CALIFORNIA
ENERGY
COMMISSION

ENERGY INNOVATIONS SMALL GRANT PROGRAM
Building End Use Technologies

Energy-Efficient Air-Handling Controls

FEASIBILITY ANALYSIS

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LEGAL NOTICE

PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million of which $2 million/year is allocated to the Energy Innovation Small Grant (EISG) Program for grants. The EISG Program is administered by the San Diego State University Foundation under contract to the California State University, which is under contract to the Commission.

The EISG Program conducts four solicitations a year and awards grants up to $75,000 for promising proof-of-concept energy research.

PIER funding efforts are focused on the following six RD&D program areas:

- Residential and Commercial Building End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research

The EISG Program Administrator is required by contract to generate and deliver to the Commission a Feasibility Analysis Report (FAR) on all completed grant projects. The purpose of the FAR is to provide a concise summary and independent assessment of the grant project using the Stages and Gates methodology in order to provide the Commission and the general public with information that would assist in making follow-on funding decisions (as presented in the Independent Assessment section).

The FAR is organized into the following sections:

- Executive Summary
- Stages and Gates Methodology
- Independent Assessment
- Appendices
  - Appendix A: Final Report (under separate cover)
  - Appendix B: Awardee Rebuttal to Independent Assessment (Awardee option)

For more information on the EISG Program or to download a copy of the FAR, please visit the EISG program page on the Commission's Web site at:
http://www.energy.ca.gov/research/innovations

or contact the EISG Program Administrator at (619) 594-1049 or email eisgp@energy.state.ca.us.

For more information on the overall PIER Program, please visit the Commission's Web site at http://www.energy.ca.gov/research/index.html.

Executive Summary

Introduction

A large fraction, in some cases as much as 24%, of the energy consumed in buildings is used to operate fans that move air for heating, ventilating, and air-conditioning (HVAC). Much of the fan energy is wasted because fans are not operated in the most efficient manner. Inefficient fan operation can increase cooling energy consumption as well as fan energy consumption when their operation causes more air to be cooled than is necessary. Furthermore, inefficient operation of HVAC fans increases grid peak demand when electricity demand is high.

If fans could be operated efficiently, moving only the air needed, when it is needed, then savings would accrue in two areas. First, the fans would operate for less time, reducing their energy consumption by 20 to 40%. Second, less fan operation means reducing the mass of air that requires cooling. This excessive or wasted cooling energy is estimated to be 10% of the total.

The researcher in this project proposed to develop new, more energy efficient strategies for operating air-handling equipment. To quantify the potential savings of these strategies the researcher embedded them into an analytical model. The model predicts the transient response of pressures, velocities, and temperatures in the system and uses sequential modes of operation to approach the set point. Actual data from a large office building in Oakland, California, were used to calibrate the model. The researcher developed a new model based on two strategies. The first strategy, called "Efficient Air-handling StrategY" (EASY), is a system control that can be implemented with a finite state machine in which states are modes of operation such as "economizer enabled" or "economizer disabled." The second strategy, called "Static Adjustment based on Volume flow" (SAV), employs resetting static pressure based on supply airflow rate. SAV can be implemented as part of EASY or as a standalone strategy. The researcher tested both strategies and found the majority of the benefits derived from SAV.

Project Objectives

The goal of this project was to determine the feasibility of using an intelligent ventilation fan controller to reduce the energy consumption of the fan by more than 20%. The specific objectives of the project were as follows:

1. Develop, using optimization and computer simulation methods, a new energy-efficient algorithm to control air-handling equipment in buildings
2. Reduce fan energy consumption by 20%-40%
3. Reduce cooling energy consumption by 10%
4. Demonstrate stable operation of the fan controls while minimum ventilation, appropriate building pressurization, and appropriate temperature control are maintained at all times

Project Outcomes

1. The researcher used an existing model of air-handling systems for a starting point. The researcher calibrated the model using data from the Elihu Harris State Office Building in Oakland, California. The researcher determined optimal system behavior and then identified

patterns of behavior that could be encoded as control rules. The rules were designed to achieve nearly optimal performance.

2. The researcher expected reductions in energy consumption from reduction of throttling losses at the control dampers (exhaust, return, and outdoor air dampers) of the air-handling unit. The researcher reported fan energy savings of 26.3% over the base case. However, the researcher chose a system with no static pressure reset as his base case. There are existing control schemes that use static pressure reset that are reputed to perform as well as or better than EASY with SAV. When compared with state-of-the-art systems the strategies developed in this project may or may not have a comparative advantage.
3. The researcher expected gains in cooling energy to arise from better control over outdoor airflow rates. Existing systems using fixed minimum damper positions for regulating outdoor airflow can over-ventilate when it is hot, increasing cooling energy consumption. The project strategy directly controls outdoor airflow rate. Cooling energy savings were reported to be 17.4%. Again, the researcher compared his results to a base case with no static pressure reset. The comparative advantage to state-of-the-art systems may be considerably less.
4. The researcher invented a simpler way to model the behavior of fans. The researcher could not get the optimizer code to converge to the best operating point. Instead, he used trial and error methods combined with knowledge of existing strategies incorporating his findings into the EASY code. With these modifications, the models were stable and met minimum HVAC conditions required for a building. The researcher reported a faster system response time for his control system.

Project Conclusions

The feasibility of the intelligent fan control strategy was proven.

1. The control strategies developed in this project cause a fan system to use less energy than the base case while ensuring that control requirements are met at all times.
2. The control strategies can reduce fan energy consumption by a much as 26.3% when compared to a system without static pressure reset.
3. The control strategies can reduce cooling energy consumption by as much as17.4% when compared to a system without static pressure reset.
4. The control strategies appear to be easier to tune than existing strategies. They exhibit faster response time when tuned properly. System settling time was reduced to 30 minutes from two hours.
5. The researcher should clearly establish the technology baseline against which he is calculating his energy savings calculations. His should compare to the best available technology.

Public Benefits to California

The project demonstrated the proposed control strategies could reduce average power by 0.23 W/ft^2/year in buildings with variable air volume (VAV) air-handling units. This is a large potential reduction in energy consumption. The researcher's calculation is based on the premise that static pressure reset is neither widely employed nor available. Based on data from DOE, the researcher estimated the proposed control strategies, if implemented in all applicable buildings, would reduce energy costs by $928 million/year nationwide and $171million/year in California. Primary beneficiaries would be the owners and/or operators of large air-handling systems incorporating variable air valve technology. Other ratepayers would benefit from the decreased load on the grid during peak demand periods.

Recommendations

The researcher is encouraged to survey manufacturers of controls for VAV systems to determine what is commercially available. Energy savings calculations should be based on the best available technology rather than the most commonly deployed. Alternately the researcher could find his concept provides large energy savings at costs significantly lower than the best technology available today. If that market study confirms a large energy savings potential, then a field test is recommended to quantify and validate the energy efficiency benefits in a large building. The tests should be conducted during the summer so cooling energy benefits and fan energy benefits can be quantified. A widely accepted test procedure should be followed to establish credible data. Methods for commissioning SAV to produce the largest energy benefits could also be investigated.

Stages and Gates Methodology

The California Energy Commission utilizes a stages and gates methodology for assessing a project's level of development and for making project management decisions. For research and development projects to be successful they need to address several key activities in a coordinated fashion as they progress through the various stages of development. The activities of the stages and gates process are typically tailored to fit a specific industry and in the case of PIER the activities were tailored to be appropriate for a publicly funded energy research and development program. In total there are seven types of activities that are tracked across eight stages of development as represented in the matrix below.

Development Stage/Activity Matrix

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Activity 1								
Activity 2								
Activity 3								
Activity 4								
Activity 5								
Activity 6								
Activity 7								

A description the PIER Stages and Gates approach may be found under "Active Award Document Resources" at: http://www.energy.ca.gov/research/innovations and are summarized here.

As the matrix implies, as a project progresses through the stages of development, the work activities associated with each stage needs to be advanced in a coordinated fashion. The EISG program primarily targets projects that seek to complete Stage 3 activities with the highest priority given to establishing technical feasibility. Shaded cells in the matrix above require no activity, assuming prior stage activity has been completed. The development stages and development activities are identified below.

Development Stages:	Development Activities:
Stage 1: Idea Generation & Work Statement Development Stage 2: Technical and Market Analysis Stage 3: Research & Bench Scale Testing Stage 4: Technology Development and Field Experiments Stage 5: Product Development and Field Testing Stage 6: Demonstration and Full-Scale Testing Stage 7: Market Transformation Stage 8: Commercialization	Activity 1: Marketing / Connection to Market Activity 2: Engineering / Technical Activity 3: Legal / Contractual Activity 4: Environmental, Safety, and Other Risk Assessments / Quality Plans Activity 5: Strategic Planning / PIER Fit - Critical Path Analysis Activity 6: Production Readiness / Commercialization Activity 7: Public Benefits / Cost

Independent Assessment

For the research under evaluation, the Program Administrator assessed the level of development for each activity tracked by the Stages and Gates methodology. This assessment is summarized in the Development Assessment Matrix below. Shaded bars are used to represent the assessed level of development for each activity as related to the development stages. Our assessment is based entirely on the information provided in the course of this project, and the final report. Hence it is only accurate to the extent that all current and past work related to the development activities are reported.

Development Assessment Matrix

Stages / Activity	1 Idea Generation	2 Technical & Market Analysis	3 Research	4 Technology Develop-ment	5 Product Develop-ment	6 Demon-stration	7 Market Transfor-mation	8 Commer-cialization
Marketing								
Engineering / Technical								
Legal/ Contractual								
Risk Assess/ Quality Plans								
Strategic								
Production. Readiness/								
Public Benefits/ Cost								

The Program Administrator's assessment was based on the following supporting details:

Marketing/Connection to the Market

The targeted market segment is buildings with VAV air-handling systems. While this is a significant market niche in California, the researcher used only U.S. Department of Energy (DOE) numbers to evaluate the potential market size. The researcher must conduct in-depth market research to determine the availability of products with similar features, the market acceptance factors, and the possible barriers to acceptance.

Engineering/Technical

The researcher proved the feasibility of the project concept. The next step is to determine the efficacy of the computer-based predictions in the field. This project showed the technology can reduce fan energy consumption by up to 26.3% and cooling energy by up to 17.4%. The researcher is working toward a pilot field test with an identified customer. The test is planned for a building in Sacramento during the summer when fan energy and cooling energy benefits can be fully evaluated and quantified.

Legal/Contractual

The researcher commissioned a patent search. The search results indicated the SAV code is patentable. An application has been filed for a United States patent.

Environmental, Safety, Risk Assessments/ Quality Plans

Quality Plans include Reliability Analysis, Failure Mode Analysis, Manufacturability, Cost and Maintainability Analyses, Hazard Analysis, Coordinated Test Plan, and Product Safety and Environmental. There are no anticipated environmental risks during the proposed pilot test. The pilot will be conducted in a building where failure will not result in a critical problem. Once the pilot study is complete, the researcher or commercial partner must prepare the necessary quality plans for the product.

Strategic

This product has no known critical dependencies on other projects under development by PIER or elsewhere

Production Readiness/Commercialization

The researcher identified two types of candidates for commercialization partners. The first type includes large organizations that could benefit from energy savings. The second is manufacturers who could embed the project-developed technology into their products and sell it as a value-added feature. The researcher identified specific parties in each group, but has not announced any cooperative venture to take this development to the market. To maximize the benefit to California ratepayers, the PA recommends the second group as commercialization partners.

Public Benefits

Public benefits derived from PIER research and development are assessed within the following context:

- Reduced environmental impacts of the California electricity supply or transmission or distribution system
- Increased public safety of the California electricity system
- Increased reliability of the California electricity system
- Increased affordability of electricity in California

The primary benefit to the ratepayer from this research is increased affordability of electricity in California. The benefits would primarily flow to occupant/owners of large buildings that use VAV systems.

According to DOE in 1998, VAV systems serve 13.5 billion square feet of space in the U.S. The California market is approximately one-seventh of the U.S. market. The average number of annual operating hours is 4150. This technology may be able to reduce average power by 0.23 watts per square foot. Nationwide, the average cost of electricity in 2000 was $0.072/kWh. In California it was $0.093/kWh. Based on these figures, the technology, if fully deployed, could save $928 million/year nationwide and $171 million/year in California. The savings could be achieved either by reprogramming existing control systems or by installing new stand-alone programmable control systems. These savings calculations assume that large building operators in California do not employ similar technology already.

Program Administrator Assessment

After taking into consideration: (a) research findings in the grant project, (b) overall development status as determined by stages and gates and (c) relevance of the technology to California and the PIER program, the Program Administrator has determined that the proposed technology should be considered for follow on funding within the PIER program. Receiving follow on funding ultimately depends upon: (a) availability of funds, (b) submission of a proposal in response to an invitation or solicitation and (c) successful evaluation of the proposal.

Appendix A: Final Report (under separate cover)

Appendix B: Awardee Rebuttal to Independent Assessment (none submitted)