CALIFORNIA
ENERGY
COMMISSION

ENERGY INNOVATIONS SMALL GRANT PROGRAM
Industrial, Agriculture and Water End Use Energy Efficiency

Modeling Greenhouse Temperature for Energy Efficient Production

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

California is the leading state in the US floriculture industry, with wholesale value over 700 million dollars per year. With more than 115 million ft^2 area under greenhouse cover, California has the largest area of protected crop production facilities in the nation [National Agricultural Statistics Service, USDA. 1998].

Greenhouse agriculture requires considerable energy for cooling in the summer and heating in the winter. While computers have been incorporated into most greenhouses, no significant environmental control software exists. Each crop that might be grown in a greenhouse has different temperature requirements. Proper use of an accurate crop model embedded within greenhouse environmental control software will enable achievement of the optimum energy efficiency for the greenhouse crop combination.

Objectives

The goal of this project was to determine the feasibility of embedding a sufficiently detailed and accurate model within the greenhouse environment control software to enable optimum energy efficiency for the greenhouse crop combination. The researchers established the following project objectives:

1. Create and integrate greenhouse climate models with crop models.
2. Validate the integrated model.
3. Develop general-purpose energy management software tools that growers could use to assist in greenhouse energy management.

Outcomes

1. A full-sized, large-scale simulation model was developed that simulates the greenhouse climate in relation to the control objectives, the outside climate, the crop growing in the greenhouse, and the various management practices. This model was then implemented on a computer simulation system. The size and complexity of the model was such that the high-end computer workstation it was hosted on would only simulate short time frames. The researcher could not fully exercise the computer model due the excessive memory demands of the program, even when running on a high capacity workstation. Evaluation of this implementation was not completed.

2. Partial validation of the model was performed. The simulation model behavior was satisfactory in most areas except for its inability to accurately predict the air temperature and humidity inside the greenhouse in the winter.

3. A software tool was developed that allows growers to calculate temperature set points in relation to rose-crop development for cut-flower roses. Presentations and training sessions at national grower meetings (March 30 2001; Denver CO) have been conducted to assist growers in using the software. The software tool was made available to the public through publication on the web to allow easy access by the greenhouse operators. The Principal Investigator has indicated that this software tool has been downloaded for use by rose growers in California.

Conclusions

1. Considerable insight was gained into the many variables that impact greenhouse thermal properties. The complexity of the modeling and simulation was greater than originally anticipated. The size and complexity of the model and its inability to run effectively, even on a high end computer workstation, makes the model impractical for real time greenhouse control in its current configuration. The accuracy of the integrated model was impacted by errors contained in existing models/data.

2. Further work is needed to validate and optimize the model for accuracy before it can be used for comprehensive energy simulations. Feasibility of integrated greenhouse climate models with crop models has yet to be established.

3. Due to the complexity of the various crop models it may not be possible to create general-purpose energy management software tools that could be applied to a variety of crops. Instead, it appears that the software tools will need to be tailored to specific crops, which will require considerable research and development.

Benefits to California

Greenhouse growers will benefit directly from the tool that was developed as part of objective 3 of this project. The tool is particularly targeted to cut-flower rose growers, to assist them in selecting temperature set-points that will allow them to schedule crop maturation to coincide with holiday sales. This tool allows growers to maximize profitability by optimizing productivity through precise energy management. Energy use by cut flower growers may be reduced by use of this energy control tool.

Recommendations

The simulation system, as an analytical tool, will require considerably more work before it will result in widespread practical applications for greenhouse energy management. Additional work is needed that would allow the model to run effectively on a standard computer. The model needs additional development to make it more accurate in the areas of noted deficiency. Specific crop models need to be developed that can be integrated into the greenhouse climate model.

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 typ es 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:	
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

Development Activities:	
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 presentations and training sessions conducted in Denver in late March, 2001, and its ready availability on the Internet will help to bring the rose grower software tool into broader use.

Engineering/Technical

Though progress was made, complete success was not achieved. It appears that the technology is feasible but it is by no means certain based on results achieved. Significant advances were made in the mathematical description of the greenhouse model and of crop models. However, the implementation of these mathematical models as a computer program simulating the greenhouse and crop environment was not sufficiently robust to fully support the intended analysis.

The Joseph Hill Foundation has committed funds to further work on the rose grower software.

Legal/Contractual

There are no known legal or contractual issues outstanding for this project.

Environmental, Safety, Risk Assessments/ Quality Plans

This is the stage of development to discover whether or not there are pertinent unknown issues which may arise in later stages. There is no indication that Quality Planning has been addressed, hence no issues were identified. Drafting of the Quality Plan is needed prior to initiation of Stage 4 development activity. Quality Planning addresses the following: Reliability Analysis, Failure Mode Analysis, Manufacturability, Cost and Maintainability Analyses, Hazard Analysis, Coordinated Test Plan, Product Safety and Environmental.

Strategic

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

Production Readiness/Commercialization

There was no mention of a commercializing partner, none has been selected, hence no commitment obtained.

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 California Greenhouse operator ratepayer from this research was increased affordability of electricity. This was accomplished by enabling more efficient utilization of the power resource by the greenhouse operator ratepayer. Specifically targeted tools, such as the rose grower's tool, allows the ratepayer to precisely apply electrical energy to most efficiently govern the rose's growth environment and maturation timing.

Technology Transfer

The principal investigator for this project has performed the following Technical transfer activities:

- Public presentations and training sessions were conducted in Denver in March 2001 to assist growers in the use of the software tools.
- Obtained follow-on funding from Joseph Hill Foundation to extend the model to incorporate additional cut rose varieties.
- Published the completed rose-crop software on the Internet to facilitate access by the greenhouse operators. An estimated 200 growers have evaluated the tool.

Appendix A: Final Report (under separate cover)

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