Final Scientific/Technical Report for Award No. DE-FC36-02GO12096

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1. Identify the DOE award number; name of recipient; project title; name of project director/principal investigator; and consortium/teaming members.

Doe Award No. DE-FC36-02GO12096

Recipient: Arizona State University

Project Title: Industrial Assessment Center Program

Principal Investigator: Patrick Phelan

Consortium/Teaming Members: none

2. Display prominently on the cover of the report any authorized distribution limitation notices, such as patentable material or protected data. Reports delivered without such notices may be deemed to have been furnished with unlimited rights, and the Government assumes no liability for the disclosure, use or reproduction of such reports.

Not applicable.

3. Provide an executive summary, which includes a discussion of 1) how the research adds to the understanding of the area investigated; 2) the technical effectiveness and economic feasibility of the methods or techniques investigated or demonstrated; or 3) how the project is otherwise of benefit to the public. The discussion should be a minimum of one paragraph and written in terms understandable by an educated layman.

This project consisted primarily of conducting energy efficiency, productivity improvement, and waste reduction assessments of small- and medium-sized industrial facilities. These assessments were carried out by groups of engineering students, mostly from Mechanical & Aerospace Engineering and Industrial Engineering, led by faculty members at Arizona State University. The assessed

industries were generally energy-intensive manufacturers located throughout Arizona, as well as some facilities in the Las Vegas, Nevada area. During the first four years of the project period, on average our recommended annual savings per plant were $224,717, of which $71,135 were energy savings. Of these recommended savings, on average $49,659 were implemented, of which $31,679 were implemented annual energy savings. These implemented savings greatly exceeded our budgeted cost to DOE, which was approximately $8,000/assessment. In addition, a number of undergraduate and graduate students were employed and trained at the IAC, and have gone on to graduate studies and engineering careers.

4. Provide a comparison of the actual accomplishments with the goals and objectives of the project.

The project was generally divided into six tasks, as detailed in our quarterly reports submitted to DOE. The following describes our accomplishments in each of these tasks, relative to the objectives of the project.

TASK 1: Conduct Industrial Assessments, to include a variety of plant types and sizes and well as coverage of the geographic area defined in the Annual Workplans.

A total of approximately 110 assessments were conducted during the five-year project. These assessments were carried out at small- and medium-sized industrial facilities throughout the state of Arizona, as well as in the Las Vegas, Nevada area. These manufacturing plants were generally in energy intensive industrial sectors, and included industries in the chemical, wood products, metal-working, mining, and other sectors.

TASK 2: Promote and increase the adoption of assessment recommendations and employ innovative methods to assist in accomplishing these goals.

We instituted a follow-up oral presentation to our clients, after they had received our written report, for the purpose of increasing implementation rates. This enabled them to ask detailed questions, and it also succeeded in bringing the report to the attention of higher management. We also collaborated with the Arizona Industries of the Future Inc. (AZIOF), a nonprofit organization formed to increase the adoption of energy efficiency measures in Arizona manufacturing plants. By working with AZIOF, our client industries were able to avail of additional expertise and funding opportunities to implement our recommendations. In addition, we conducted 12-month follow-up contacts with some of our clients in order to ascertain the long-term implementation status of our recommendations.

TASK 3: Promote the IAC Program and enhance recruitment efforts for new clients and expanded geographic coverage.

During the course of this project we expanded our area coverage to the Las Vegas, Nevada, region. Previously, we had confined ourselves to industries throughout the state of Arizona. This opened up numerous potential clients for us, as the Las Vegas area had only been sporadically served in the past by any of the IAC's (note that previously there was an IAC in Reno, Nevada). To expand our client base in Arizona, we partnered with SRP, a utility company serving the Phoenix metropolitan area. They identified a number of clients for us, and one of their representatives attended the assessments with us. They also reviewed our reports, and gave us some valuable technical feedback. Finally, the IAC Director made numerous presentations describing the IAC program, generally in the Phoenix metropolitan area.

TASK 4: Provide educational opportunities, training, and other related activities for IAC students.

The students, as well as the faculty, attended a number of DOE Best Practices training sessions. We made it a priority to attend these sessions whenever they were held in the Phoenix area. The training topics included Pumping Systems Assessment Training, Compressed Air Systems Training (1st and 2nd levels), and Steam Systems Assessment Training. Note that the IAC Director (Phelan) is a Qualified Specialist in the DOE *AirMaster* Best Practices software on compressed air systems, and the IAC Manager (Pacheco) is a Qualified Specialist in the *PHAST* (Process Heating Assessment and Survey Tool) DOE Best Practices software. In addition, two courses co-taught by the IAC Director have relevance to the IAC mission: MAE 446/598 Thermal Systems Design/Energy Systems Engineering and MAE/CEE 498/598 Sustainable Urban Energy Engineering. A number of the IAC students, at both the undergraduate and graduate levels, took at least one of these classes.

TASK 5: Coordinate and integrate Center activities with other Center and IAC Program activities, DOE's Industrial Technologies programs and other EERE programs.

As mentioned above, we teamed with Arizona Industries of the Future Inc., a nonprofit group dedicated to improving energy efficiency in Arizona manufacturers. Their target industries are forest products, chemicals, metalcasting, and mining, which were identified as being particularly relevant to Arizona. We also participated in the DOE Save Energy Now (SEN) initiative. One of our major SEN activities was the organization of a workshop entitled the *Industrial Energy Efficiency and Productivity Workshop*, which was held on June 30, 2006, on the ASU campus. Approximately 40 people attended this free one-day workshop, including representatives from the utility companies, manufacturers, AZIOF, and government.

TASK 6: Other tasks or special projects, as needed, and as determined by

DOE to be advantageous to the program and in furtherance of IAC Program goals.

Several of the graduate students supported by the IAC conducted their thesis research on energy-related topics, including:

Lionel Metchop, 2007, "1-D Analysis of Desorption Phenomenon & Performance Analysis of a Desiccant Air Conditioning System," Arizona State University, Department of Mechanical & Aerospace Engineering.

Ahmed Alghandoor, 2005, "A Multi-Level Energy Modeling of U.S. Manufacturing: Tools, Analyses and Applications," Department of Mechanical & Aerospace Engineering.

Anastasios Frantzis, 2005, "Viability of Solar-Powered Adsorption Cooling in Phoenix, Arizona," Arizona State University, Department of Mechanical & Aerospace Engineering.

Carlos Ernestos Flores Padilla, 2002, "Analysis of Industrial Electricity Consumption for the U.S.A. and for the Mexican Border States' Maquiladoras," Arizona State University, Department of Industrial Engineering (co-chaired with Professor J. Mou).

These theses led to a number of publications, as detailed below in section 6.a.

5. Summarize project activities for the entire period of funding, including original hypotheses, approaches used, problems encountered and departure from planned methodology, and an assessment of their impact on the project results. Include, if applicable, facts, figures, analyses, and assumptions used during the life of the project to support the conclusions.

As described above, our primary activity involved conducting energy efficiency, productivity improvement, and waste reduction assessments of small- and medium-sized manufacturing firms. These assessments were carried out by teams of undergraduate and graduate engineering students, led by faculty members from Arizona State University. During the first four years of the project period, on average our recommended annual savings per plant were $224,717, of which $71,135 were energy savings. Of these recommended savings, on average $49,659 were implemented, of which $31,679 were implemented annual energy savings. These implemented savings greatly exceeded our budgeted cost to DOE, which was approximately $8,000/assessment.

6. Identify products developed under the award and technology transfer activities, such as:

a. Publications (list journal name, volume, issue), conference papers, or other public releases of results. If not provided previously, attach or send copies of any public releases to the DOE Project Officer identified in Block 11 of the Notice of Financial Assistance Award;

A. Alghandoor, P.E. Phelan, R. Villalobos, & B.E. Phelan, "U.S. Manufacturing Aggregate Energy Intensity Decomposition: the Application of Multivariate Regression Analysis," to appear in the *International Journal of Energy Research* (2007).

Y. Gupta, L. Metchop, T. Frantzis, & P.E. Phelan, "Quantitative and Qualitative Comparison of Low-Temperature, Heat-Activated Cooling Systems," Paper No. IMECE2006-14489, *ASME International Mechanical Engineering Congress & Exposition*, Chicago, Illinois, November (2006).

A. Alghandoor, R. Villalobos, & P.E. Phelan, "Projected Impact of Industrial Assessment Center Program Recommendations on US Manufacturing Aggregate Energy Consumption," *ACEEE Summer Study on Energy Efficiency in Industry*, West Point, New York (2005).

A. Ranes, P.E. Phelan, R. Pacheco, A. Frantzis, & L. Metchop, "Optimization of the Adsorber in an Adsorption Solar-Powered Cooling System," HTD Vol. 376, pp. 555 – 560, *ASME International Mechanical Engineering Congress & Exposition*, Orlando, Florida, November (2005).

C.E. Flores, P.E. Phelan, J.-I. Mou, & H. Bryan, "Forecasting the Electricity Consumption of the Mexican Border States Maquiladoras," *International Journal of Energy Research* **28**, pp. 641 – 660 (2004).

b. Web site or other Internet sites that reflect the results of this project;

http://www.eas.asu.edu/~iac/

c. Networks or collaborations fostered;

Not applicable.

d. Technologies/Techniques;

Not applicable.

e. Inventions/Patent Applications, licensing agreements; and

Not applicable.

f. Other products, such as data or databases, physical collections, audio or video, software or netware, models, educational aid or curricula, instruments or equipment.

Not applicable.

7. For projects involving computer modeling, provide the following information with the final report:

Not applicable.

a. Model description, key assumptions, version, source and intended use;

b. Performance criteria for the model related to the intended use;

c. Test results to demonstrate the model performance criteria were met (e.g., code verification/validation, sensitivity analyses, history matching with lab or field data, as appropriate);

d. Theory behind the model, expressed in non-mathematical terms;

e. Mathematics to be used, including formulas and calculation methods;

f. Whether or not the theory and mathematical algorithms were peer reviewed, and, if so, include a summary of theoretical strengths and weaknesses;

g. Hardware requirements; and

h. Documentation (e.g., users guide, model code).