PROGRAMS IN RENEWABLE ENERGY

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Solar Buildings Program Summary

Volume II: Research Summaries

Fiscal Year 1989

U.S. Department of Energy

Prepared by the
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Contents

Introduction

The U.S. Department of Energy (DOE) Solar Buildings Technology Program was initiated in 1975 to provide focus, direction, and funding for the development of solar technologies for buildings as an energy option for the United States.

The program's progress has been impressive: Active solar water and passive space heating systems are now widely available and have operated reliably throughout the United States. The efficiency of flat-plate collectors has increased 35%, and the incidence of system problems has markedly decreased. Whereas design tools for passive solar homes were once unavailable, DOE-sponsored research has led to the development of widely accepted guidelines, suitable for designing passive solar homes for any locale. Under DOE sponsorship, researchers have developed new window glazing materials such as low-emissivity films that significantly reduce heat loss over standard windows. Proven strategies have also been developed for using daylight to provide 50% of the lighting needs for small nonresidential buildings, substantially reducing electricity and cooling requirements.

The *Solar Buildings Program Summary* is a two-volume reference set describing the technological advances and future research and development (R&D) directions of the Solar Buildings Technology Program for FY 1989 (October 1, 1988, through September 30, 1989).

Volume I: Overview contains capsule descriptions of the various activities undertaken in the year, a brief history of the program, and the significant accomplishments realized. It also describes the management framework for the program and presents the FY 1989 budget. This document, *Volume II: Research Summaries*, consists mainly of detailed descriptions of the various R&D activities performed by the national laboratories and their subcontractors from industry, academia, and nonprofit research institutions.

This summary is divided into three main sections. Following the introduction, the first section includes the individual contract descriptions, grouped by directing organization and project area/task. A list of current publications is presented in the second section. The publications are listed alphabetically. The third section of this document contains a list of subcontractors, including the page numbers of the applicable contract descriptions.

For additional information on the Solar Buildings Technology Program, see the *Solar Buildings Technology Program, Five Year Research Plan 1989-1993* (draft). This document gives an overview of the program's history, framework, technical management plans, and goals. It can be obtained from the Department of Energy, Solar Buildings Technology Division, Washington, DC 20585.

Organizational Relationships

The Solar Buildings Technology Program is conducted by DOE and is organizationally assigned to the Assistant Secretary for Conservation and Renewable Energy. Day-to-day research activities are conducted by the Solar Energy Research Institute (SERI) in Golden, Colorado, and the Lawrence Berkeley Laboratory (LBL) in Berkeley, California. The Department of Energy San Francisco Operations Office is responsible for managing major contracts with industry and universities.

FY 1989 Contract Descriptions

Lawrence Berkeley Laboratory

Advanced Solar Cooling Technology

Project/Area/Task:
Solar Buildings Technology Program/Solar Cooling/Advanced Solar Cooling Technology

Directing Organization:
Applied Science Division
Lawrence Berkeley Laboratory

Project Manager: Michael Wahlig

Telephone: (415) 486-5787

Contractor: In-House

Principal Investigator: Michael Wahlig

Telephone: (415) 486-5787

Contract Number: N/A

Contract Period: 07/74 – 09/89 (continuing)

Contract Funding (Source):
FY 1985: $515,000 (DOE)
FY 1986: $240,000 (DOE)
FY 1987: $170,000 (DOE)
FY 1988: $120,000 (DOE)
FY 1989: $135,000 (DOE)

Objectives:

To investigate solar cooling and heating opportunities that take advantage of advanced, high-efficiency absorption chiller and heat pump technology currently under development elsewhere and to study the practicality of driving this absorption equipment with advanced, evacuated-tube solar collectors.

Approach/Background:

Although absorption chillers are no longer being developed as part of the Solar Buildings Program, this technology is continuing to be developed for gas-driven applications, supported by the Office of Buildings and Community Systems, the Gas Research Institute, and others. The solar cooling program can potentially benefit by driving these new chillers with advanced, evacuated-tube solar collectors. The project is evaluating the practicality of such solar cooling systems by first modeling the chillers and then analytically investigating the coupled performance of the chillers and collectors. A joint U.S./Israel effort is capitalizing on prior work in this area by the Technion group.

Status/Accomplishments:

LBL initiated an analytic investigation of the coupling of high-temperature, evacuated-tube solar collectors to advanced absorption chillers/heat pumps. A recently developed chiller simulation model was used to characterize the cooling-mode and heating-mode performance of an absorption heat pump, based on the generator-absorber heat exchange cycle, for a range of operating conditions. Parameterizations of advanced, evacuated-tube solar collectors are being used to determine reasonable strategies for solar-driven cooling system operation. Interactions with the Technion group continued on improving the convergence properties of absorption chiller/heat pump models.

Major Project Reports:

Rasson, J., and M. Wahlig, "Progress Report on Development of Improved Chiller Simulation Models as Part of the U.S./Israel Joint Project on Solar Cooling."

Rasson, J., M. Wahlig, and K. Dao, *Regenerative Absorption Heat Pump.*

Summary Date: September 1989

Nickel-Based Electrochromic (EC) Optical-Switching Films

Project/Area/Task:
Solar Buildings Technology Program/
Daylighting/Nickel-Based EC
Optical-Switching Films

Directing Organization:
Applied Science Division
Lawrence Berkeley Laboratory

Project Manager: Stephen Selkowitz

Telephone: (415) 486-5064

Contractor: In-House

Principal Investigator: Stephen Selkowitz

Telephone: (415) 486-5064

Contract Number: N/A

Contract Number: N/A

Contract Period: 07/84 – 09/89 (continuing)

Contract Funding (Source):
FY 1987: $110,000 (DOE)
FY 1988: $170,000 (DOE)
FY 1989: $285,000 (DOE)

Objective:

To develop optical-switching devices to regulate daylight and solar heat gain for all building glazing applications.

Approach/Background:

LBL is developing electrochromic (EC) nickel oxide-based switching devices fabricated by electrochemical and sputter deposition processes. These multilayer devices contain electronic, ionic, and mixed conductor layers. It is important to develop durable layers that are electrochemically compatible. Research is under way to fabricate and characterize the active nickel EC layer using several different deposition techniques and to develop compatible counterelectrode and ion-conducting layers for both proton-based and lithium-based systems. The immediate goal is to make a laminated device using a solid polymer electrolyte. The goal of future work is to develop all-solid-state devices.

Status/Accomplishments:

EC nickel films were made at LBL by electrochemical deposition processes and reactive sputtering. The electrochemical and optical-switching properties of these films were compared to films fabricated by industry using evaporation and sputtering techniques. Significant differences were observed in resultant film properties, reinforcing previous interest in exploring the relationship between deposition parameters, coating structure, electrochemical properties, and optical properties. Lithiated nickel oxide films were successfully produced with relatively high coloration efficiency, opening the possibility of a lithium-based nickel EC device. Stable manganese oxide films were fabricated for testing as counterelectrodes. The polymer electrolyte used in previous studies was improved; new solid-state and polymeric candidate materials were identified and will be tested.

The performance of various window designs incorporating EC coatings is being studied using building energy analysis tools. Results show that the overall energy performance depends not only on what the coating properties are but also on how the coating is used within the window and how the coating properties are switched over the daily cycle.

Major Project Reports:

Goffer, Z., and C. M. Lampert, *Investigation of Transparent Electrochromic Nickel Oxide Devices for Windows.*

Lampert, C. M., "Advances in Optical Switching Technology for Smart Windows."

Lampert, C. M., *Characterization Parameters and Testing Technology for Electrochromic Films and Devices.*

Lampert, C. M., ed., *Failure and Degradation Modes of Selected Solar Materials.*

Lampert, C. M., and C. G. Granqvist, *Large-Area Chromogentics.*

Wruck, D., S. Ramamurthi, and M. Rubin, "Electrochromic Properties of Sputtered Nickel-Oxide Films in a Nonaqueous Electrolyte."

Wruck, D., S. Ramamurthi, and M. Rubin, "Sputtered Electrochromic V_2O_5 Films."

Summary Date: September 1989

Core Daylighting System Design

Project/Area/Task:
Solar Buildings Technology Program/
Daylighting/Core Daylighting System Design

Directing Organization:
Applied Science Division
Lawrence Berkeley Laboratory

Project Manager: Stephen Selkowitz

Telephone: (415) 486-5064

Contractor: In-House

Principal Investigator: Stephen Selkowitz

Telephone: (415) 486-5064

Contract Number: N/A

Contract Period: 07/84 – 09/89 (continuing)

Contract Funding (Source):
FY 1986: $100,000 (DOE)
FY 1987: $ 70,000 (DOE)
FY 1988: $ 80,000 (DOE)
FY 1989: $ 40,000 (DOE)

Objective:

To develop practical and economic design concepts for daylighting systems that will provide natural illuminance to deep interior building zones.

Approach/Background:

Outdoor illuminance levels under clear sunny skies are typically 100 times greater than indoor illuminance requirements. If just a fraction of the available sunlight impinging on the exterior envelope of the building could be distributed to core building zones, daylight could offset a building's entire electric lighting load during sunny periods, with automatically dimming electric luminaires providing light at other times. This concept is an old one, but it has only been the recent availability of new reflective, refractive, and diffractive optical elements that make such a concept potentially cost effective for lighting buildings. A complete core daylighting system requires subsystems to (1) collect sunlight, (2) transmit light over long distances to required building locations, and (3) distribute light at the point of use. The system must be integrated with an electric lighting system and must provide good lighting quality as well as adequate quantity.

Status/Accomplishments:

In previous studies, each of the key core daylighting subsystems was analyzed. Work continued on the design and development of a prototypical core daylighting system using a simplified mechanical tracker for light collection, a fiber optic link to couple the collector to the light guide system, and a light distribution system within the interior space. The design of a fresnel lens with a dispersion-compensating grating was completed and is the subject of a patent application. A second patent application was filed on a mechanical tracking mechanism that is potentially lower in cost than previous designs when mass produced. Plans to build a core daylighting test facility were deferred because of budget limitations. Discussions were held with Canadian researchers and funding agencies to conduct a joint demonstration and field test of core daylighting systems in the United States and Canada.

Major Project Reports:

Johnson, K., *Chromatic Dispersion Correction in a Fresnel Lens by Means of a Diffraction Grating.*

Summary Date: September 1989

Atria Systems

Project/Area/Task:
Solar Buildings Technology Program/
Daylighting/Atria Systems

Directing Organization:
Applied Science Division
Lawrence Berkeley Laboratory

Project Manager: Ron Kammerud

Telephone: (415) 486-6620

Contractor: In-House

Principal Investigator: Ron Kammerud

Telephone: (415) 486-6620

Contract Number: N/A

Contract Period: 10/83 – 9/89 (continuing)

Contract Funding (Source):
FY 1986: $260,000 (DOE)
FY 1987: $180,000 (DOE)
FY 1988: $175,000 (DOE)
FY 1989: $200,000 (DOE)

Objectives:

To advance the analytic capabilities for design and evaluation of atria and to further develop methods for evaluating the performance of daylighting systems in commercial buildings.

Approach/Background:

Over several years, the Building Energy Systems Program at LBL has been involved in a series of daylighting and thermal simulation, analysis, evaluation, and design projects. LBL has collaborated and is collaborating with Europeans to accomplish joint research, including both building monitoring and simulation. In FY 1986-1987, the Daylighting Performance Evaluation Method (DPEM) was developed in the United States and tested jointly by the United States and the United Kingdom. Currently, the area of interest in both the United States and Europe is the thermal, daylighting, and comfort analysis of atria in commercial buildings.

Status/Accomplishments:

The United States has been participating with five other countries in the Atrium Working Group of International Energy Agency Task XI. In FY 1989, collaborations were established with the United Kingdom and Norway for performance evaluations of atrium buildings in the two countries. The United States is performing simulations of buildings being monitored by the collaborators. The simulations will (1) provide insight on why atrium buildings perform as they do and what design factors affect their thermal and daylighting performance and (2) allow an estimate of the performance of similar buildings in climates characteristic of the United States. Other participants are monitoring and simulating four or five additional atrium buildings. During FY 1989, detailed design, construction, occupancy, and operating data for the two buildings were assembled and initial simulations carried out.

In addition, the United States is the leader of the Simulation Subtask of Task XI and has provided thermal and daylighting analysis assistance to several of the participating countries. Software was developed for interfacing measured or simulated daylight performance data with thermal analysis codes such as DOE-2 and BLAST. This allows the thermal analysis codes, which have limited capability to analyze daylighting configurations, to account for the full range of energy impacts of daylighting for a broader range of configurations. This software is being used by several of the Task XI participants in performance evaluation of daylit buildings.

Major Project Reports:

Gordon, H. T., and B. Andersson, "U.S. Participation in International Atrium Research."

Summary Date: October 1989

DOE San Francisco Office

Advanced Evacuated Tubular Concentration Research

Project/Area/Task:
Solar Buildings Technology Program/
Solar Heating/Collector Materials and Concepts

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: M. Lopez

Telephone: (415) 273-4264

Contractor:
University of Chicago
The Enrico Fermi Institute
5640 Ellis Avenue
Chicago, IL 60637

Principal Investigators: R. Winston,
J. O'Gallagher

Telephone: (312) 702-7757

Contract Number: DE-FG03-85SF15753

Contract Period: 09/85 – 12/90

Contract Funding (Source):
FY 1985: $69,000 (DOE)
FY 1986: -0- (---)
FY 1987: $50,000 (DOE)
FY 1988: $53,000 (DOE)
FY 1989: $63,000 (DOE)

Objective:

To develop a manufacturable version of an advanced evacuated compound parabolic concentrator (CPC)-type collector that has an annual efficiency of 50% at temperatures as high as 350°F (175°C) and is economically competitive with flat-plate collectors.

Approach/Background:

Several years ago, in a proof-of-concept effort, an experimental panel of CPC tubes achieved the highest operating efficiency at high temperatures ever measured with a nontracking stationary solar collector. Subsequent studies indicate that a mass-producible collector incorporating the same concepts can be developed that will deliver excellent performance across a broad range of temperatures, extending from about 50°C (suitable for domestic hot water and space heating) to well above 200°C (suitable for space cooling, process steam, and other end uses). In the effort to create a prototype of a manufacturable CPC, both small-tube and large-tube designs are being explored. Several international cooperative efforts are being pursued.

Status/Accomplishments:

Preliminary testing and evaluation of both large-tube and small-tube prototype manufacturable collectors has been completed. During FY 1989, an evaluation was initiated on design concepts of the leading-edge nonimaging concentrator technology, including assessment of current applications of CPC technology in Japan, Europe, and Israel.

Major Project Reports:

O'Gallagher, J., *The Integrated CPC: Recent Progress, Present Status, Future Directions.*

O'Gallagher, J., R. Winston, and W. Schertz, "Design and Development of a New Generation of Evacuated Compound Parabolic Concentrators."

O'Gallagher, J., R. Winston, W. Duff, and A. Bellows, "Development of Evacuated Integrated CPC Solar Collectors."

O'Gallagher, J., R. Winston, W. Schertz, and A. Bellows, "Systems and Applications Development for Integrated Evacuated CPC Collectors."

Summary Date: September 1989

Field Test of Standard Design Methodologies for Solar Domestic Water Heating (DWH) Systems

Project/Area/Task:
Solar Buildings Technology Program/
Solar Heating/Generic Systems Development

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: W. Bryan

Telephone: (415) 273-6412

Contractor:
Energy Technology Engineering Center (ETEC)
P.O. Box 1449
Canoga Park, CA 91304

Principal Investigator: O. Hillig

Telephone: (818) 700-5512

Contract Number: DE-AC03-76SF00700
(umbrella contract)

Contract Period: 09/88 – 09/89

Contract Funding (Source):
FY 1988: $40,000 (DOE)
FY 1989: $35,000 (DOE)

Objectives:

To design and install a standard active solar water heating system at a military barracks and to monitor its performance.

Approach/Background:

This project, cofunded by the U.S. Department of Defense (DoD) and DOE, will establish the cost and performance of one of the standard systems described in both the DoD-funded Civil Engineering Research Laboratory (CERL) technical manual *Solar Energy Systems* and the DOE-funded *Active Solar Heating Systems Design Manual.* It will be a closed-loop domestic water heating (DWH) system with freeze protection provided by propylene glycol in the collector array and will be installed in a Bachelor Officer Quarters building at Ft. Huachuca, Ariz.

Status/Accomplishments:

During FY 1989, the site was selected, and the CERL closed-loop solar DWH system design was reviewed using the DOE design manual. A bid package was prepared and released for the purchase and installation of the system. Installation, instrumentation, and monitoring will take place during FY 1990.

Major Project Reports: None.

Summary Date: September 1989

Solar in Federal Buildings Program (SFBP)

Project/Area/Task:
Solar Buildings Technology Program/
Solar Heating/Generic Systems Development

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: W. Bryan

Telephone: (415) 273-6412

Contractor:
Energy Technology Engineering Center (ETEC)
P.O. Box 1449
Canoga Park, CA 91304

Principal Investigator: O. Hillig

Telephone: (818) 700-5512

Contract Number: DE-AC03-76SF00700
(umbrella contract)

Contract Period: 09/88 – 09/89

Contract Funding (Source):
FY 1981-1987: $10,822,000 (DOE)
FY 1988: $ 442,000 (DOE)
FY 1989: $ 35,000 (DOE)

Objective:

To provide technical support to the Solar in Federal Buildings Program (SFBP).

Approach/Background:

The SFBP is a legislated solar program sponsored by DOE, involving some 700 projects for 16 federal agencies. Most of the projects are active solar heating systems. The design, testing, monitoring, and reporting associated with these projects is being done by ETEC and its subcontractors.

Status/Accomplishments:

During FY 1989, two comprehensive manuals were completed—an installation manual and an operations and maintenance manual. These two manuals are the culmination of several years of cooperative effort by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers; the Solar Energy Industries Association; the American Consulting Engineers Council; academia; and DOE contractors. The manuals will be published in FY 1990. Together with the design manual completed in FY 1988, these manuals give solar designers an effective means for using the collective knowledge of government and industry to better select options for improving the quality and energy efficiency of the solar systems they design and build.

Major Project Reports:

The Active Solar Heating Systems Design Manual.

The Active Solar Heating Systems Installation Manual.

The Active Solar Heating Systems Operation and Maintenance Manual.

Summary Date: September 1989

IEA Task VII: Technical Support Services

Project/Area/Task:
Solar Buildings Technology Program/
Solar Heating/Thermal Storage and Transport Materials

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: M. Lopez

Telephone: (415) 273-4264

Contractor:
CBY Associates, Inc.
5039 Cathedral Ave., NW
Washington, DC 20016

Principal Investigator: C. Bankston

Telephone: (202) 363-6693

Contract Number: DE-AC03-87SF16799

Contract Period: 04/87 - 07/89

Contract Funding (Source):
FY 1987: $ 95,000 (DOE)
FY 1988: $100,000 (DOE)
FY 1989: $ 88,000 (DOE)

Objective:

To provide technical support services as the DOE representative to International Energy Agency (IEA) Task VII.

Approach/Background:

The IEA initiated Task VII in 1981 to assess the technical and economic feasibility of central solar heating plants with seasonal storage (CSHPSS). Worldwide interest in the Task VII concept has greatly increased, and the outlook for commercialization appears to be very favorable. CSHPSS technology is based on large-scale systems for multiple buildings, collection of solar heat during periods of greatest solar insolation, and storage of this heat in large volumes for trans-seasonal use.

Status/Accomplishments:

Analysis showing that CSHPSS systems are already cost competitive in some parts of the world was completed and the findings presented at three major international energy conferences. The contractor coordinated the Task VII Phase III Working Group Meeting held in Taormina, Sicily, in February. Also during FY 1989, in an effort to secure a U.S. site for a CSHPSS project, negotiations were conducted with the Commonwealth of Massachusetts, leading to the drafting of a memorandum of understanding between the state and DOE that provides for consideration of seasonal storage in the design phase of the Franklin School Project. Negotiations were also conducted to secure a second potential site at the University of Massachusetts.

Major Project Reports: None.

Summary Date: September 1989

Testing, Evaluating, and Optimizing Performance of Solar Heating & Cooling Systems and Components

Project/Area/Task:
Solar Buildings Technology Program/
Solar Heating and Cooling/Generic Systems Development/Innovative Systems and Advanced Control Concepts/Desiccant Materials and Concepts

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: M. Lopez

Telephone: (415) 273-4264

Contractor:
Colorado State University (CSU)
Solar Energy Applications Laboratory
Fort Collins, CO 80523

Principal Investigator: D. Hittle

Telephone: (303) 491-8617

Contract Number: DE-FG03-86SF16306

Contract Period: 06/86 – 03/89

Contract Funding (Source):
FY 1986: $396,000 (DOE)
FY 1987: $398,000 (DOE)
FY 1988: $320,000 (DOE)
FY 1989: $333,500 (DOE)

Objectives:

To develop, integrate, and evaluate integrated heating and cooling system concepts for residential and commercial use.

Approach/Background:

The three Colorado State Solar Houses are used as working laboratories in the areas of solid desiccant cooling and heating (House I), open-cycle liquid desiccant cooling (House II), and boiling and condensing self-pumping space heating and cooling (House III). International Energy Agency Task VI on evacuated-tube collectors is also coordinated by the operating agent at CSU, and the results of project studies in Solar House I are contributed to this task. Under Task 4, CSU researchers are working cooperatively with Solar Rating and Certification Corporation (SRCC), SERI, the University of Wisconsin, solar industry, and DOE to establish and test a methodology by which manufacturers and installers of solar domestic hot water (SDHW) systems can obtain an SRCC rating, without retesting, when components in the originally tested system are substituted. The goal is to develop a nameplate rating for SDHW systems that will assist consumers in their purchase. Task 5 involves evaluating the performance of the internal compound parabolic concentrator evacuated collector being developed in a multilateral CSU/University of Chicago/Corning France project.

Status/Accomplishments:

Specific accomplishments during FY 1989 include improvement of the method of augmenting cooling demand and increasing temperature and humidity of supply air so that continuous performance data can be obtained (House I); evaluation of solar space heating improvements resulting from reduced collector flow rate and highly stratified storage; evaluation of a coupled dehumidifier/regenerator, and collection of performance data for the open-cycle liquid desiccant system (House II); redesign of the boiling collector system to minimize thermal losses and maximize solar collection efficiency (House III); and participation in planning program and construction of facilities for a generic DHW system (Task 4).

Major Project Reports:

Davidson, J. H., H. A. Walker, and S. Karaki, *Development and Improvement of a Self-Pumping Boiling Collector Solar Hot Water Storage System.*

Lenz, T. G., G. O. G. Löf, M. Flaherty, S. Misra, and S. Patnaik, *Testing and Design of Solar Cooling Systems Employing Liquid Desiccants—Regenerator/Dehumidifier Experiments in Colorado State University Solar House II.*

Löf, G. O. G., S. Beba, G. Cler, M. Birdsong, and B. McLay, *Performance of Solar Heating and Cooling Systems—Solid Desiccant Cooling/Fresh Air Heating with Evacuated-Tube Collectors in CSU Solar House I.*

Summary Date: September 1989

Open-Cycle Absorption Solar Cooling

Project/Area/Task:
Solar Buildings Technology Program/
Solar Cooling/Chiller Materials and Concepts

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: M. Lopez

Telephone: (415) 273-4264

Contractor:
Arizona State University
College of Engineering and Applied Sciences
Tempe, AZ 85287

Principal Investigator: B. Wood

Telephone: (602) 965-7298

Contract Number: DE-FG03-86SF16345

Contract Period: 05/86 – 09/90

Contract Funding (Source):
FY 1986: $162,000 (DOE)
FY 1987: $209,000 (DOE)
FY 1988: $110,000 (DOE)
FY 1989: $125,000 (DOE)

Objective:

To advance lower-cost solar cooling technology through feasibility analysis, design, and evaluation of open-cycle solar cooling concepts.

Approach/Background:

This is a three-phase project: (1) design analysis and resolution of critical design issues, (2) design, construction, and experimentation; and (3) extended system testing and evaluation, which will emphasize improving efficiency. The open-cycle system has the lowest initial cost potential of all the solar cooling systems evaluated in DOE programs. Analysis of a computer simulation of an open-cycle absorption refrigeration (OCAR) system has demonstrated that the OCAR system with an unglazed collector/regenerator (C/R) can supply over 95% of the cooling load for a structure in the Phoenix, Ariz., climate and 40% (70% with glazed C/R) in Washington, D.C.

Status/Accomplishments:

A prototype OCAR system, currently producing chilled water at 10°C-12°C, was developed. Mixtures of hygroscopic salts as alternative low-cost absorbent materials were identified; low-cost absorbents are important because to achieve solar fractions greater than 0.90 using an OCAR system, considerable sorbent solution storage is necessary. During FY 1989, excellent progress was made in Phase II concerning the understanding of the performance of a glazed C/R and an absorber heat transfer prototype. Also, alternative low-cost absorbent materials were evaluated.

Major Project Reports:

Habib, H. M., B. D. Wood, and J. Y. Murthy, "Effect of Non-Absorbable Gases on the Heat and Mass Transfer for Gas Absorption by a Falling Liquid Film."

Nelson, D. J., and B. D. Wood, "Combined Heat and Mass Transfer Natural Convection between Vertical Parallel Plates."

Nelson, D. J., and B. D. Wood, "Fully Developed Combined Heat and Mass Transfer Natural Convection between Parallel Plates with Asymmetric Boundary Conditions."

Wood, B. D., *Heat and Mass Transfer from Glazed and Unglazed Open Flow Liquid Absorbent Solar Collector/Regenerator.*

Wood, B. D., "Open-Cycle Absorption Research—Research Summary."

Wood, B. D., and A. P. Stack, "Open-Cycle Absorption Solar Cooling: Glazed and Unglazed Open Flow Liquid Absorbent Solar Collector/Regenerator."

Wood, B. D., D. A. Siebe, and R. K. Collier, "Open-Cycle Absorption System—A Low-Cost Solar Heating and Cooling Option."

Yang, R., and B. D. Wood, "Heat and Mass Transfer in Laminar Wavy Film Absorption with the Presence of Non-Absorbable Gases."

Summary Date: September 1989

Solar Cooling Research Facility

Project/Area/Task:
Solar Buildings Technology Program/
Solar Cooling/Desiccant Materials and Concepts

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: M. Lopez

Telephone: (415) 273-4264

Contractor:
Florida Solar Energy Center (FSEC)
300 State Road 401
Cape Canaveral, FL 32920

Principal Investigators: P. Fairey, S. Chandra

Telephone: (407) 783-0300

Contract Number: DE-FG03-86SF16305

Contract Period: 09/86 – 12/89

Contract Funding (Source):

FY 1986:	$610,000	(DOE)
FY 1987:	$200,000	(GRI)
	$149,000	(FPL)
	$196,000	(FSEC)
FY 1988:	$575,000	(DOE)
	$200,000	(GRI)
	$ 86,000	(FPL)
	$143,000	(FSEC)
FY 1989:	$425,000	(DOE)
	$200,000	(GRI)
	$149,000	(FPL)
	$100,000	(FSEC)

Objective:

To establish a comprehensive experimental and analytic capability for the study and advancement of solar cooling technologies applicable to hot, humid climates.

Approach/Background:

The recent population increase in hot, humid regions of the United States has significantly increased the energy demand for air conditioning in these climates, resulting in the need for research on solar cooling and dehumidification technologies. The research will concentrate on moisture research and analysis and on integrated systems.

Status/Accomplishments:

The Diurnal Test Facility was completed. A moisture properties data base and handbook were prepared and algorithms developed for combined heat and mass transfer in buildings. The Radiant Barrier Facility was constructed, and a draft American Society for Testing and Materials standard for the use and installation of radiant barrier systems was prepared. During FY 1989, high-quality moisture transport data for both common and innovative building materials were collected for use in solar building dehumidification and cooling strategies; the combined heat and mass transfer algorithms developed in FY 1988 were extended during FY 1989 to incorporate phase change and other innovative building materials; candidate roof geometries for the Desiccant Enhanced Nocturnal Radiative Cooling System (DESRAD) were tested. A new public domain software, FSEC, was released, which calculates dehumidification and cooling loads in buildings based on the combined heat and mass transfer algorithms.

Major Project Reports:

Cromer, C. J., *Dehumidification Enhancement of Air Conditioners by Desiccant Moisture Exchange.*

Cummings, J. B., and A. A. Kamel, *Whole-Building Moisture Experiments and Data Analysis.*

Fairey, P., and M. Swami, *Analysis of Attic Radiant Barrier Systems Using Mathematical Models.*

Keresteciogiu, A., and L. Gu, *Evaporation and Condensation Theory.*

Keresteciogiu, A., M. Swami, P. Fairey, L. Gu, and S. Chandra, *Modeling Heat, Moisture and Contaminant Transport in Buildings: Toward a New Generation Software.*

Keresteciogiu, A., et al., *Theoretical and Computational Investigation of Algorithms for Simultaneous Heat and Moisture Transport in Buildings.*

Solar Cooling Research Project: Second Year (1988) Final Report.

Summary Date: September 1989

Tungsten-Based Electrochromic (EC) Materials Research for Controlled Radiant Energy Transfer in Buildings

Project/Area/Task:
Solar Buildings Technology Program/
Daylighting/Aperture Materials

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: J. Aaron

Telephone: (415) 273-4265

Contractor:
Tufts University
Department of Electrical Engineering
Medford, MA 02155

Principal Investigator: R. Goldner

Telephone: (617) 628-5000, x2492

Contract Number: DE-FG03-85SF15927

Contract Period: 9/85 – 12/89

Contract Funding (Source):
FY 1985: $ 35,000 (DOE)
FY 1986: $132,000 (DOE)
FY 1987: $187,000 (DOE)
FY 1988: $230,000 (DOE)
FY 1989: $222,000 (DOE)

Objectives:

To develop and model robust all-solid prototypes based on tungsten trioxide electrochromic (EC) films and other identified candidate materials in a generic electrochemical structure: TC/CE/IC/EC/TC (where TC = transparent conductor, CE = counterelectrode, IC = ion conductor, and EC = electrochromic layers).

Approach/Background:

Electrically switchable glazings can economically and automatically control the radiant energy transfer in buildings and other enclosed spaces (e.g., vehicles), thereby significantly improving their energy efficiency. The approach is fourfold: (1) to demonstrate feasibility and identify candidate materials (Phase I, completed), (2) to improve and model each of the window layers and build prototypes (Phase II, in progress), (3) to use these prototypes to help solve the problems associated with large-area EC window development (Phase III), and (4) to transfer the technology (Phase IV).

Status/Accomplishments:

The feasibility of variable reflectivity in (poly-)crystalline films of WO_3 (c-WO_3) was demonstrated. During FY 1989, the Tufts research team focused on fundamental scaleup and materials problems of the ion-conducting, counterelectrode, and transparent conductor layers and on low-temperature deposition processes. The major conclusions based on the year's investigations are (1) further improvement in reflection modulation in c-WO_3 films for the EC layer should be attainable; (2) further increase in the electronic resistivity of the IC layer is imperative if further scaleup is to be successful; (3) In_2O_3 is a satisfactory optically passive CE layer; (4) $LiCoO_2$ may have too small an optical band gap to be a useful optically active CE layer; (5) a replacement for indium tin oxide (ITO) as the TC layer is needed because ITO is permeable to lithium; and (6) ion-beam-based deposition techniques, and particularly ion-assisted deposition, appear to be very promising.

Major Project Reports:

Goldner, R. B., et al., "Electrochromic Smart Window Glass."

Goldner, R. B., et al., *Sixth Annual Report on Optics and Materials Research for Controlled Radiant Energy Transfer in Buildings (1/1/88 - 2/28/89).*

Goldner, R. B., et al., "Some Aspects of Charge Transport in Electrochromic Films."

Goldner, R. B., et al., "Thin Film Solid State Ionic Materials for Electrochromic Smart Window™ Glass."

Haas, T. E., and R. B. Goldner, "Fundamentals of Electrochromism in Metal Oxide Bronzes."

Summary Date: September 1989

Solid-State Tungsten-Based Electrochromic (EC) Films for Windows

Project/Area/Task:
Solar Buildings Technology Program/
Daylighting/Aperture Materials

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: J. Aaron

Telephone: (415) 273-4265

Contractor:
EIC Laboratories, Inc.
111 Downey Street
Norwood, MA 02062

Principal Investigator: D. Rauh

Telephone: (617) 769-9450

Contract Number: DE-AC03-87SF16602

Contract Period: 05/87 – 04/90

Contract Funding (Source):
FY 1987: $127,000 (DOE)
FY 1988: $130,000 (DOE)
FY 1989: $120,000 (DOE)

Objective:

To develop an all-solid-state thin film electrochromic (EC) coating for windows.

Approach/Background:

These "smart" windows will offer a means of regulating solar input to and radiation heat loss from building interiors, with accompanying dramatic improvements in energy management, fuel economy, and comfort. The EC coating actively controls solar gains through windows with the application of a small DC current. The fabrication processes are intended to be appropriate for large areas using standard thin film vacuum deposition techniques.

Status/Accomplishments:

Laboratory-scale thin film laminated tungsten-based EC devices with typical five-layer configurations (transparent conductor, electrochromic, ion-conducting, counterelectrode, transparent conductor layers on glass) have been fabricated and their optical and electrochemical behavior characterized. The devices exhibit reversible EC switching over approximately 100 cycles. The primary focus of FY 1989 work was on appropriate materials for the various layers of solid-state films, in particular the ion-conducting, counterelectrode, and transparent conductor layers and the behavior when used with one another.

Major Project Reports:

Cogan, S. F., N. M. Nguyen, and R. D. Rauh, "Electrochromism in Sputtered Vanadium Pentoxide."

Rauh, R. D., and S. F. Cogan, "Counter Electrodes in Transmissive Electrochromic Light Modulators."

Rauh, R.D., and S.F. Cogan, *Solid State Electrochromic Light Modulator.*

Summary Date: September 1989

Holographic Diffractive Structures (HDSs) for Enhanced Daylighting

Project/Area/Task:
Solar Buildings Technology Program/
Daylighting/Daylighting Concepts

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: J. Aaron

Telephone: (415) 273-4265

Contractor:
Advanced Environmental Research Group (AERG)
RD#1, Box 1830
Woolwich, ME 04579-1830

Principal Investigator: R. Ian-Frese

Telephone: (207) 443-2946

Contract Number: DE-FG03-86SF16590

Contract Period: 09/86 - 06/89

Contract Funding (Source):
FY 1986: $152,000 (DOE)
FY 1987: $ 46,000 (DOE)
FY 1988: $110,000 (DOE)
FY 1989: $125,000 (DOE)

Objective:

To develop a low-cost holographic diffractive structure (HDS) system to be incorporated into windows. This holographic glazing material diverts and redistributes sunlight to illuminate architectural spaces for energy conservation and human comfort and is suitable for both retrofit and new construction.

Approach/Background:

HDSs are designed to direct and distribute sunlight into inaccessible areas (holographic solar access) or can make the energy of the sun available during the hours of the day when solar angles would otherwise be unfavorable for the practical use of solar energy.

Status/Accomplishments:

A verified mathematical model, optimized for high-efficiency diffraction of the visible solar spectrum (80%-85%), has been developed; altitude and azimuth acceptance angles have been verified at ±25° and ±50°, respectively; grating designs allowing for altitude variations of at least 45° (the difference in summer and winter noon altitudes) have been accomplished experimentally. During FY 1989, holographic diffractive structure materials were developed; installed in a scaled architectural model; and evaluated under real-time, real-sky conditions at Harvard University and later at Lawrence Berkeley Laboratory.

Major Project Reports:

Ian-Frese, R., "Future Glazings and Lightwave Technology."

Ian-Frese, R., and E. King, "Lightwave Technology and Holographic Comfort Systems."

Ian-Frese, R., and E. King, "Natural Illumination and Lightwave Technology."

Summary Date: September 1989

Research on Active Solar Processes

Project/Area/Task:
Solar Buildings Technology Program/
Systems Integration/Analysis

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: M. Lopez

Telephone: (415) 273-4264

Contractor:
University of Wisconsin
Solar Energy Laboratory
1500 Johnson Drive
Madison, WI 53706

Principal Investigator: W. Beckman

Telephone: (608) 263-1590

Contract Number: DE-FG03-84SF15303

Contract Period: 09/84 – 09/89

Contract Funding (Source):
FY 1986: $125,000 (DOE)
FY 1987: $100,000 (DOE)
FY 1988: $190,000 (DOE)
FY 1989: $180,000 (DOE)

Objectives:

To continue developing research and design tools for solar thermal processes in buildings and using this ability to produce solar heating and cooling system designs that are attractive to the solar energy industry.

Approach/Background:

The project focuses on methods for predicting thermal performance by simulating solar process systems (with TRNSYS) and developing design methods (e.g., F-CHART). New solar process systems are explored on an ongoing basis with TRNSYS, which is maintained as a useful public-domain program. This work represents the leading systems research in the solar buildings program and provides a training facility for the next generation of solar scientists.

Status/Accomplishments:

Numerous practical analyses on a wide variety of topics have been completed over the years; TRNSYS and F-CHART development, expansion, and maintenance have been ongoing activities. For example, during FY 1989, TRNSYS 12.2 for the Mac II was completed. Reports were produced on enthalpy exchangers, heat transfer, and annual heat storage. Research continued on solar radiation and related meteorological data, and a weather generator component was added to TRNSYS.

Major Project Reports:

Braun, J. E., S. A. Klein, J. W. Mitchell, and W. A. Beckman, "Application of Optimal Control to Chilled Water Systems without Storage."

Beckman, W. A., and J. W. Mitchell, "Theoretical Limits for Storage of Energy in Buildings."

Fanney, A. H., and S. A. Klein, "Thermal Performance Comparisons for Solar Hot Water Systems Subjected to Various Collector and Heat Exchanger Flow Rates."

Klein, S. A., D. Nugent, and J. Mitchell, "Investigation of Control Alternatives for a Steam Turbine Driven Chiller."

Seem, J. E., S. A. Klein, W. A. Beckman, and J. Mitchell, "Comprehensive Room Transfer Functions for Efficient Calculation of the Transient Heat Transfer Processes in Buildings."

Seem, J. E., S. A. Klein, W. A. Beckman, and J. Mitchell, "Transfer Functions for Efficient Calculation of Multidimensional Transient Heat Transfer."

Sick, F., T. K. Bushulte, S. A. Klein, P. Northey, and J. A. Duffie, "Analysis of the Seasonal Performance of Hybrid Liquid-Desiccant Cooling Systems."

Stevens, D. I., J. E. Braun, and S. A. Klein, "An Effectiveness Model of Liquid-Desiccant System Heat/Mass Exchangers."

Van den Bulck, E., S. A. Klein, and J. Mitchell, "Second Law Analysis of Solid Desiccant Rotary Dehumidifiers."

Summary Date: September 1989

Energy Research Program for the Profession of Architecture

Project/Area/Task:
Solar Buildings Technology Program/
Systems Integration/Design Tools

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: J. Aaron

Telephone: (415) 273-4265

Contractor:
AIA/ACSA Council for Architectural Research
c/o Association of Collegiate Schools of Architecture (ACSA)
1735 New York Avenue
Washington, DC 20006

Principal Investigator: R. McCommons

Telephone: (202) 785-2324

Contract Number: DE-FG03-88SF17538

Contract Period: 03/88 - 06/89

Contract Funding (Source):
FY 1988: $150,000 (DOE)
FY 1989: -0- (---)

Objective:

To provide support for the transfer of the results of government-sponsored research to members of the design profession and others who seek authoritative information for integrating advances in solar building technologies into the design and performance of buildings.

Approach/Background:

The American Institute of Architects (AIA)/ACSA Council on Architectural Research provides a unique framework for conducting these collaborative activities because it represents both licensed architects (through AIA) and architectural educators (through ACSA). Leading experts in the practice of architectural design and researchers in architectural schools conducted research, assembled vital data, and developed guidelines essential to the utilization of solar technologies in building designs. The work focused on atria, evaluation of analytic tools, development of building design guidelines, and institutional and industry interfaces.

Status/Accomplishments:

Conducted research, convened workshops, and provided reports on (1) atrium design concepts and applications, (2) solar systems integration and advanced energy concepts, (3) design guidelines and analytic tools for solar technologies in buildings, and (4) institutional mechanisms in the building industry concerned with solar building technologies.

Major Project Reports:

AIA/ACSA Council on Architectural Research, *Atrium Building Study: Four Case Studies.*

The Energy Design Research Program, AIA/ACSA Council on Architectural Research, *Building Design Guidelines for Solar Energy Technologies: Final Report.*

The Energy Design Research Program, AIA/ACSA Council on Architectural Research, *Building Design Guidelines for Solar Energy Technologies, Phase I: Annotated Bibliography.*

The Energy Design Research Program, AIA/ACSA Council on Architectural Research, *Evaluation of Analytical Tools for the Solar Energy Design of Buildings.*

The Energy Design Research Program, AIA/ACSA Council on Architectural Research, *Opportunities in Solar Energy Research over the Next Decade.*

Summary Date: September 1989

IEA Task VIII: Administrative Support— DOE Operating Agent and Subtask C Lead Country Responsibility

Project/Area/Task:
Solar Buildings Technology Program/
Systems Integration/Design Tools

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: M. Lopez

Telephone: (415) 273-4264

Contractor:
Architectural Energy Corporation (AEC)
2540 Frontier Avenue, Suite 201
Boulder, CO 80301

Principal Investigator: M. Holtz

Telephone: (303) 444-4149

Contract Number: DE-AC03-87SF16667

Contract Period: 04/87 - 09/89

Contract Funding (Source):
FY 1987: $130,000 (DOE)
FY 1988: $101,000 (DOE)
FY 1989: $ 53,000 (DOE)

Objective:

To administer the Operating Agent and Subtask C (design methods) Lead Country responsibilities assigned to the United States in Annex VIII to the International Energy Agency (IEA) Solar Heating and Cooling Implementing Agreement.

Approach/Background:

The IEA initiated Task VIII to accelerate the development and use of passive and hybrid solar low-energy buildings in the participants' countries. AEC is providing administrative support to DOE for its roles as Operating Agent and Subtask C Lead Country. IEA Task VIII has four subtasks: (1) performance measurement and analysis; (2) modeling and simulation; (3) design methods; and (4) building design, construction, and evaluation.

Status/Accomplishments:

Three passive solar home design/build projects were developed, and two were constructed—in Oakton, Va., and Boulder, Colo. During FY 1989, data collection, analysis, and reporting on these two projects were completed. Also completed were five Design Information Booklets, and the project final report to the IEA Solar Heating and Cooling Executive Committee was presented in Helsinki.

Major Project Reports:

Construction Details: Design Information Booklet No. 5.

Design Context: Design Information Booklet No. 2.

Design Tool Selection and Use: Design Information Booklet No. 4.

Energy Design Principles in Buildings: Design Information Booklet No. 1.

"Performance Evaluation Procedures."

Post-Construction Activities: Design Information Booklet No. 8.

Residential Energy Design Guidelines Development Methodology: Technical Supplement.

Summary Date: September 1989

IEA Task XII: Building Energy Analysis and Design Tools for Solar Applications

Project/Area/Task:
Solar Buildings Technology Program/
Systems Integration/Design Tools

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: M. Lopez

Telephone: (415) 273-4264

Contractor:
Architectural Energy Corporation (AEC)
2540 Frontier Avenue, Suite 201
Boulder, CO 80301

Principal Investigator: M. Holtz

Telephone: (303) 444-4149

Contract Number: DE-AC03-89SF17966

Contract Period: 07/89 - 03/90

Contract Funding (Source):
FY 1989: $100,000 (DOE)

Objective:

To provide administrative and technical support services as the operating agent for International Energy Agency (IEA) Task XII under the Solar Heating and Cooling Implementing Agreement.

Approach/Background:

Analysis and design tools play a central role in the development and design of active, passive, and hybrid solar heating, cooling, and daylighting systems. IEA Task XII focuses directly on the integration of solar materials, components and systems and the user characteristics of these tools.

Status/Accomplishments:

New project.

Major Project Reports: None.

Summary Date: September 1989

International Solar Program Coordination Support

Project/Area/Task:
Solar Buildings Technology Program/
Planning and Management

Directing Organization:
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612

Project Manager: M. Lopez

Telephone: (415) 273-4264

Contractor:
International Planning Associates (IPA)
5010 Sunnyside Avenue
Suite 303
Beltsville, MD 20705

Principal Investigator: S. Blum

Telephone: (301) 345-8800

Contract Number: DE-AC03-87SF17117

Contract Period: 09/87 – 09/89

Contract Funding (Source):
FY 1987: $ 5,000 (DOE)
FY 1988: $110,000 (DOE)
FY 1989: $121,000 (DOE)

Objectives:

To provide nontechnical coordination and management support services for the DOE Office of Solar Heat Technologies in connection with its participation in international collaborative activities, including the International Energy Agency (IEA) Solar Heating and Cooling Program and various bilateral activities.

Approach/Background:

Under the terms of an implementing agreement with the IEA, DOE is committed to cooperative research, development, demonstrations, and the exchange of information. To execute its responsibilities under current staffing limitations, DOE requires the assistance of a support contractor. This support contractor is responsible for (1) conducting various technical, programmatic, and administrative assessments; (2) providing communication links among IEA program participants; (3) documenting meetings, activities, and program deliverables; (4) preparing scheduled reports; and (5) coordinating information exchange.

Status/Accomplishments:

During FY 1989, assistance was provided to coordinate U.S. participation in IEA solar heating and cooling research and development programs and in the bilateral agreements. Activities included information dissemination, coordination of new task start-up activities (Tasks 12, 13, and 14), and status reports. The contractor facilitated various meetings and prepared and distributed the newsletter *Solar Update* and other technical reports and papers. Under a new information dissemination initiative, the first two IEA research briefs were prepared.

Major Project Reports: None.

Summary Date: September 1989

Solar Energy Research Institute

Solar Heating Research and Development—Generic Systems Research

Project/Area/Task:
Solar Buildings Technology Program/Solar Heating/Generic Systems Research

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: J. Burch

Telephone: (303) 231-1453

Contractor: In-House

Principal Investigator: J. Burch

Telephone: (303) 231-1453

Contract Number: N/A

Contract Period: 10/87 – 09/88

Contract Funding (Source):
FY 1988: $190,000 (DOE)
FY 1989: $295,000 (DOE)

Objectives:

To lower generic system costs through the development of a low-cost calculation-based certification procedure and to increase credibility of generic hot water systems through the development of a consumer performance label and field testing method.

Approach/Background:

In FY 1988, SERI worked closely with industry members and other researchers to develop simplified generic system designs for drainback, recirculation, and glycol systems. To lower system certification costs, a Solar Rating and Certification Corporation (SRCC) process allowing the substitution of components that deviate from the tested generic system, based on simulation, is being developed at the University of Wisconsin. Standard tests (SRCC-200) are being done at Colorado State University to test the process. A procedure for producing a system performance label based on the SRCC test result was developed by the University of Wisconsin and is being reviewed by the Solar Energy Industries Association.

To provide field validation of SRCC test results and an overall system performance check, a short-term test method for installed systems was developed at SERI and was successfully tested on two generic systems.

Status/Accomplishments:

A calculation-based methodology for low-cost certification of complete systems was developed. Testing results will be available in November 1989. The development of a method to produce a consumer label from the SRCC-200 test results was completed. The method to predict the long-term performance of installed generic systems from short-term test data was further refined and validated.

Major Project Reports:

Barker, G., C. Christensen, and E. Hancock, "Simulation Study of a Short-Term Monitoring Method for Active SDHS Systems."

Minnerly, B. V., S. A. Klein, and W. A. Beckman, "A Rating Procedure for Solar Domestic Hot Water Systems Based on ASHRAE-90 Test Data."

Summary Date: September 1989

Technology Transfer of Solar Industry Design Methods and Test Standards

Project/Area/Task:
Solar Buildings Technology Program/Solar Heating/Technology Transfer of Design, Installation, and Procurement Manuals and Interaction with HUD

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: C. Kutscher

Telephone: (303) 231-7067

Contractor:
Solar Energy Industries Association (SEIA)
1730 N. Lynn Street
Arlington, VA 22209

Principal Investigator: K. Sheinkopf

Telephone: (703) 524-6100

Contract Number: RH-9-19072

Contract Period: 01/89 - 07/90

Contract Funding (Source):
FY 1988: $100,000 (DOE)
FY 1989: $121,000 (DOE)

Objective:

To develop means for improving the acceptance of solar energy systems for building applications and to transfer solar design, installation, operations, and procurement information to the user community.

Approach/Background:

In FY 1987, the SEIA coordinated industry input and review of an active solar heating design manual for commercial buildings. In FY 1988, SEIA gave presentations on these manuals to various organizations and began a dialogue with the Department of Housing and Urban Development (HUD) to determine how Solar Rating and Certification Corporation (SRCC) solar system certification procedures could be brought in line with HUD requirements. In FY 1989, SEIA broadened its presentations to include new installation, operations, and maintenance manuals. SEIA is also finalizing an agreement with HUD regarding SRCC test procedures and is developing a manual to help the solar industry learn federal procurement procedures.

Status/Accomplishments:

Working with SERI, SEIA updated and improved its slide show on design, installation, operations, and maintenance manuals and presented it at a number of conferences and meetings, including the Renewable Energy in the Americas Conference in May and the American Solar Energy Society Annual Conference in June. Revisions were made in the SRCC test procedure to make it compatible with HUD requirements. A draft test procedure for thermosiphon and integral collector/storage systems was also developed.

Major Project Reports: None.

Summary Date: September 1989

Solar Heating Research and Development—Systems Effectiveness Research

Project/Area/Task:
Solar Buildings Technology
Program/Solar Heating/Systems
Effectiveness Research

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: N. Carlisle

Telephone: (303) 231-1036

Contractor: In-House

Principal Investigator: N. Carlisle

Telephone: (303) 231-1036

Contract Number: N/A

Contract Period: 10/88 – 12/89

Contract Funding (Source):
FY 1988: $220,000 (DOE)
FY 1989: $150,000 (DOE)

Objectives:

To determine the reliability of recently installed solar water heating systems and to investigate the causes of scale buildup in active solar systems using recirculation as a freeze protection strategy.

Approach/Background:

In FY 1988, reliability and maintainability (R&M) data were collected on 256 residential active solar domestic water heaters installed since 1985. In FY 1989, R&M data were collected on solar water heating systems to supplement the data collection survey taken in FY 1988. The data were collected on system types (primarily batch and thermosiphon) or in locations (northeastern states, California) not covered in the FY 1988 survey. The information collected included historical repair data on systems as well as data collected through an inspection of the system.

In response to concerns raised by the solar industry, the problem of scale build-up in solar systems was studied at SERI using data collected by industry, literature reviews, and computer simulations to study collector fluid temperatures under various conditions.

Status/Accomplishments:

In FY 1989, SERI contracted with two chapters of the Solar Energy Industries Association and one Solar Energy Association chapter to collect data to supplement the FY 1988 data collection survey. The data are due by September 30, 1989.

The major focus of the FY 1989 task was to analyze the primary causes of the problem of scale buildup in domestic hot water systems that use recirculation as a freeze protection strategy. SERI has simulated fluid temperatures under stagnation and pump-on conditions using TRNSYS. These temperatures serve as input, along with the chemical state of the incoming water, to a computer program written at SERI that determines the rate of scale buildup under various conditions. Based on these simulations, SERI will offer appropriate solutions to resolve this problem.

Major Project Reports:

Carlisle, N., R. Farrington, and J. Burch, "Systems Effectiveness Research, Program at the Solar Energy Research Institute."

Summary Date: September 1989

Solar Heating Research and Development—Advanced Systems Research

Project/Area/Task:
Solar Buildings Technology Program/Solar Heating/Advanced Systems Research

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: C. Christensen

Telephone: (303) 231-1204

Contractor: In-House

Principal Investigator: C. Christensen

Telephone: (303) 231-1204

Contract Number: N/A

Contract Period: 10/88 - 09/89

Contract Funding (Source):
FY 1988: $190,000 (DOE)
FY 1989: $175,000 (DOE)

Objective:

To investigate innovative system concepts to determine the potential for improved system effectiveness (performance, reliability, and cost).

Approach/Background:

This task focuses on evaluating potential future technologies and identifying favorable applications of solar heating to residential and commercial buildings. Efforts will focus on those designs that are best suited to the latest building trends and utility concerns. These trends include reduced heating loads, greater use of water-conserving appliances, combined space and water heating appliances, and the incorporation of advanced building materials. Increased ventilation rates to reduce indoor air pollution of residential and commercial buildings is also becoming an important consideration. The ultimate goal is to identify reliable systems with lowered delivered energy costs. Development of advanced systems may occur in collaboration with researchers in International Energy Agency (IEA) countries (under the proposed Task XIV of the Solar Heating and Cooling Agreement).

Status/Accomplishments:

Research on advanced systems is currently focused on systems for preheating ventilation air using low-cost collectors, evacuated-tube integral-collector-storage systems, and large-scale water heating systems. Preliminary analyses, based on F-CHART calculations and a new methodology for plotting results, were performed as a part of an IEA feasibility study. Performance for a range of applications, collector types, and climates was compared and opportunities for significant cost/performance identified. For example, ventilation preheat systems operate efficiently because the air entering the collectors is at ambient temperature, thus minimizing heat losses and allowing use of simple low-cost collectors. Program researchers have developed innovative collector concepts for ventilation preheat systems and TRNSYS models for detailed analysis.

In passive solar heating, research on phase-change materials (PCMs) for thermal energy storage was undertaken, focusing on composite PCM/wallboard. Program researchers developed target values for material properties and estimates of energy benefits for representative buildings.

Major Project Reports:

Christensen, C. B., "Performance Predictions for Advanced Active Solar Concepts."

Summary Date: September 1989

Advanced Desiccant Materials (ADMs) Research

Project/Area/Task:
Solar Buildings Technology Program/
Solar Cooling/ADMs Research

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: A. W. Czanderna

Telephone: (303) 231-1240

Contractor: In-House

Principal Investigator: A. W. Czanderna

Telephone: (303) 231-1240

Contract Number: N/A

Contract Period: 10/88 – 09/89

Contract Funding (Source):
FY 1987: $150,000 (DOE)
FY 1988: $150,000 (DOE)
FY 1989: $100,000 (DOE)

Objective:

To identify a next-generation, low-cost, desiccant material with which solar radiation or heat from another low-cost energy source can be used for regenerating the water vapor sorption activity of the material for desiccant cooling applications.

Approach/Background:

This research is attempting to match the properties of polymeric desiccants with those of an ideal material. The following variables are particularly relevant for advanced desiccant materials (ADMs): (1) selection, preparation, and study of a particular material; (2) water vapor sorption capacity and heat of adsorption by the solid desiccant; (3) rate of adsorption at 22°C and desorption at a modestly elevated temperature; (4) repeatability of points 2 and 3 as a function of cycles with short time intervals; (5) effect of chemical modification of the desiccant on points 2, 3, and 4; and (6) changes in the composition and topography of desiccant surfaces and the bonding of water vapor during cycling. For point 1, polymers that are candidate ADMs will be modified, and a new potential ADM polymer will be synthesized to obtain the desired sorption performance properties.

Status/Accomplishments:

The sorption performance of a series of salts of polystyrene sulfonic acid (PSSA) have been studied for lithium salt (LS), sodium salt (SS), potassium salt (KS), and ammonium salt (AS). From the isotherm data, PSSALS was identified as the best of these PSSA derivative materials; this information was immediately communicated to an industrial collaborator for testing in a commercial desiccant cooling system. With a new data-acquisition system for our experimental measurements, kinetic data can now be taken every two seconds, stored, and recalled for detailed plots of water sorption for pressure changes comparable to those in commercial systems. Our industrial collaborators desire good kinetic data in the first three to five minutes of sorption, and we now have the capability to deliver this information on ADMs. An additional industrial partner was placed on subcontract to prepare PSSA salts under carefully controlled conditions and produce a new hydrophilic polymer for our characterization. A Sartorius beam microbalance system was assembled for use in 1989.

Major Project Reports:

Czanderna, A. W., "Polymers as Advanced Materials for Desiccant Applications: 1987."

Czanderna, A. W., "Polymers as Advanced Materials for Desiccant Applications. 1. Commercially Available Polymers."

Czanderna, A. W., and H. H. Neidlinger, "Polymers as Advanced Materials for Desiccant Applications: 1988."

Summary Date: September 1989

Desiccant Concepts

Project/Area/Task:
Solar Buildings Technology Program/Solar Cooling and Dehumidification/Desiccant Concepts

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: A. A. Pesaran

Telephone: (303) 231-7636

Contractor: In-House

Principal Investigator: A. A. Pesaran

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Contract Number: N/A

Contract Period: 10/88 – 09/89

Contract Funding (Source):
FY 1988: $150,000 (DOE)
FY 1989: $125,000 (DOE)

Objective:

The objective of this project is to generate experimental data bases to investigate the impact of desiccant contamination resulting from airborne pollutants (particularly cigarette smoke) on the performance of desiccant materials for desiccant cooling systems to improve their durability.

Approach/Background:

The reliability and long-term performance of desiccant cooling systems depend on the durability of their components. Researchers have studied the factors affecting the durability of desiccant dehumidifiers. Theoretical analyses have shown that the coefficient of performance and cooling capacity of a desiccant system could be reduced by as much as 35% as a result of degradation in the performance of desiccant materials. A desiccant contamination test facility was designed per industry recommendations to obtain data on the degradation of common desiccants.

Status/Accomplishments:

The desiccant contamination test facility was fabricated and made operational in June 1989. In the facility, 100 samples of 10 desiccant materials are exposed to humid air charged with a variety of common contaminants (such as cigarette smoke). Another hundred samples of the same desiccants are exposed to clean humid air in the facility. Both desiccant sets are cycled between adsorption and regeneration temperatures typical of those encountered in the operation of solar-regenerated desiccant cooling systems. The contamination experiment, started in August 1989, will continue to run 24 hours/day over 9 months (equivalent to five years of field operation) and will provide data to determine the degradation effects as a result of contaminants and thermal cycling.

During the duration of the experiments, desiccant samples from both clean and contaminated batches are removed at predetermined time intervals. The sorption capacity of the samples after exposure are measured to obtain the time history of degradation. The data are also used to determine the service life of desiccants and methods to mitigate the potential contaminant-induced degradation.

Major Project Reports:

Pesaran, A. A., and C. E. Bingham, "Desiccant Contamination Research: Report on the Desiccant Contamination Test Facility."

Pesaran, A. A., and C. E. Bingham, "Testing of Novel Desiccant Materials and Dehumidifier Matrices for Desiccant Cooling Applications."

Summary Date: September 1989

Durability Testing Methods for Optical-Switching Films and Glazings

Project/Area/Task:
Solar Buildings Technology Program/
Daylighting/Durability Testing

Directing Organization:
Solar Energy Research Institute
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Project Manager: A. W. Czanderna

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Contractor: In-House

Principal Investigator: A. W. Czanderna

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Contract Number: N/A

Contract Period: 1/1/89 – 12/31/89

Contract Funding (Source):
FY 1987: $175,000 (DOE)
FY 1988: $100,000 (DOE)
FY 1989: $100,000 (DOE)

Objective:

To identify test and measurement methods that can be used to evaluate the performance and durability of electrochromic (EC) devices in glazing applications.

Approach/Background:

Evaluation criteria, test methods for establishing detailed performance criteria, and methodologies for durability testing have not previously been identified. The approach to supply the needed information was to contact groups that are concerned with studying EC devices, establishing their performance criteria, assessing the test methods, and conducting durability testing on other solar devices and to solicit their opinions.

Status/Accomplishments:

A draft report was prepared on evaluation criteria and test methods for EC windows. The objectives of the report were to present background about EC window applications, identify general evaluation criteria, and list expected performance criteria. An additional objective was to identify and discuss methods needed for testing prototype EC windows in laboratory research, including their durability. Other objectives were to rank and recommend methods for evaluating laboratory and prototype EC windows and make recommendations for advancing the state of the art beyond the laboratory to prototype durability testing and commercialization. An EC window forum was held in August in San Diego, Calif., where 16 participants (of the 21 contacts) provided input to the draft report. Their constructive input will be used to improve the final version of the report. For preparing all-solid-state prototype EC coatings for glazing applications, one publication and one progress report about using the plasma-enhanced chemical vapor deposition processing were completed early in the task year. These were used for extensive discussions with nine industrial firms for potential collaboration with SERI.

Major Project Reports:

Benson, D. K., and J. S. E. M. Svensson, "Plasma Enhanced CVD of W and Mo Oxides."

Benson, D. K., C. E. Tracy, J. S. E. M. Svensson, and A. Johncock-Krisko, "Electrochromic Tungsten and Molybdenum Oxides."

Czanderna A. W., and C. M. Lampert, "Evaluation Criteria and Test Methods for Electrochromic Windows."

Summary Date: September 1989

Systems Integration-Analysis

Project/Area/Task:
Solar Buildings Technology Program/
Systems Integration/Analysis

Directing Organization:
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1617 Cole Boulevard
Golden, CO 80401

Project Manager: R. Anderson

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Contractor: In-House

Principal Investigators: R. Anderson, R. Judkoff, D. Balcomb

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Contract Number: N/A

Contract Period: 10/88 – 09/89

Contract Funding (Source):
FY 1989: $200,000 (DOE)

Objective:

To determine the thermal effects and performance of integrated solar heating, solar cooling, and daylighting technologies when combined with each other and existing building systems.

Approach/Background:

This task encompasses three primary activities: (1) analysis and testing of advanced transport and collection techniques for control of solar gains; (2) design tool evaluation; and (3) the study of advanced solar low-energy buildings. Recent studies in area 1 demonstrated that many of the problems associated with the lack of control of solar gains can be solved by using energy-absorbing materials to intercept solar gains and convert them to concentrated hot air flows immediately after they enter a building. SERI researchers demonstrated that it is possible to design the absorbing layer to be an integral part of a window or window shade. Current research efforts focus on determining the geometry and material properties that maximize the performance of the window systems.

As part of design tool evaluation, SERI and other International Energy Agency (IEA) Task XII participants are developing quantitative procedures for evaluating solar building design and analysis tools.

The study of advanced solar low-energy buildings is being conducted under IEA Task XIII.

Status/Accomplishments:

Research was conducted on thermal boundary layer flow as a way to enhance energy transport within solar buildings. Increased understanding of mass transfer within buildings has resulted in several collaborative projects with industry involving the investigation of air pollutant distribution and the "sick building syndrome." A feasibility study was conducted under IEA Task XII to evaluate the ability of current building simulation programs to model cooling, overheating, peak loads, and thermal conditions. The results from the study were fed into the IEA Task XII multiyear planning process, and a draft multiyear plan was produced. Similarly, feasibility studies were carried out to develop a multi-year collaborative research plan for Task XIII. A standard building performance index was developed, a draft National Participation Plan was written, and initial evaluation of advanced concepts was begun.

As a result of activity in IEA Tasks VIII and XII, ASHRAE formed a committee to develop a Standard Method of Test for Building Energy Software. The state of Colorado used the SERI/IEA model evaluation method to select the calculational tool for its statewide Home Energy Rating System (HERS).

Major Project Reports:

Anderson, R. *Techniques for Modeling Ventilation Efficiency and Air Distribution in Occupied Spaces.*

Judkoff, R., *A Quantitative Procedure for Evaluating Home Energy Rating Systems (HERS) Evaluation Methods.*

Judkoff, R., "IEA Task XII Multi-Year Plan for Model Evaluation."

Neymark, J., A. Kirkpatrick, R. Anderson, and C. Boardman, "High Rayleigh Number Natural Convection in Partially Divided Air and Water Filled Enclosures."

Summary Date: September 1989

Builder Guidelines

Project/Area/Task:
Solar Buildings Technology Program/
Systems Integration/Builder Guidelines

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: R. Anderson

Telephone: (303) 231-1756

Contractor:
Passive Solar Industries Council (PSIC)
2836 Duke Street
Alexandria, VA 22314

Principal Investigators: Doug Balcomb, SERI;
Helen English, PSIC

Telephone: (303) 231-1102, SERI;
(703) 371-0357, PSIC

Contract Number: HK-7-07175

Contract Period: 10/88 - 09/89

Contract Funding (Source):
FY 1988: $ 80,000 (DOE)
FY 1989: $265,000 (DOE)

Objective:

To develop design methods and guidelines for designers, manufacturers, builders, and developers to facilitate the transfer of DOE research results in the area of emerging buildings technology to the buildings community.

Approach/Background:

SERI is working closely with PSIC and its member organizations, including the National Association of Home Builders (NAHB), to reach local home builders associations and assist them in conducting local workshops to encourage and explain the use of the Builder Guidelines packages.

A Solar Buildings Technology Service (SBTS) was established at SERI to provide unique design assistance services in the area of solar building technology.

Status/Accomplishments:

During FY 1989, a computer program that automatically produces site-specific Builder Guidelines booklets was completed. The program automatically customizes the design information to account for local variations in building techniques and weather conditions. The guidelines provide simple methods of evaluating the impact of building orientation and thermal mass on solar gains, thermal comfort, and heating and cooling loads. The builder guidelines booklets were officially endorsed by the NAHB Standing Committee on Energy and are being distributed to local Home Builder Associations (HBAs) through workshops by the PSIC. PSIC prepared and is implementing a dissemination plan for the builder guidelines. Four workshops were held, attended by a total of 120 builders/ designers. SERI also produced a spreadsheet version of the guidelines to speed design calculations for builders who have access to personal computers. It is currently being reviewed and tested by PSIC members.

An SBTS brochure was produced and mailed to all members of the Solar Energy Industries Association and all attendees of the Soltech '89 conference. Current SBTS clients include E. A. Mueller—design review of a solar industrial process heat system in Egypt; the DOE Facilities Branch—energy conservation study of the SERI Field Test Laboratory Building; and the National Center for Atmospheric Research—assistance in evaluating advanced renewable energy opportunities for a new office/laboratory building (under negotiation).

Major Project Reports:

Balcomb, J. D., and A. Lekov, "Algorithms for Builder Guidelines."

Passive Solar Industries Council and Solar Energy Research Institute, *Solar Design Strategies: PSIC's Guidelines for Builders.*

Summary Date: September 1989

Short-Term Energy Monitoring (STEM) of Solar Buildings

Project/Area/Task:
Solar Building Technology Program/Systems Integration/Short-Term Energy Monitoring (STEM) of Solar Buildings

Directing Organization:
Solar Energy Research Institute
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Golden, CO 80401

Project Manager: R. Anderson

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Contractor: In-House

Principal Investigator: K. Subbarao

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Contract Number: N/A

Contract Period: 10/88 – 09/89

Contract Funding (Source):
FY 1988: $288,000 (DOE)
FY 1989: $260,000 (DOE)

Objectives:

To conduct field applications of the short-term energy monitoring (STEM) technique—a method for the rapid, inexpensive, and accurate evaluation of actual building energy performance—in collaboration with appropriate agencies and organizations. To develop software enhancements as well as a software demonstration of the capabilities of the STEM method.

Approach/Background:

STEM was developed in FY 1988 for short-term tests involving low-cost instrumentation and data acquisition for three to four days, using the results to derive a realistically complex thermal model of the building, which is then used for extrapolation to annual energy use and peak loads. FY 1989 activities were largely directed toward method validation and field applications in collaboration with various organizations as well as enhancements to the software.

Status/Accomplishments:

Two houses were tested in California in collaboration with the Berkeley Solar Group under contract with the California Energy Commission. The objective was to evaluate residential energy standards against measurement-based performance. One house was tested in New York State in collaboration with the National Association of Home Builders National Research Center under contract with the New York State Energy Research and Development Agency. The objective was to evaluate STEM as a short-term testing tool for retrofits and new home ratings. Five houses were tested in Colorado in collaboration with the Architectural Energy Corporation under contract with the Colorado Division of Housing. The objective was to determine heating system improvements as a result of furnace retrofits.

Demonstration software to highlight the salient feature of STEM was developed. In addition, several enhancements were made to STEM-1 software and incorporated into a new version, STEM-2.

Major Project Reports:

Short-Term Energy Monitoring-STEM-1.0 User Manual.

"Short-Term Test of a House in San Jose, California."

Subbarao, K., J. D. Burch, C. E. Hancock, A. Lekov, and J. D. Balcomb, "Summary of Short-Term Tests on Four Houses."

Summary Date: September 1989

Current Publications

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Lampert, C. M., 1989, "Advances in Optical Switching Technology for Smart Windows, LBL-27720, Berkeley, CA: Lawrence Berkeley Laboratory. Also in *Proceedings of 1989 ISES*, International Solar Energy Society, Kobe, Japan, September 1989.

Lampert, C. M., ed., 1989, *Characterization Parameters and Testing Technology for Electrochromic Films and Devices*, International Energy Agency, forthcoming.

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Lampert, C. M., and Granqvist, C. G., 1989, "Large-Area Chromogentics," Bellingham, WA: Optical Engineering Press.

Rasson, J., and M. Wahlig, April 1989, *Progress Report on Development of Improved Chiller Simulation Models as Part of the U.S./Israel Joint Project on Solar Cooling*, LBL-26657, Berkeley, CA: Lawrence Berkeley Laboratory.

Rasson, J., M. Wahlig, and K. Dao, 1989, *Regenerative Absorption Heat Pump*, LBL-27439, Berkeley, CA: Lawrence Berkeley Laboratory.

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DOE San Francisco Office

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The Active Solar Heating Systems Installation Manual, 1989, ASHRAE publication, Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, forthcoming.

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Braun, J. E., S. A. Klein, J. W. Mitchell, and W. A. Beckman, 1989, "Application of Optimal Control to Chilled Water Systems without Storage," *ASHRAE Transactions*, Vol. 95, No. 1.

Carlson, S., 1988, Modeling of Heat Transfer in Buildings Using Comprehensive Room Transfer Functions, M.S. Thesis, Madison, WI: University of Wisconsin.

Cogan, S. F., N. M. Nguyen, and R. D. Rauh, 1989, "Electrochromism in Sputtered Vanadium Pentoxide," *Proceedings SPIE*, forthcoming.

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