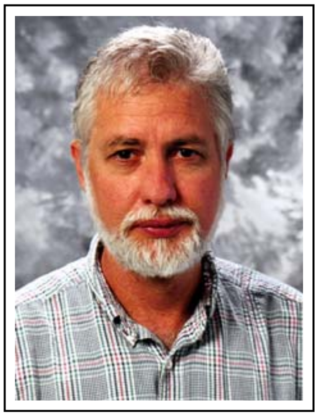

Education:
M.S. Environmental Science
University of Montana, Missoula, Montana 1983

Research Focus
Mr. Parker specializes in collecting and analyzing measured data taken from residential and commercial buildings to determine how results may be applied to reducing energy needs. Over the last 16 years, he has studied technologies to improve energy efficiency in Florida's buildings. He has extensive experience with building energy and field monitoring.

Mr. Parker has spent the last 25 years of his career in the field of energy-efficiency research. He has been involved in a number of field projects in residential and commercial buildings and is expert in building energy measurement and monitoring.

Much of Mr. Parker's research over the last several years has been specifically related to research in highly efficiency buildings and potential impacts when mated with renewable energy resources. He also has extensive experience with large-scale utility monitoring projects and evaluation of load control options. He holds several patents associated with innovative energy efficiency technologies.

Over the last decade, Mr. Parker's residential research includes the following: impact of white roofing on residential cooling energy use, impact of utility load control on appliance demand profiles in large-scale monitoring, impact of attic radiant barrier and attic ventilation performance, evaluation of the impact of programmable thermostats, whole house fan impact on thermal comfort, evaluation of residential AC sizing methods, photovoltaics and solar energy sources as optimized for buildings, potential of energy efficient lighting in residences, impact of reduced evaporator air flow on AC performance, development of a zero energy home where cooling was reduced by 84% and development of a low-energy high performance ceiling fan.

John R. Sherwin
Senior Research Engineer

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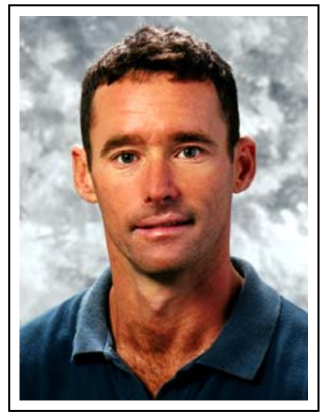

Education:
B.S. Electrical Engineering
University of Central Florida, Orlando, FL 1988
B.S. Finance
University of Central Florida, Orlando, FL 1991

Research Focus

Mr. Sherwin has twelve years experience in energy field monitoring and instrumentation. This includes selection, calibration, setup, and installation of experimental apparatus. Coincidental to these activities is the retrieval, analysis, and presentation of data and results. He also has technical experience in the installation, diagnosis and repair of HVAC and electrical systems. He has been involved in numerous projects involving both field and laboratory monitoring. These were largely detailed monitoring efforts that characterized both thermal and electrical energy performance.

Mr. Sherwin has been in charge of instrumentation and evaluation efforts for utility projects, the Building America program, DOE's Zero Energy Homes effort and most of the residential monitoring projects at Florida Solar Energy Center. Over the last two years, he has also assisted others at FSEC with evaluation of high efficiency air conditioner condenser fan designs. This laboratory work has resulted in several pending patents and development of technology that has large potential to reduce space cooling energy use in U.S. homes.

Stephen F. Barkaszi
Senior Research Engineer

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Education:
M.S. Ocean Engineering
Florida Institute of Technology

B.S. Ocean Engineering
Florida Institute of Technology

Research Focus

Stephen Barkaszi is a Senior Research Engineer in the Photovoltaics and Advanced Technologies Division at FSEC. Mr. Barkaszi joined FSEC in 1993 and initially worked in the Building Design Assistance Center evaluating building systems and equipment for energy and costs-savings potential for utilities and consumers.

He joined the Photovoltaics and Advanced Technologies Division in 1997 and his current research includes: distributed generation, utility-interconnection issues, micro turbines, fuel cells, building-integrated PV, and roof-mounted PV arrays.

Mr. Barkaszi continues to conduct research on high performance buildings. This work includes a holistic approach to design and construction of buildings that effectively incorporate energy savings features and on-site energy production technologies.

Teaching activities include various seminars and short courses such as the quarterly FSEC course *Installing Photovoltaic Systems*.

Mr. Barkaszi received his B.S. and M.S. degrees in Ocean Engineering from the Florida Institute of Technology. He is a licensed Civil Engineer in the state of Florida and previously managed the construction materials testing division for a private civil engineering firm.

David Beal
Research Analyst
Buildings Research Division

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Education:
B.S. in Engineering Technology
University of Central Florida

Research Focus

David Beal has been a Research Analyst at the Florida Solar Energy Center since 1987. He has been Principle Investigator on several FSEC projects and has been involved in various building Science Projects including Radiant Barrier Technology, Roof Material Testing, Ventilation Studies, and Industrialized Housing. At present he acts as a consultant to various HUD Code manufacturers, focusing on moisture problems and duct systems.

David has been responsible for instrumentation, monitoring and analysis of many projects and was integral to FSEC's early work on wall and roof systems, including radiant barrier performance that led to Florida energy code credit for the technology. Recently, he conducted experiments on the effect of various ground cover systems on the relative humidity under manufactured homes.