Building America Technical Systems Project Description

1. **Project Title**: **High Efficiency Condenser Fans**

Figure 1. FSEC researchers install hardware for outdoor test of AC condenser fan.

2. **Principal Investigator**: Danny Parker, Building America Industrialized Housing Project (BAIHP), Florida Solar Energy Center, 1679 Clearlake Road, Cocoa, FL 32922, Phone: 321-638-1405, FAX: 321-638-1439, email: dparker@fsec.ucf.edu

3. Other participating organizations: Cooperatively working with AeroVironment, Inc., a private aeronautical engineering firm in Monrovia, CA.

4. Project:
   1. Schedule
      a) Initiation Date: 2002
      b) Phase Completions: Reports on evaluated configurations issued annually
      c) Original expected completion date: 2005
   2. Funding Status: non-competitively awarded as a BAIHP supplemental task
   3. Project/technology maturity: applied research and evaluation. Field evaluation of technology. Licensing of patents and manufacture.

5. **Statement of Problem**: Air-cooled condensers in residential air conditioning (AC) systems, employ finned-tube construction to transfer heat from the refrigerant to the outdoor air. Electrically powered fans are used to draw large quantities of air across the heat transfer surfaces to remove refrigerant heat. Although intensive research effort has examined improvements to compressors, much less effort has targeted to improvements of system fans – particularly the outdoor fan used by air conditioners and heat pumps. Conventional fan blades used in most AC condensers are curved, stamped metal blades which are inexpensive to manufacture, but may not be not optimized in terms of providing maximum air flow at minimum input motor power as shown in Figure 2.

Figure 2. Stamped metal condenser fan blades for a 3-ton condenser

6. **Project Objectives**: The primary objective was to improve condenser fan performance while reducing motor power. We also examined potential changes to the condenser exhaust configuration to enhance air moving efficiency performance. A secondary objective was to provide sound reductions as lower noise AC equipment is important to consumers. All identified improvements were to be evaluated relative to potential practicality in terms of implementation which would allow for beneficial economics within manufacture.

7. **Project History**: Florida Solar Energy Center has completed all the work involved with the project under sponsorship by the U.S. Department of Energy. The project was originally funded in March of 2002 for one year under the Building Technology program under Mr. Terry Logee. FSEC has continued with the research within the Building America project after the original year of initial funding.

8. **Technical Approach**: Within the project, we used a standard 3-ton air conditioning system produced by a major U.S. manufacturer. The system uses R-22 refrigerant, although all the testing in our evaluation was done with condenser fan only operation. The system has a rated SEER of 12 Btu/Wh when mated with a compatible evaporator and air handler. The 19" fan in the original outdoor unit consists of four metal paddle blades, powered by a six

pole 1/8th hp motor with a rated flow of 2500 cfm for the condenser. As measured in the baseline condition, the fan motor drew 190 Watts at 208 Volts and produced 2,180 cfm turning a 1010 rpm. At the 95/80/67 ARI test condition the fan power for the entire AC system represents about 6% of total system power.[1]

For the research, we needed the ability to accurately measure power, condenser air flow, fan motor power and rpm as well and environmental conditions. Secondly, we desired to measure sound levels. For diagnostic purposes, we used flow visualization tools to aid our understanding of the air flow dynamics of some of the processes involved.

An indoor test facility was constructed. A precision power transducer provided motor power measurements (±1 Watt resolution) and air temperature and relative humidity. As the facility had 208 single-phase power, this electrical source was used for the measurements involved. As condenser air flow was a critical measurement, we constructed flow measurement chamber in conformance with ASHRAE Standard 51-1985. The constructed chamber was then calibrated at another facility with NIST traceable air flow equipment. The final chamber was estimated to yield an absolute air flow measurement accuracy of approximately ± 5% (125 cfm). The relative air flow measurement accuracy was much better. We found the equipment could reliably measure changes in air flow from design changes as small as 20 cfm out of a 2500 cfm air flow level. A laser tachometer was used to measure fan rpm and a precision portable dB meter was used to measure nearby sound levels. A digital manometer was used to measure static pressure within the condenser underneath the exhaust fan.

Once the test bench was established, fans were designed for test. FSEC tested potential enhancements to the outdoor unit condenser fan by altering its shape and aerodynamic characteristics. Optimized fan blades were designed via a numerical flow simulation and fabricated using stereo lithography. Each design featured tapered, twisted blades with air foil optimized for the expected operational velocities. A similar approach was used to design optimized conical diffusers. The highly-instrumented test facility allowed evaluation of air flow, motor power, fan rpm and sound emanation. After several months of testing, the research produced a fan exhibiting greatly superior air moving efficiency compared with conventional stamped metal blades. Other improvements were demonstrated using conical flow diffusers and an innovative method of reducing fan tip clearances that reduce produced sound levels.

9. **Technical Work Plan for 2005 - 2006**: Current project efforts in 2005 - 2006 are evaluating potentially more efficient larger fans (27.6") for the larger air flows (4200 cfm+) needed for the most efficient current AC condensers. Other research is evaluating the combined potential with ECM motors as well as potentially shorter annular flow diffusers with temperature adaptive controls. Even higher efficiency levels are anticipated.

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[1] Within our testing, we also are evaluating improvements to a higher-efficiency condenser using R-410A. This condenser is physically larger with also a larger fan (27.6") and a 1/4 hp PSC motor. Within this configuration, fan power (240 Watts) represents 8% of overall system power at the ARI 95/80/67 condition.

10. **Technical Barriers**: Although fan manufacturers have examined forward swept designs to lower sound levels, little evaluation has been made of optimized models using air foils in residential AC equipment to determine savings potentials. Moreover, no evaluation has been made of residential AC equipment which has looked at integrating optimized fans with improved exhaust diffusers that allow pressure recovery and improved air moving performance. To be convincing to the AC industry, comparative tests must be done on conventional versus proposed equipment.

    Designs must be aesthetically acceptable and reasonable in incremental cost over current methods and tooling.

11. **Status of Research and Work Plans**: The evaluation was performed on a standard 3-ton AC condenser (Figure 1). Measurements were made of condenser air flow, motor power, sound levels and condenser cabinet pressures.

    Within the effort, we developed new twisted and tapered propeller air foils that demonstrated greater air moving efficiency. Fan only savings were 40 watts (21%) for the same motor and condenser top. We also showed how a lengthened diffuser with a conical insert after the motor (detailed below) can improve air moving efficiency by over 16% for standard fans and over 27% for high performance fans. Fan tip losses and associated vortex shedding was reduced though the use of a porous foam strip to improve air flow performance while helping to reduce sound (see Figure 3 below). This also allows slower fans to provide superior air moving performance along with sound control. Highlights of results are summarized below:

    - Provides 49 Watt reduction in fan power (114 W vs. 190 Watts) with permanent split capacitor (PSC) motors.

    - Increases condenser air flow by 100 cfm (5% increase in fan flow).

    - Provides 102 W power reduction with brushless DC (BDC) ECM motor.

    - Reduces fan-only ambient sound level by 1-2 dBA. Ground level sound reduction is greater.

    - BDC motor allows lower fan speeds for ultra-quiet night operation, higher flows for maximum capacity during very hot periods (temperature based control)

    Advanced Diffuser Design

    An optimized exhaust assembly for the condenser fan was found to be an important integral method of achieving more efficient and quiet fan designs. Diffusers are an expanding duct which provides recovery of air static pressure by reduction of the flow velocity as the flowing air mass expands. Practically, the condenser fan air velocity is lowered prior to exhaust, thereby increasing the overall mass flow rate from the system. The exhaust configuration of a standard unitary air conditioner consists of a short 4" 10 degree divergent diffuser covered by a slotted grate or wire grill with the fan is nestled in the bottom of the diffuser section.

Examining interactions between high efficiency propeller designs and external static pressure, we determined that an optimized diffuser section would allow large improvements in air moving efficiency. Diffuser theory would suggest that large improvements in fan efficiency are possible by lengthening the diffuser stage. Theoretically, an 18" diffuser should provide about 25% added pressure recovery over that from a short 4" diffuser. While a longer length would provide still greater pressure recovery, we judged an 18" height to be the maximum practical for consumer acceptance.

Thus, we constructed a larger 18" tall 7 degree divergent diffuser with the motor and fan located in the bottom of the assembly. Figure 3 shows the overall assembly fan and diffuser assembly as produced with the elongated diffuser. Essentially this modifies the overall fan design from more of a shallow ducted propeller to a true tube-axial design.

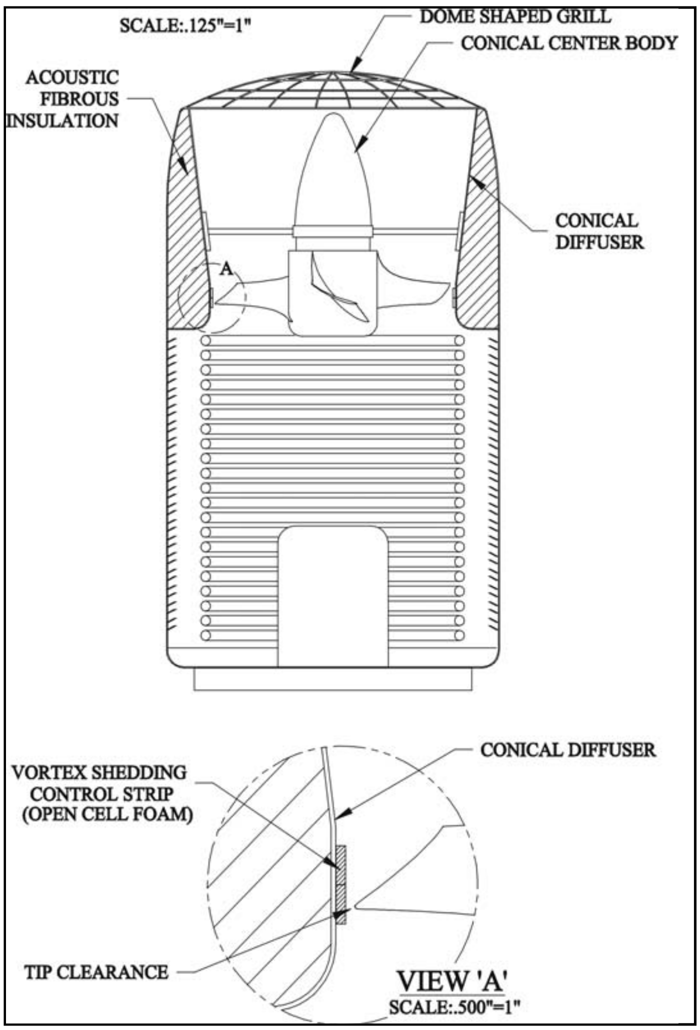


Figure 3. Schematic of AC condenser fan design.

The diffuser increases the exhaust diameter from 19.75" to 24" at the wire grill top. While testing with an experimental stator stage did not demonstrate any added flow, we did find other changes in geometry to yield modest improvement. As the motor occupies the center of the diffuser, the swirl set up by the fan as it expands through the diffuser tends to collapse on the low pressure zone immediately behind the motor. Through trial and error, we found that by using a smooth conical center body on the other side of the motor, we could increase flow by 20 cfm and reduce power by about 2-5 Watts.

Fan tip losses and associated vortex shedding was reduced though the use of an porous foam strip to improve air flow performance while helping to control sound. This ability allows considerably slower fans to provide superior air moving performance along with sound control. The overall final system configuration with diffuser, fan and housing is shown in Figure 4 below.

Figure 4. Improved condenser fan with enhanced diffuser.

12. **Commercialization Plans**: Several patents are pending on the described technology. FSEC is working closely with a major U.S. AC manufacturer in the proprietary research. The AC industry is potentially interested in using the developed technology and presentation of a full scale operational prototype was shown in May of 2004. The research has the potential to reduce air conditioning energy use in U.S. manufactured AC equipment by 2-4%.

    Unlike many other improvements, the reductions to peak electrical demand are as large as energy savings. With 50 million AC and heat pumps in use in the U.S., the potential energy savings are potentially 3 - 6 GWh annually. Utility co-incident peak reductions are potentially 2500 - 5000 MW– the output of five to ten typically sized combined cycle power plants. Thus utility interest in the technology is high. FSEC is working with Proctor Engineer Group and the California Energy Commission to develop a similar exhaust assembly for a prototype air conditioner optimized to save energy use in hot arid climates. Prototypes of the appropriate fan and exhaust assembly are currently under development.

13. **Efficiency Improvement Metrics**: Include in Technical Approach.

14. **Project Output:**

D. Parker, Outdoor Air Conditioner Condenser Fan Research, FSEC-PR-097-2002, Florida Solar Energy Center, March 2002.

Parker, D., Sherwin, J., Hibbs, B., " Development of High Efficiency Air Conditioner Condenser Fans", Draft paper to be published in ASHRAE Transactions in June 2005.

Presentation of technology to *Trane Corporation* in May 2004.

Filed Patent: UCF-386, "*High Efficiency Air Conditioner Condenser Fan*," Appl. No. 10/400,888, University of Central Florida.

15. **Budget:**

The approximate budgets for this task since inception in 2002 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$**

	2002	2003	2004	2005	Totals
DOE Funding	75	50	50	50	225
Costshare	25	20	20	30	95

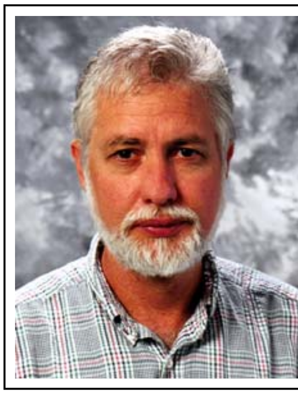
16. **Principal Project Personnel**:

Danny Parker: Serves as the Principal Investigator for this task. Devotes approximately 25% of his time to this task

John Sherwin: John@fsec.ucf.edu (laboratory test bench, testing and development). Devotes approximately 25% of his time to this task.

Resumes of Danny Parker and John Sherwin are provided at the end.

17. Other Information Sources: ASHRAE draft paper is available online at http://www.fsec.ucf.edu/bldg/baihp/pubs/develop/index.htm



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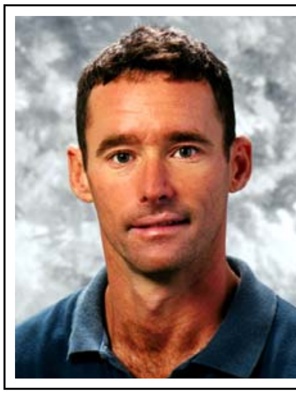
Research Focus
Mr. Parker specializes in collecting and analyzing measured data taken from residential and commercial buildings to determine how results may be applied to reducing energy needs. Over the last 16 years, he has studied technologies to improve energy efficiency in Florida's buildings. He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



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Education:
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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.