CALIFORNIA
ENERGY
COMMISSION

ENERGY INNOVATIONS SMALL GRANT PROGRAM
Building End Use Energy Efficiency

Ventilation Measurement and Control

FEASIBILITY ANALYSIS

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Prepared By:
Hal Clark
Grant Program Administrator

Prepared For:
California Energy Commission
Energy Innovations Small Grant Program

Researcher:
Clifford Federspiel

Philip Misemer
Grant Program Manager

Terry Surles
Deputy Director
Technology Systems Division

Steve Larson
Executive Director

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

Cost-effective and accurately-measured airflow rates, especially at outdoor air intake locations, is a recognized difficulty with ventilation controls. Typically, outdoor air intakes have no ductwork either upstream or downstream. The most common configuration is a set of dampers mounted in a large opening of a mixing plenum. This configuration can cause large non-uniformities in the velocity distribution. Existing airflow measurement technology is not effective with non-uniform airflow. Since outdoor airflow rates cannot be measured accurately or cost-effectively, ventilation systems are routinely operated without knowing ventilation rates, and other key airflow variables. The result is wasted energy or compromised air quality, or in some cases both.

The purpose of this project was to develop an energy-efficient, cost-effective, accurate, and maintenance-free flow measurement and control technique for ventilation systems. This program has a specific technical goal: airflow measurement accuracy of ±10% of actual or ±5% of full scale, whichever is greater. This criterion is derived from an addenda to ASHRAE Standard 62.1. Broader goals included a controller design that requires less maintenance than current technology at lower first cost.

The researchers proposed to use torque characteristics of control dampers to measure flow. They theorized that if the position and aerodynamic torque were measured, then it should be possible to deduce the flow rate. The hypothesis is that torque-based flow measurement (TBFM) should be accurate at low velocities if the damper is constructed to induce aerodynamic torque when throttling. The TBFM should also be insensitive to non-uniform flow because the entire surface of the damper blades is used as the sensing means.

Objectives

The goal of this project was to determine the feasibility of the TBFM technique as a cost effective ventilation airflow measurement device with an accuracy of ±10% of actual flow or ±5% of full scale, whichever is greater. The following project objectives were established.

1. Develop a correlation function (mathematical model) that accurately describes the relationship between the position, aerodynamic torque, and air velocity of control dampers.
2. Perform a computer-based sensitivity analysis using the correlation function. Determine whether or not the goal of ±10% of actual flow or ±5% of full scale can be achieved given typical torque and position measurement errors.
3. Design and construct a prototype flow measurement device and test stand based on the results of the modeling and sensitivity analysis.
4. Demonstrate an accuracy in airflow measurement of ±10% of actual flow or ±5% of full scale, whichever is greater.
5. Achieve a cost effective design that requires less maintenance than current technology.
6. Assess the accuracy of TBFM in the presence of flow disturbances.

Outcomes

1. Existing theories on the torque characteristics of butterfly valves were combined with published experimental results to formulate a model that predicts the torque characteristics of multi-blade control dampers. The development of the correlation function demonstrated that the relationship between position, torque, and airflow has a simplified form that makes calibration of the correlation function relatively simple. The correlation function predicts that the velocity is the product of a function of the position and a function of the torque.
2. The sensitivity analysis predicted that the technical goal could not be achieved when the damper was nearly open, but it should be easily achievable for the most important operating conditions. The most important operating condition is when the damper is about 10% - 20% open because that is the range of conditions for controlling minimum ventilation. Under that condition, the sensitivity analysis predicted that the technical goal could be achieved, and that the torque-based flow measurement should significantly outperform a pitot tube or similar flow measurement technology.
3. A test stand was constructed that used five high-accuracy pitot tubes in a constricted duct as a measurement standard. A prototype flow measurement device with an offset-blade design was constructed. The offset-blade design uses standoffs to make the damper blades rotate about an axis that is displaced by two inches. This design induces torque even when the damper is fully open.
4. The laboratory-scale tests confirmed the results of the sensitivity analysis. The tests showed that when nearly open, the torque was very low even with the offset-blade damper.
5. To provide a more cost effective device, the flow measurement device was designed without pitot tubes. This eliminated the recurring maintenance task of verifying that the air passages are clear of dust.
6. Tests were conducted to assess the ability of the TBFM technology to operate accurately in the presence of a flow disturbance. To simulate a disturbance, a commercially available louver was mounted to the frame of the TBFM prototype and to the frame of the commercially available flow station. These tests illustrated that the TBFM technology is insensitive to the flow disturbance when the damper is less than 70% open. When the TBFM damper is more than 70% open, the flow disturbance has a significant negative impact on the accuracy.

Conclusions

1. The TBFM technology can outperform conventional flow measurement technology under a wide range of operating conditions. The TBFM technology is more accurate than a pitot tube when the damper is less than 80% open. This project found that the TBFM technology is insensitive to the presence of a significant upstream flow disturbance when the damper is less than 70% open. The accuracy of a commercially available airflow station was strongly affected by the presence of the same upstream disturbance.
2. The fact that the TBFM technology cannot provide accurate measurement of velocity when the damper is nearly open is a problem for a small percentage of applications.

3. One significant obstacle to commercialization of the TBFM technology is that it cannot be used in the retrofit market because of the expense of retrofitting dampers. Some dampers are embedded in HVAC units, and can only be replaced by dismantling the HVAC equipment. The researcher contacted a manager from a leading energy service company (ESCO) to get an opinion on the commercial viability of the TBFM. The manager told the researcher that his company would have no interest in the TBFM technology because of the cost of retrofitting dampers.
4. A significant obstacle to commercialization of the TBFM technology in the new construction market is that it requires substantial change in the way damper devices are designed and manufactured. In order to get the full benefit, the damper design would have to be changed to an offset-blade design with low-friction bearings, which would involve some re-tooling for an equipment manufacturer.

Benefits to California

If the TBFM technology were widely used, California would benefit from reduced energy consumption, reduced peak demand, and improved productivity and health. Energy consumption and peak demand would be reduced because the technology would prevent over-ventilation and enable demand-controlled ventilation. Fisk and Rosenfeld (1997) estimate that improvements in indoor air quality could save $12-43 billion nationally in lost productivity due to health problems in buildings. The developed technology, if implemented could recover some of that lost productivity by providing better ventilation at a lower energy cost. This would be one step toward improved indoor air quality.

Recommendations

Follow-on development should focus on the design and cost of the damper system so that this technology could be applied to the new construction market. In addition future work should attempt to improve the measurement accuracy when the dampers are nearly open.

The developers of this technology should work closely with potential manufacturers. Before pursuing follow-on technical effort, the developers should achieve positive indications of interest and support for this technology from members of the HVAC industry. Minimum levels of support would include the provision of acceptable end item cost targets and desired technical specifications.

The awardee has presented a number of technical approaches to resolve the implementation difficulties. These could be pursued once the interest of the industry and the market requirement specifications are established.

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.

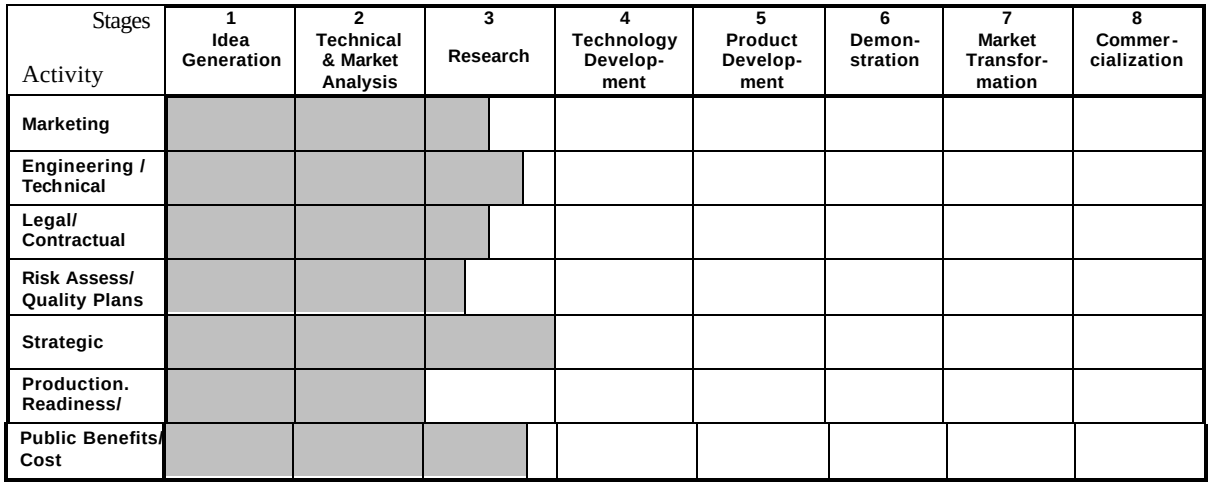
As the matrix implies, as a project progresses through the stages of development, the work activities associated with each stage needs to be advanced in a coordinated fashion. The EISG program primarily targets projects that seek to complete Stage 3 activities with the highest priority given to establishing 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	Activity 1:	Marketing / Connection to Market
Stage 2:	Technical and Market Analysis	Activity 2:	Engineering / Technical
Stage 3:	Research & Bench Scale Testing	Activity 3:	Legal / Contractual
Stage 4:	Technology Development and Field Experiments	Activity 4:	Environmental, Safety, and Other Risk Assessments / Quality Plans
Stage 5:	Product Development and Field Testing	Activity 5:	Strategic Planning / PIER Fit - Critical Path Analysis
Stage 6:	Demonstration and Full-Scale Testing	Activity 6:	Production Readiness / Commercialization
Stage 7:	Market Transformation	Activity 7:	Public Benefits / Cost
Stage 8:	Commercialization		

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



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

Marketing/Connection to the Market

The awardee suggested that potential markets for the technology are in equipment for new construction and equipment for the retrofit of HVAC systems in existing buildings. Initial probes were made into the retrofit market, the results of which were quite discouraging based on economics. Numerous implementation challenges have to be addressed before the technology is ready for the new construction market.

Engineering/Technical

This study proved the feasibility of determining airflow volumes in a ventilation duct by measuring the torque exerted on the control dampers. The researchers used an inherent low maintenance design. The Torque Based Flow Measurement technology was proven to be technically feasibly for HVAC systems using low friction bearings and offset-blade control dampers. The TBFM method was shown to achieve accurate of ±10% of actual flow or ±5% of full scale when the damper is less than 80% open. The test plan for field experiments has not been completed.

Legal/Contractual

No path to commercialization has been identified. The Program Administration is not aware of any patent applications or issues.

Environmental, Safety, Risk Assessments/ Quality Plans

Documented Quality Plans as appropriate are required prior to initiation of Stage 4 development activity. The final design may include cost-effective, low-friction bearings and off-set dampers. Incorporation of these components presents major design and manufacturability issues. Because of these issues the awardee has not completed the manufacturability planning. In addition, the awardee must complete the following items: Reliability Analysis, Failure Mode Analysis, Manufacturability, Cost and Maintainability Analyses, Hazard Analysis, Coordinated Test Plan, and Product Safety.

Strategic

This project has no known dependencies on other projects under development by PIER or elsewhere.

Production Readiness/Commercialization

The product is not ready for commercialization, and no manufacturer has been identified.

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 public benefit offered by the proposed technology is to increase the affordability of electricity in California. This will be accomplished by reducing the power consumed by the building HVAC systems. A lifecycle cost analysis of the system under study should be done once a more commercially acceptable design has been developed. Preliminary analysis suggests that energy savings could be substantial if this technology were to be adopted in a large number of commercial buildings statewide. Adoption will depend on the specific product design and the willingness of the industry to promote that design.

Appendix A: Final Report (under separate cover)

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