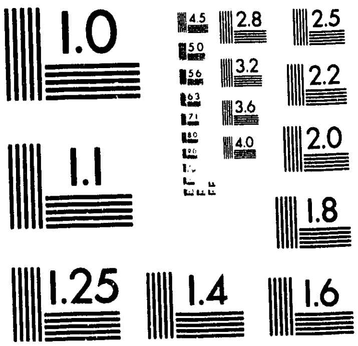
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1993 ANNUAL CONFERENCE

CIEE

PROGRAM

CIEE Sponsors: Pacific Gas and Electric, Southern California Gas, Southern California Edison, San Diego Gas and Electric, Los Angeles Department of Water and Power, California Public Utilities Commission, California Energy Commission, Sacramento Municipal Utility District

AUGUST 4–6, 1993 • SAN DIEGO, CALIFORNIA

PRESENTED BY THE CALIFORNIA INSTITUTE FOR ENERGY EFFICIENCY

WELCOME

to CIEE's 1993 Annual Conference

The California Institute for Energy Efficiency's third Annual Conference highlights the results of CIEE-sponsored multiyear research in three programs: Building Energy Efficiency, Air Quality Impacts of Energy Efficiency, and End-Use Resource Planning. Results from scoping studies, Director's discretionary research, and exploratory research are also featured.

We at CIEE wish to thank Pacific Gas and Electric, Southern California Edison, Southern California Gas, San Diego Gas and Electric, the Los Angeles Department of Water and Power, the Sacramento Municipal Utility District, the California Public Utilities Commission, the California Energy Commission, the University of California, and Lawrence Berkeley Laboratory for supporting and guiding our 1992-1993 research program.

CIEE's Background and Mission

The California Institute for Energy Efficiency was established in 1988 by the University of California in cooperation with California's electric and gas utilities, the California Public Utilities Commission, the California Energy Commission, and the U.S. Department of Energy's Lawrence Berkeley Laboratory. CIEE's mission is to coordinate, plan, and implement a statewide program of medium- to long-term (5 to 15 years) applied research aimed at advancing the energy efficiency and productivity of all end-use sectors in California. This research is conducted primarily at colleges, universities, and university-affiliated research laboratories statewide and is designed to complement the research efforts of CIEE's sponsors and of other significant public and private research organizations.

CIEE's R&D has two primary goals. The first is to identify, develop, and demonstrate efficient end-use energy technologies and processes that:

- Increase the security and sustainability of energy systems in California.
- Help assure continued access to reliable, affordable energy services for all California end users.
- Enhance the productivity and competitiveness of California's agricultural, manufacturing, and service industries.
- Contribute to improving the environment, including regional air and water quality and the quality of the indoor built environment, while remaining sensitive to global-warming issues.

The second overall goal is to improve the data and analytical tools related to the end use of energy. The objective is to support sound utility and public-sector planning decisions on the balanced development of demand- and supply-side energy resources in California.

CIEE emphasizes collaboration in its multisponsor structure, multicampus approach to research, and commitment to translating successful energy-efficiency R&D into practical products and processes. CIEE incorporates sponsor input into the design and management of its R&D programs, primarily through policy and program funding guidance from the Research Board and program planning, management, and technology transfer support from the Planning Committee and Project Advisory Committees (for each major multiyear project).

1993

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LBL CONFERENCE COORDINATORS

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AGENDA

Wednesday, August 4

3:00 pm - 5:00 pm **REGISTRATION**

5:30 pm - 7:30 pm **LUAU**

All participants and spouses/guests are invited to attend an informal dinner.

7:30 pm - 8:00 pm **OPENING REMARKS**

Edward Vine, CIEE Conference Chair
James Cole, CIEE Director
George Strang, Southern California Gas; CIEE Research Board Chair

8:00 pm - 9:00 pm **PLENARY SESSION - KEYNOTE ADDRESS**

Commissioner Charles Imbrecht, Chairman, California Energy Commission

Thursday, August 5

8:30 am - 10:00 am **FIRST MORNING SESSIONS (Concurrent)**

Session A: **Air Quality Impacts Program - Gas Combustion Systems Topic**
Formation of Nitrogen Oxides in Industrial Natural-Gas Burners

Scott Samuelsen (UCI)	Project Overview and Teaming Strategy
Derek Dunn-Rankin (UCI)/ Roger Farrow (SNLL)	Diagnostic Strategy
Bill Sowa (UCI)/ Larry Cloutman (LLNL)	Modeling Strategy

Session B: **Building Energy Efficiency Program - Residential Cooling Systems Topic**

Mark Modera (LBL)	Improving the Energy Efficiency of Residential Air-Distribution Systems in California
Mark Modera (LBL)	Peak-Demand Impacts of Residential Cooling
Hashem Akbari (LBL)	Peak Power and Cooling Energy Savings of Shade Trees and White Surfaces

10:00 am - 10:30 am **BREAK**

Thursday, August 5 (continued)

10:30 am - 12:00 noon **SECOND MORNING SESSIONS (Concurrent)**

Session A: **Air Quality Impacts Program - Alternative Transportation Systems Topic Assessment of Natural-Gas and Electric Vehicles**

Dan Sperling (UCD)	Project Summary
Andy Ford (WSU)	The Impact of Electric Vehicles on the Southern California Edison System

Session B: **Building Energy Efficiency Program - Commercial Buildings**

Mort Blatt (EPRI)	Office Technology Efficiency Consortium: Office Technologies Assessment
Steve Selkowitz (LBL)	Envelope and Lighting Technology to Reduce Electric Demand: Project Overview
Francis Rubinstein (LBL)	Envelope and Lighting Technology to Reduce Electric Demand: Integrating Fenestration Controls with Lighting Controls

12:15 pm - 1:15 pm **LUNCH**

1:30 pm - 3:15 pm **POSTER SESSION (5-Minute Presentations)**

Hashem Akbari (LBL)	Neighborhood Cooling by Vegetation
Paul Berdahl (LBL)	Energy Efficiency and Fire Safety Aspects of Reflective Coatings
James Bobrow (UCI)	Adaptive Optimization of Internal Combustion Engines for Fuel Variability
Ed Carnegie (Cal Poly/SLO)	Walking System for the Cal Poly Controlled Traffic Farming System
Bailey Green (UCB)	Methane Recovery in Advanced Integrated Ponding Systems: An Update
Brent Griffith (LBL)	Advanced Refrigerator/Freezer Design Concepts
Ian Kennedy (UCD)	Utilization of Waste Oxygen for Low-Emission Combustion
Sukhbir Mahajan (CSU Sacramento)	Use of EMCS Technologies to Reduce Peak Cooling Loads in Nonresidential Buildings: An Update
Ashish Gupta (UCLA)	Design of Hybrid Power Cycles for Waste Heat Recovery Applications
John La Porta (Cal Poly/SLO)	Computer-Based Design Advisor for Energy-Efficient Building Design
Anthony Sebald (UCSD)	Use of Intelligent Control Techniques for Energy-Efficient Smart Buildings
Steve Selkowitz (LBL)	A Computerized Design Aid for Utility Demand-Side Management Programs
Steve Selkowitz (LBL)	Interactive Information Kiosk: Providing Information About Energy Efficiency in Buildings
Richard Snyder (UCD)	Wind Machines for Freeze Protection
Richard White (UCB)	Ultrasonic Silicon-Based Air-Quality Monitor
Fred Winkelmann (LBL)	Model to Simulate the Performance of Hydronic/Radiant Cooling Ceilings

3:15 pm - 5:00 pm **POSTER SESSION (Posters)**

Friday, August 6

8:30 am - 10:00 am **FIRST MORNING SESSIONS (Concurrent)**

Session A: **Air Quality Impacts Program - Gas Combustion Systems Topic**
Energy-Efficient, Low-NO_X and -CO Burners for Residential, Small Industrial, and Commercial Gas Appliances

Bob Dibble (UCB)	Diode Laser Diagnostics, Combustion Modeling
Catherine Koshland (UCB)	Experimental Burners
Greg Traynor (LBL)	Residential Emission Modeling and Forecasting

Session B: **Mini-Poster Session**
Building Energy Efficiency Program - Residential Cooling Systems Topic
Alternatives to Compressor Cooling in California Transition Climates

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Posters:	**Joe Huang (LBL)**	Analysis of Climatic Conditions and Preliminary Assessment of Alternative Cooling Strategies
	Fred Bauman (UCB)	Comfort Analysis
	Helmut Feustel (LBL)	Ventilative Cooling and Control Strategies
	Baruch Givoni (UCLA)	Nocturnal Ventilative Cooling
	Fred Winkelmann (LBL)	Improved DOE-2/COMIS Residential System Model
	Loren Lutzenhiser (WSU)	Cultural, Sociological, and Institutional Issues
	Hofu Wu (Cal Poly/Pomona)	Architectural Integration and Performance Optimization of Evaporative Cooling Systems

10:00 am - 10:30 am **BREAK/Continuation of Mini-Poster Session**

10:30 am - 12:00 noon **SECOND MORNING SESSIONS (Concurrent)**

Session A: **End-Use Resource Planning Program**

Alan Meier (LBL)	California Utility Database on Monitored Performance of Efficient End-Use Technologies
Joe Eto (LBL)	Residential Sector Space-Conditioning Load Data Analysis
Hashem Akbari (LBL)	Integrated Estimation of Commercial-Sector End-Use Load Shapes and Energy-Use Intensities in the PG&E Service Area

Session B: **Scoping Activities/Upcoming Projects**

Anthony Sebald (UCSD)	Building Performance Measurement, Operation, and Control
Mark Rea/ Dorene Maniccia (LRC)	Improved Optimization of Energy Efficiency and Load Shaping Through Lighting Controls: A Scoping Study
Helmut Feustel (LBL)	Residential Ventilation Systems

Friday, August 6 (continued)

12:15 pm - 1:30 pm	**LUNCH/SPEAKER: James Cole - Future Directions for CIEE**	
1:45 pm - 3:15 pm	**AFTERNOON SESSIONS (Concurrent)**	
Session A:	**Air Quality Impacts Program - Emission Reduction Strategies Topic Analysis of Energy Efficiency and Air Quality**	
	Haider Taha (LBL)	Introduction and Project Overview
	Arthur Winer (UCLA)	The Role of Vegetation as a Source and Sink for Air Pollution in the South Coast Air Basin
	Dave Sailor (LBL)	Meteorological Modeling Investigation of Mitigation Strategies for the South Coast Air Basin
	Haider Taha (LBL)	Urban Airshed Modeling of the South Coast Air Basin: Preliminary Sensitivity Analysis
Session B:	**Building Energy Efficiency Program - HVAC Distribution Systems Topic**	
	Eric Matthys (UCSB)	Reducing Pumping Power in Hydronic Distribution Systems Through the Use of Fluid Additives
	Fred Bauman (UCB)	Localized Thermal Distribution Systems for Office Buildings
	Mark Modera (LBL)/ Fred Bauman (UCB)	Efficient Thermal Energy Distribution in Commercial Buildings
3:15 pm - 3:45 pm	**CONFERENCE SUMMARY/CLOSING REMARKS: James Cole**	

FORMATION OF NITROGEN OXIDES IN INDUSTRIAL NATURAL-GAS BURNERS

PROJECT OVERVIEW AND TEAMING STRATEGY

Scott Samuelsen
Professor
University of California, Irvine, Combustion Laboratory

New demands to improve air quality have resulted in a need to equip a broader population of industrial sources with low-NO_x burners, develop burners for this population that attain the lowest possible NO_x emission, and assure maintenance of this ultralow-NO_x performance using active control.

The research challenge is to develop design criteria for ultralow-NO_x industrial burners while maintaining or enhancing both burner combustion efficiency and overall system energy efficiency. Empirical, trial-and-error methods using "input/output" experiments are no longer sufficient; the process of NO_x formation within the burner must be understood. This requires in-situ, detailed measurements within the burner; complementary modeling to determine the sensitivity of these fields and mixing processes to system geometric features and operating conditions; and development of the optimal combination of geometric features, operating conditions, and an active control procedure to attain and maintain ultralow-NO_x performance in practical operation.

The technical approach encompasses:

- Design, fabrication, installation, and operation of a 100,000 Btu/hr model industrial gas burner with full optical access for visualization and laser diagnostics.
- Development and application of a novel laser diagnostic for the in-situ measurement of NO and NO_2.
- Acquisition of in-situ measurements to reveal the aerodynamic, thermal, and chemical fields of the burner as well as the sensitivity of these fields to parametric variation.
- Modification of a comprehensive code to incorporate a mixing model with thermal NO, prompt NO, NO_2, and N_2O kinetics.
- Use of the code in conjunction with the experiment to develop further insight.
- Identification of the boundary and operating conditions that minimize NO formation while maintaining or improving energy efficiency.
- Development and application of an active control methodology for attaining and maintaining high-efficiency, ultralow-NO_x performance in practical systems.

The program, cofunded by Southern California Gas, was initiated in June 1991. The goals of the first phase were to design, build, and bring on-line the 100,000 Btu/hr research burner and test stand; apply and demonstrate the comprehensive modeling for the research burner; and develop and demonstrate the adaptation of degenerate four-wave mixing for the in-situ measurement of NO and NO_2. The goals of the past year were to obtain preliminary "proof-of-concept" measurements to demonstrate the potential of ultralow-NO_x performance, integrate the advanced diagnostics and modeling into a common experiment, and begin developing the active control. Each objective has been achieved.

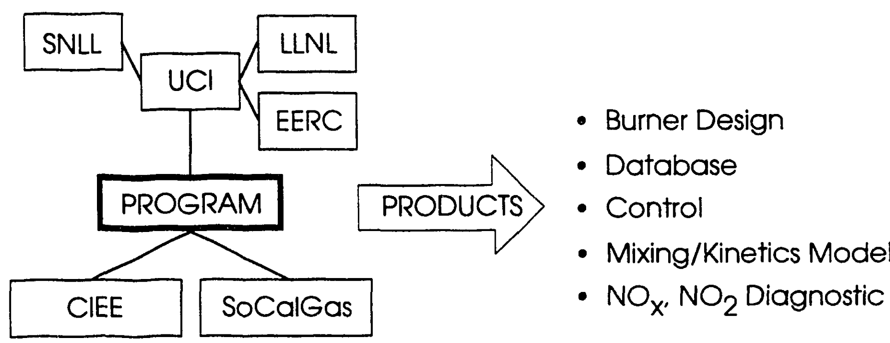
The third phase will focus on detailed test matrices. Design-of-experiments methodologies will be used to reveal the geometric and operating characteristics that produce ultralow-NO_x performance while enhancing overall combustion and energy efficiency. The teaming program will follow a fully integrated, systematically managed path of discovery in two phases: exploratory and full production testing. Based on these findings, design criteria will be established and the active control developed and implemented to attain and maintain ultralow-NO_x, high-efficiency operation in practical applications.

The program team includes:

- University of California, Irvine (UCI): Matt Miyasato, John Garman, David Moyeda, David St. John, and Suresh Vilayanur (students); Dr. Derek Dunn-Rankin, Dr. William Sowa, and Dr. Scott Samuelsen (faculty).
- Lawrence Livermore National Laboratory (LLNL): Dr. Larry Cloutman and Dr. Charles Westbrook.
- Sandia National Laboratories, Livermore (SNLL): Dr. Roger Farrow and Dr. David Rakestraw.

This effort is coordinated with CIEE-funded work on low-NO_x combustion for residential and small commercial and industrial applications.

As the primary institution, UCI is responsible for the experiment, the active control, and overall program coordination. LLNL provides critical modeling expertise, while SNLL is pioneering a major advance in optical diagnostics for measuring NO and is collaborating with UCI on the NO_2 measurement.



FORMATION OF NITROGEN OXIDES IN INDUSTRIAL NATURAL-GAS BURNERS

DIAGNOSTIC STRATEGY

Derek Dunn-Rankin
Professor
University of California, Irvine, Combustion Laboratory

Roger Farrow
Senior Research Scientist
Sandia National Laboratories, Livermore

To understand NO_x formation in nonpremixed industrial gas burners, we need diagnostic tools to measure NO concentration, temperature, and velocity with spatial and temporal resolution. These tools must not perturb the system they are measuring, a requirement that laser-based diagnostics usually satisfy. In the case of temperature and velocity, appropriate and well-established laser diagnostic techniques are available. For species concentration, however, the techniques are not as well developed.

The goals of this project's diagnostic strategy are to integrate existing laser diagnostics with the model industrial gas research burner, develop a diagnostic tool capable of spatially resolving NO and NO_2 species concentration in the gas burner environment, and measure local temperature, velocity, and species concentration fields as a function of burner operating conditions.

Laser velocimetry is used to map the velocity fields in the burner; coherent anti-Stokes Raman scattering (CARS) is used to measure the temperature field. Both instruments reside at the University of California, Irvine (UCI). The species concentration diagnostic is either laser-induced fluorescence (LIF) or degenerate four-wave mixing (DFWM) or both. LIF is a mature technique but suffers from quenching correction ambiguities; DFWM is less mature than LIF but has promise as a diagnostic technique because it can provide strong signals that are collimated and easily isolated from background light. The conceptual layout of the diagnostics is shown in the figure, which highlights the complication of applying several laser techniques simultaneously.

The diagnostic activity is divided among team members at UCI and Sandia National Laboratories, Livermore: UCI is responsible for the layout, coordination, and application of the laser velocimetry and CARS, LIF, and DFWM diagnostics; SNLL is responsible for developing DFWM from a promising diagnostic technique to a quantitative method for measuring NO concentration in the UCI gas burner.

At UCI, the following diagnostic activity has been completed:

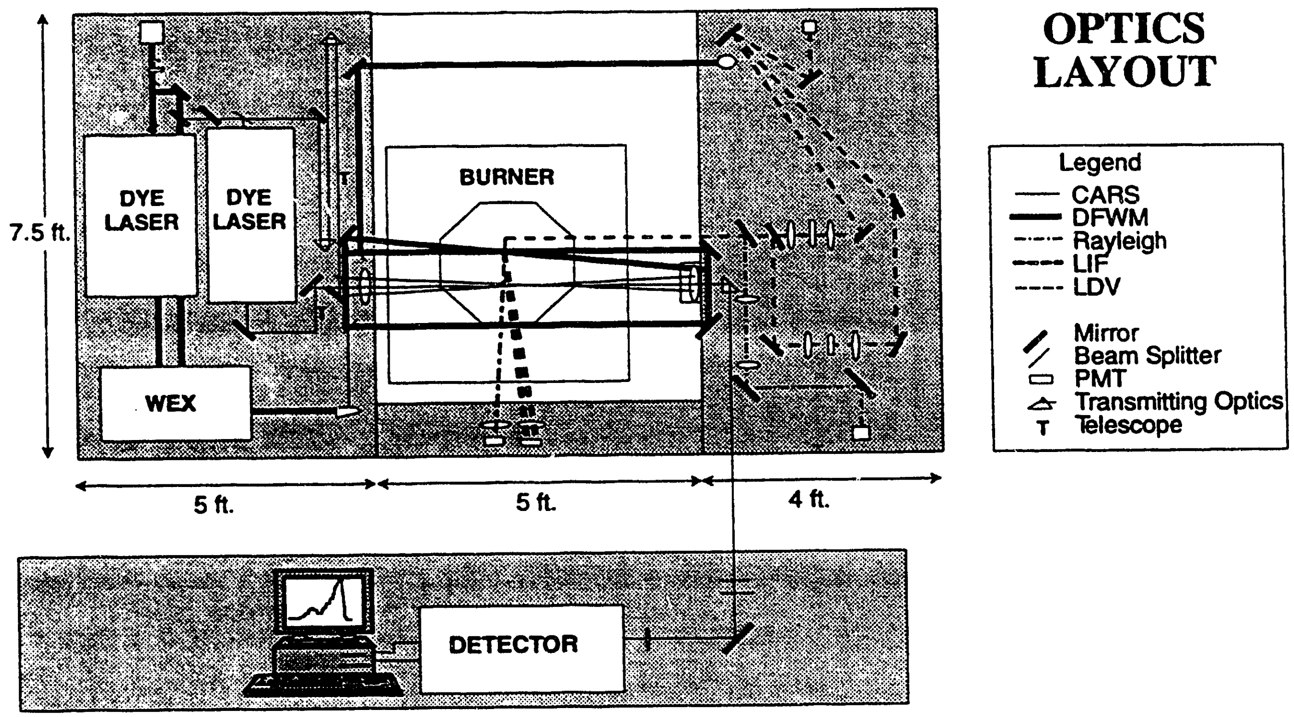
- A pilot study of DFWM signals from room-temperature NO_2 as a function of buffer gas pressure in a test cell.
- The conceptual layout of all laser diagnostics on the optical breadboards surrounding the gas burner.
- Mounting of the laser equipment necessary for DFWM measurements of NO.

The progress at SNLL includes:

- Completion of a detailed physical model of the DFWM process, including saturation effects.
- Exploration of the thermal grating phenomenon in DFWM measurements, including an assessment of its implications for DFWM use in a burner.
- Development of a user-friendly fitting code that allows matching of measured and theoretical DFWM spectra to determine temperature and species concentration.

- Technology transfer of DFWM and LIF methodology to UCI for use in the burner.

Conceptual layout of diagnostics.



FORMATION OF NITROGEN OXIDES IN INDUSTRIAL NATURAL-GAS BURNERS

MODELING STRATEGY

Bill Sowa
Associate Director
University of California, Irvine, Combustion Laboratory

Larry Cloutman
Senior Research Scientist
Lawrence Livermore National Laboratory

The first phase of this project focused on preparing burner modeling tools; the past year has focused on understanding how these tools can be applied to the burner system at the University of California, Irvine. Both UCI and Lawrence Livermore National Laboratory have played a critical role in the progress of the past year: In addition to conducting the burner simulations identified by the UCI team, the LLNL team has evaluated code sensitivity to boundary conditions and modified the code to provide NO_x data. The UCI team identified the cases to be simulated, established the needed data sets and geometries to initiate the modeling activity, identified the required code output, and critiqued and focused the direction of the modeling activity. UCI also addressed the statistical modeling of the experimental data and evaluated the steady-state, industrial-type modeling approaches.

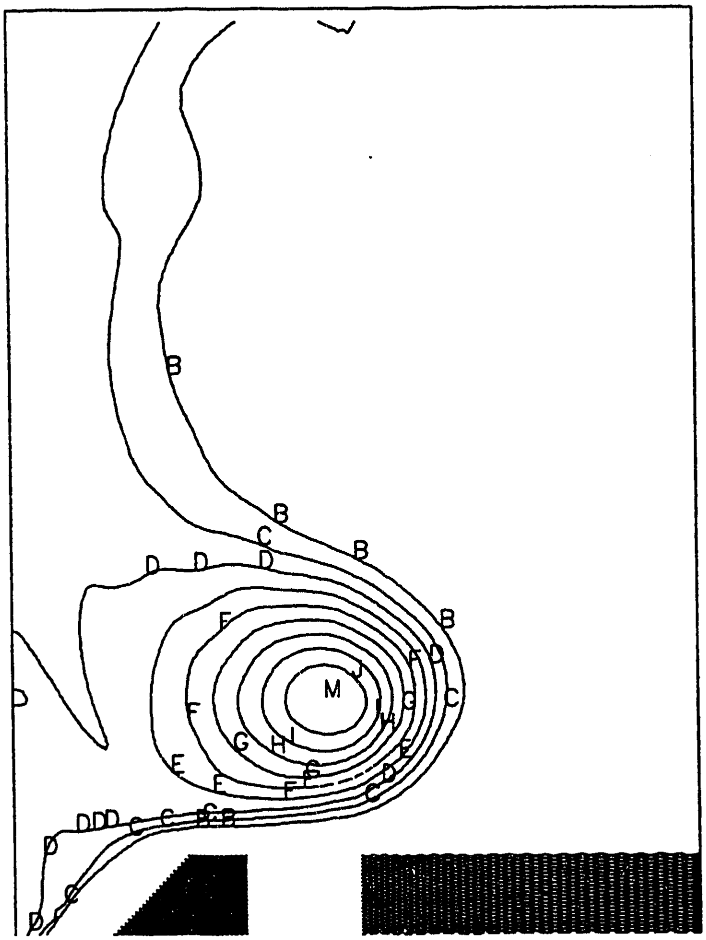
The model industrial research gas burner poses a significant challenge of resolution. In the near burner region, the velocity and composition gradients are steep. This region represents less than 10% of the total chamber volume. Creating numerical grids that contain a sufficiently fine resolution of the near burner region and are not computationally expensive is critical.

Simulations conducted to study the sensitivity of modeling the entire burner chamber (versus modeling only the near burner region) revealed that secondary flows, established in the bulk of the chamber, have a significant impact on the flame shape and performance. This finding represents both a challenge and an opportunity: a challenge in that burner performance is tied to chamber geometries, and the burner design and chamber design must be considered in parallel; an opportunity in that the comprehensive model is sensitive to the burner and chamber designs, suggesting that it represents a vehicle by which the results can be extrapolated (albeit cautiously) to different boundary conditions and scales.

A second important study during this past year addressed the unsteady features of a stable flame. High-speed video imaging demonstrated that the reaction, which appears steady to the eye, in reality is made up of fluctuating packets of fuel-rich and fuel-lean mixtures. Understanding and controlling the spatial distribution, fluctuation frequency, and degree of variation in the composition of these gas packets is critical in attaining and maintaining ultralow NO_x in burners. Modeling activities are in progress to identify the sensitivity of NO_x production to these time-dependent departures from mean properties in a visually stable flame.

A third focus has been on understanding the mechanisms of NO_x formation and transport in flames. The figure on the following page illustrates total predicted NO_x in the near burner region a short time after ignition, before operation has stabilized. The fuel injector is located in the lower left-hand corner. The local NO_x concentration can be divided into that generated locally by chemistry and that transported via either advection or diffusion. (In this case, high concentrations of advected NO_x have been found near the fuel inlet.) This method of separating the local transport and formation/destruction mechanisms is an invaluable tool in engineering ultralow-NO_x burners.

Total predicted NO_x in the near burner region.



NO MASS FRACTION

IMPROVING THE ENERGY EFFICIENCY OF RESIDENTIAL AIR-DISTRIBUTION SYSTEMS IN CALIFORNIA

Mark Modera
Staff Scientist
Lawrence Berkeley Laboratory

This multiyear research program, now in its third phase, is investigating ways to improve the efficiency of air-distribution systems in single-family, detached residences in California. The objectives of this effort are to:

- Obtain representative data on the implications of air-distribution systems on residential energy consumption, peak power demand, and ventilation in California.
- Develop, test, and evaluate the cost-effectiveness of alternative approaches to the problems with residential air-distribution systems in both new and existing buildings (including duct installation standards, sealing technologies, and non-air-distribution systems).
- Deliver a field-tested retrofit package for residential air-distribution systems to California utilities and other residential audit and retrofit groups.
- Provide a technically and economically defensible analysis of residential distribution system options for new buildings as well as a set of recommendations for the Title 24 residential energy code.

The third-phase efforts are focused primarily on the last three objectives, the results and implications of which are discussed in the following subsections.

BACKGROUND

Approximately half of the households in the U.S. have central warm-air furnaces and air-distribution ducts. Given their widespread use and the fact that they are a vital link between houses and their space-conditioning plants, residential duct systems—in particular, their comfort and energy-effectiveness—are regularly revisited as a topic of study. Those studies have uniformly concluded that the performance of thermal energy distribution merits further examination. The issue of residential air-distribution system performance, particularly the duct-leakage problem, is especially important in California, where just over half of the residences contain a total of approximately 100,000 miles of ductwork and where virtually all new construction uses air-distribution systems.

Duct leakage is especially important in California because ductwork is almost invariably in unconditioned attics and crawl spaces (due to the scarcity of basement construction in the state). Earlier studies suggested that the air leakage from a typical duct system in a Sacramento house represents between 1 and 2 kW (depending on the location of the ducts) of peak-hour demand and 20 to 40% of the peak cooling day consumption; it also represents approximately 1 kW of peak heating demand and 2,000 to 3,500 kWh of annual electricity consumption for a heat-pump-heated house. In addition to their energy and peak-demand implications, leaky duct systems have also been shown to double air-infiltration rates when the distribution system is on, representing between 20 and 40% of the average annual ventilation of residences.

In the first phase of this project, researchers studied the air-distribution systems of 31 houses in California, developed a detailed simulation tool for such systems, and conducted a survey of HVAC contractors. The first-phase results generally confirmed earlier findings and pinpointed several additional ways to improve duct efficiency.

RESULTS

Phase III tasks include:

- With the Department of Energy and Sacramento Municipal Utility District, field-testing a duct-system retrofit protocol.

- Continuing development of an aerosol-based duct-sealing technology.
- Refining and applying an integrated duct-system/infiltration/thermal performance simulation tool.
- Investigating high-R-value duct technologies and air-tight duct fittings (with the Electric Power Research Institute).

The aerosol-sealant effort yielded two particularly significant results: confirmation that a spherical aerosol can seal slot-type leaks at least as large as 4 mm across and duct-joint-type leaks with 2 mm openings as far as 8 m from aerosol injection, and confirmation that the leaks could be filled even with the registers completely sealed.

Based on numerous tests with the experimental apparatus developed, researchers found the aerosol-injection process to be a critical factor in sealing effectiveness.

Simulations with the tool developed in Phases I and II allowed researchers to quantify the savings potential of duct insulation and sealing in different California climates. These simulations also indicated that a duct-improvement package that yields 17% energy savings also improves peak duct efficiency by 45%. This improvement translates to a 45% downsizing of cooling equipment without affecting occupant comfort.

ACCOMPLISHMENTS

The major accomplishments of the past year are:

- Experimental demonstration of the sealing effectiveness of a spherical aerosol under realistic conditions in the laboratory and design of an apparatus to be tested in the field.
- Completion of a sensitivity analysis of the impacts of various system-improvement options for different California climates.
- Development and construction of a prototype duct section employing the gas-filled-panel insulation technology developed in another CIEE project.
- Development and deployment of a new cellular-telephone-based data acquisition system for detailed examination of duct-system and duct-retrofit performance in the field.

PEAK-DEMAND IMPACTS OF RESIDENTIAL COOLING

Mark Modera
Staff Scientist
Lawrence Berkeley Laboratory

The goal of this project is to develop demand-side management (DSM) program strategies for residential cooling that address both peak-demand issues and energy issues. The specific objectives of this work are to:

- Modify existing detailed simulation tools to accommodate time- or load-dependent variations in the performance of DSM program options for residential cooling (for example, high Seasonal Energy Efficiency Ratio, or SEER, air conditioners and duct-system retrofits).
- Use those tools to break down the loads and inefficiencies contributing to system and power-distribution peak electricity demand.
- Use laboratory and field-test data (including load research data) within the detailed simulation tools to analyze the electricity-demand implications of DSM program options addressing residential cooling.
- Use field studies to obtain primary data on the field performance of residential HVAC systems and envelopes, including peak-demand performance.
- Develop simplified analysis tools and standardized demand performance characterizations for residential HVAC system and envelope components.

BACKGROUND

The cost-effectiveness of utility DSM programs for residences is generally based on energy savings and demand reduction. In fact, the cost to the utility and ratepayers of peak demand (both system and local transmission and distribution) is particularly dramatic for residences, whose air-conditioning electricity demand is large and occurs during only a few hours of the year.

Various groups have assessed the demand-side potential of residential technologies from the point of view of energy savings and demand savings; however, the degree of sophistication and understanding of the issues and the data needed to verify the field performance of cooling technologies and retrofits have not been available. In many instances, the peak-load impacts of many DSM measures are assumed to scale with their energy savings. This presumes that the measures have the same performance under average and peak conditions, when in fact the ratio of percentage peak-load impacts to percentage energy-consumption impacts can be significantly higher or lower than unity.

As an example, sealing duct leakage in single-family residences has been shown to save energy. However, the peak-demand impacts of that sealing remain unclear. Simulations indicate that duct leaks have disproportionately higher energy penalties under peak cooling or heating conditions, implying that the peak-demand benefits of sealing should be disproportionately higher than the average energy-savings benefits.

On the other hand, depending on the degree of oversizing of the air conditioner in the house in which the ducts are being sealed, the utility may realize only a fraction of the nominal peak-savings potential. In a house that was undercooled on peak days, the owner is likely to "take back" many of the duct-efficiency improvements in the form of improved comfort during the hours of peak cooling-energy demand.

A related example is high-efficiency air conditioners, which are generally characterized in DSM programs by their SEER. The problem in this case is that although SEER might be a reasonable indicator of annual energy consumption, it is not necessarily a good indicator of peak-load performance. The peak-demand implications of these air conditioners depend on the measures taken by the manufacturer to improve their SEER, and some of those measures do not significantly improve the unit's performance under extreme temperature conditions. These examples are by no means unique; the same issues are germane to most residential space-conditioning DSM measures in both new and existing construction.

In the long term, we need to evaluate the economic performance of utility DSM programs based on all of their energy-use and demand impacts. This includes their impact on local distribution peaks as well as on the system peak. To evaluate these impacts accurately, we need improved analysis tools and data.

RESULTS TO DATE

Analysis of residential duct-improvement simulations were examined in terms of their conservation load factors. This factor is the ratio of the percent improvement in performance during peak-demand conditions to the average percent improvement. Duct retrofits were found to have conservation load factors between 2 and 4. In particular, a standard retrofit package that should save 17% of the space-conditioning energy used results in a 45% efficiency under peak conditions. This analysis points out that the entire cost of duct improvement could be more than compensated for by equipment downsizing. The implication is that duct DSM programs targeted toward new construction and/or equipment replacement (at burnout) have enormous potential for peak-demand reduction, with virtually no risk of customer take-back. Moreover, proper design of these programs will give the customer improved service year-round, including during periods of peak demand.

PLANNED ACTIVITIES

This effort is restricted to DSM technologies specifically targeted at reducing residential space-cooling consumption, focusing primarily on high-efficiency air-conditioner and duct-system issues. The approach comprises five principal activities: simulation, measurement, analysis, synthesis, and management. Specific activities include:

- Acquiring manufacturers' data on capacity and efficiency variations of standard and high-SEER central air conditioners with temperature.
- Using existing load-research data to characterize the oversizing and occupant-control scenarios of typical residential installations.
- Modifying and using the DOE-2/COMIS and DUCTSIM simulation codes to examine average and peak-demand impacts of residential cooling technologies (including the use of heat-storm data to simulate peak-demand conditions).
- Developing and using a data acquisition and analysis protocol for a field study of air-conditioner peak-load performance, analysis and synthesis of field measurement and simulation results, and development of standardized characterizations of the peak-load performance of residential cooling options.

PEAK POWER AND COOLING ENERGY SAVINGS OF SHADE TREES AND WHITE SURFACES

Hashem Akbari
Staff Scientist
Lawrence Berkeley Laboratory

The goal of this project is to monitor peak power and cooling energy savings from shade trees and white surfaces in Sacramento. The second phase of the project is focusing on the data and experimental control problems encountered in the first phase. The air-conditioning energy savings of shade trees and albedo changes in two temporary school buildings and three houses in Sacramento will be monitored and this data compared with simulation results. This phase is also addressing issues related to the durability and market availability of high-albedo materials and assessing procedures for measuring and labeling their albedo.

For most sites, data was collected on air-conditioning electricity use, indoor and outdoor dry-bulb temperature and humidity, roof and ceiling surface temperature, inside and outside wall temperature, insolation, and wind speed and direction. The collected data has been analyzed to estimate the effects of shade trees and albedo modification on cooling energy use of the monitored sites. The buildings are also being modeled with the DOE2-1.D simulation program.

SHADE TREES

Sites 7 and 8 were monitored during the summer of 1992 to quantify the impact of shade trees. A three-stage "flip-flop" experiment was designed to quantify those effects. By comparing measurements at the two sites, researchers estimated the savings during the shaded periods at Sites 7 and 8 at 46% and 26%, respectively. Further, the shade trees dramatically reduced the wind speed as measured on the roofs of the houses.

Analysis has revealed the total daily cooling energy use at each site to be well correlated with the daily average temperature. Using this correlation, researchers estimated the savings over the entire summer at 400 kWh (29%) at Site 7 and 330 kWh (31%) at Site 8. They also found that at Site 8, during the late summer, the indoor air temperature rises faster at a given roof insolation than during the early summer. This finding indicates that heat gain through walls increases during the late summer and that shade trees are most effective during that time.

WHITE SURFACES

Site B and Site 2 were monitored to determine the effects of modifying a roof's albedo on cooling energy use in a building. Site 2 was monitored with a dark roof (albedo 0.18) and the roof painted white. In 1992, albedo was measured at 0.73.

At Site B, the school site, two similar buildings were monitored. In 1991, the roof of one building (the control) was left alone, while the test building was painted brown and then white. In 1992, the building that served as the control in 1991 was painted brown and then white, and data was collected for both buildings.

Cooling energy consumption at Site 2 after the roof was painted white was compared to cooling energy use during the 1991 premodification period (albedo 0.18). The data indicated that with a white roof the outdoor average daily temperature would be 2°C higher before air conditioning was necessary.

Compared to data collected in 1992, the premodification data from the same period in 1991 indicated an energy savings of about 2 kWh per day; that's almost half of the cooling energy use for this part of the year. The hourly averages indicated a two-hour delay in the indoor temperature's response to the outdoor temperature, so the outdoor temperature two hours earlier could be used as an indicator of cooling energy use. Comparison of cooling energy use before and after modification with the difference between the indoor temperature and the outdoor temperature two hours earlier showed that before the roof is painted white, cooling needs encompass a range from 1 to 10°C; in the high-albedo case, the cooling needs were confined to a range of 4 to 6°C.

SIMULATION MODELS

The primary purpose of this work is to investigate whether or not the simulations can be used to extrapolate the results of this project to other buildings, locations, and tree and albedo strategies. It is an effort not to validate the DOE2-1.D program, but rather to determine whether the models as developed are as sensitive to the shading and albedo changes as the buildings in the field.

The data collected in 1992 offers a much better opportunity to investigate these issues than does the data collected in 1991; that's because of the longer period of data collection, monitoring during the peak cooling season in August, more comprehensive data collection at Site B2, and the larger trees installed at Sites 7 and 8.

A "first cut" of the simulations has been run and compared to the measured data, helping define the most interesting areas for further analysis. Based on the work to date, the necessary refinements include using site temperature, wind speed, and solar data as model inputs, particularly at Site 2; investigating possible biases in the models with respect to the tree cases at Sites 7 and 8; determining the source of the large overestimation of cooling energy use at Site 8; and investigating the possible biases in the models with respect to roof albedo. At Site B2, which underwent various roof-painting regimes, the model tends to underpredict energy use in the metal and brown roof cases.

ASSESSMENT OF NATURAL-GAS AND ELECTRIC VEHICLES

PROJECT SUMMARY

Daniel Sperling, Professor
Cathy Kling, Associate Professor
University of California, Davis

Andy Ford
Associate Professor
Washington State University

Motor vehicles are major energy users and polluters in California, accounting for about half the hydrocarbon and nitrogen oxide emissions, about 30% of the greenhouse gases, more than 80% of the carbon monoxide, and more than half the petroleum consumed.

This research program comprises four projects: consumer demand for electric and natural-gas vehicles; fleet demand for EVs and NGVs; incentive-based regulatory approaches to introducing EVs and NGVs; and utility impacts of EVs and NGVs. The first three are being conducted at the University of California, Davis, and the fourth at Washington State University (initially at the University of Southern California).

The overall goal of this project is to identify and evaluate transportation end-use technologies and strategies—specifically, vehicles powered by natural gas and electricity—that contribute to the cost-effective reduction of air pollution and greenhouse gas emissions in California's urban and rural areas.

CONSUMER DEMAND

The topic of this study is the potential demand for EVs and NGVs in the California passenger-vehicle market, focusing on underlying consumer behavior regarding vehicle purchase and use. The goal is to identify the incentives most likely to increase the purchase and use of EVs and NGVs. Time-of-day consumption of electricity will also be projected.

The heart of this project is an interactive interview technique developed especially for analyzing consumer purchase and use of EVs. This PIREG (Purchase Intentions and Range Evaluation Games) technique has been administered in 50 households during the past year. Households kept detailed diaries of travel for one week and then were interviewed in detail about how a limited-range, home-recharge vehicle would fit into their lifestyle. Findings from a previous analysis of one-day diary studies, corroborated by initial PIREG findings, suggest that 50 to 60% of American households could use a limited-range vehicle with relatively few adaptations.

PIREG interviews demonstrated that once consumers learn more about the effects of limited ranges on their household travel, they accept much lower ranges and become more interested in other attributes of the vehicles. The interviews also showed that consumers are more interested in inexpensive batteries for short ranges than expensive batteries for longer ranges and that, for some households, the ability to refuel at home rather than at a station is a significant advantage. Over the coming year, PIREG interviews will be extended to include NGVs, neighborhood EVs, and station cars.

The findings of this project will be used as input to the EV forecasting subproject under way at UC Irvine and UC Davis with funding from Southern California Edison (SCE) and Pacific Gas and Electric (PG&E).

FLEET MARKET DEMAND

The goals of this project are to identify early fleet markets for EVs and NGVs, characterize the diverse fleet market for use in alternative-fuel vehicle (AFV) market studies, determine the responsiveness of different types of fleet owners and operators to various incentives, and forecast the likely penetration of AFVs into the fleet market for a range of economic and technological conditions.

During the past year, a series of focus groups and one-on-one interviews with fleet managers was the basis for developing a fleet typology and decision-making model that will enable researchers to categorize fleets and predict how they will react to various incentives and market and regulatory conditions.

This project is being integrated with a similar project on fleet demand for EVs, conducted by UC Irvine and UC Davis and funded by SCE and PG&E. Costs and research activities will be fully coordinated in the next phase, when surveys are conducted and the data is analyzed.

REGULATORY INCENTIVES

This project designed and evaluated marketable credit programs for introducing EVs and NGVs in California that are targeted at vehicle and energy suppliers. The economic costs of reducing air pollution using various marketable credit schemes—such as the motor vehicle emission trading and banking program adopted in late 1990 by the California Air Resources Board—and the value of the credits for suppliers of electricity, natural gas, EVs, and NGVs were quantified.

A draft report on AFVs' emission levels and emission costs was completed this past year. Cost-effectiveness ratios were calculated for a multitude of AFVs based on production costs, fuel costs, and life-cycle costs. Additionally, a draft report on marketable permits for fuel suppliers was completed that presents a theoretical model of a marketable permit system from the perspective of individual fuel producers. A market equilibrium model and its empirical analog are now being completed. Based on an emissions and cost model (developed in the previous year) and the fuel supplier marketable-permits model, the cost savings associated with a permit system relative to command and control standards are being estimated.

UTILITY IMPACTS

The Phase I analysis of EVs' impact on the SCE system indicated that EVs could be used extensively without the need for extra generating resources in SCE's resource plan. Phase I demonstrated that EVs could lead to flatter electric loads, improved operation of SCE generating resources, and reduced average electric rate.

These potential benefits raised an important question: Should utilities step forward with financial incentives to promote the sale and use of EVs? Phase II research focused on the extent to which utilities could finance incentive programs through the improved operations identified in Phase I. The major development in this phase was the Alternative Vehicle Incentive Simulation System. AVISS is a PC-based model that simulates the impact of utility and/or governmental incentives to promote the sale of alternative vehicles. Phase II demonstrated that AVISS provides an integrated portrayal of incentives over a 30-year planning period. The demonstration relied on the Phase I results and was limited to a vehicle marketplace with only two choices: EVs and conventional vehicles (powered by gasoline or diesel fuel).

Phase III will extend AVISS by adding vehicles fueled by compressed natural gas (CNGVs) and other alternative fuels. AVISS will then be adapted to the planning situation faced by San Diego Gas and Electric, a joint gas-electric utility with an interest in both CNGVs and EVs. The SDG&E application will demonstrate the transferability of the findings and methods.

TECHNOLOGY TRANSFER

The results of this overall project have been presented at more than 15 conferences and various other forums in the past year. The researchers have actively participated in various state, national, and international organizations dealing with EVs and NGVs, and the utility-impact models developed by Andy Ford were the focus of a statewide workshop in April 1993. In addition, considerable leveraging of funds has occurred through the solicitation of matching funds and coordination with other projects.

ASSESSMENT OF NATURAL-GAS AND ELECTRIC VEHICLES

THE IMPACT OF ELECTRIC VEHICLES ON THE SOUTHERN CALIFORNIA EDISON SYSTEM

Andrew Ford
Associate Professor
Washington State University

Electric vehicles' impact on utility companies in Southern California has been studied by investigators from academia, state agencies, and the utilities themselves. They have found that EVs can lead to improved shape of the electric load, improved efficiency of utility operations, and a potential reduction in the average electric rate. EVs also contribute to improved air quality in Southern California. These benefits have prompted many to ask whether the utilities and the state should step forward with financial incentives to promote the sale and use of EVs.

These benefits and the question of financial incentives are the focus of the utility impacts research component of the *Assessment of Natural-Gas and Electric Vehicles* project. The main challenge in this research is to develop analytical tools that permit internally consistent analyses of the impact of EVs on the utility as well as the impact of the utilities' rates and incentives on the potential purchasers of EVs. This challenge is being met with a three-phase effort.

PHASE I: IMPACT OF EVs ON THE SOUTHERN CALIFORNIA EDISON SYSTEM

Phase I was a case study of the EV scenarios for the Southern California Edison (SCE) system. Eight scenarios were designed to allow for a wide range of EV numbers and assumptions. The electric loads were studied with a spreadsheet program designed to "stack" the EV loads on top of SCE's regular loads. The impacts of the extra loads were then analyzed using ELFIN, a utility production costing and financial model.

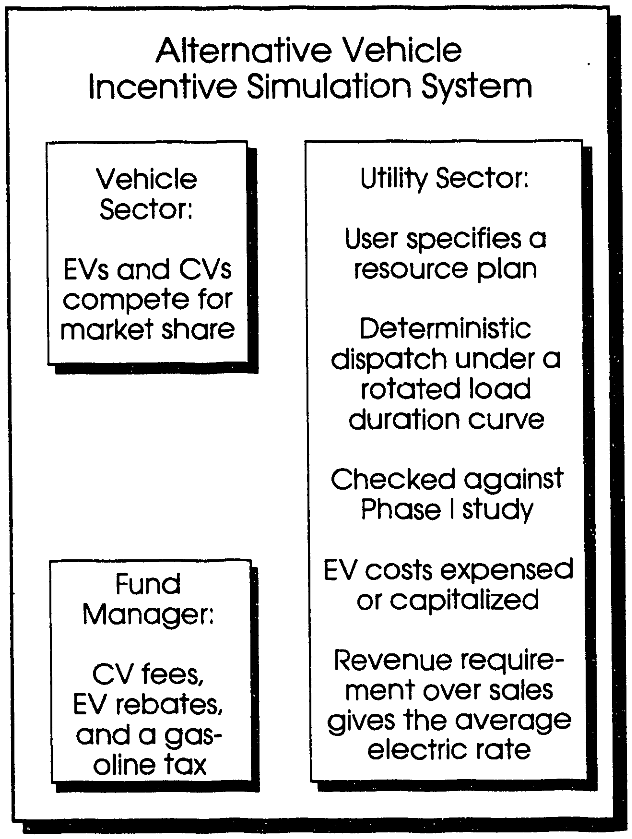
The Phase I findings are similar to what previous investigators have found: EVs can lead to improved load shapes, improved efficiency of operations, and a potential reduction in the average electric rate. There were two surprises, however. First, an unusually large number of EVs could be accommodated within the company's existing resource plan. Second, part of EVs' rate benefits can be erased if loads are flattened, thereby moving coal plants off the margin and increasing the marginal cost basis for payments to qualifying facilities.

PHASE II: THE ALTERNATIVE VEHICLE INCENTIVE SIMULATION SYSTEM

Phase II focused on developing an integrated treatment of the utility impacts that incorporates utilities and EV owners within a single simulation model, the Alternative Vehicle Incentive Simulation System. AVISS comprises the three sectors shown in Figure 1: The utility sector builds from the Phase I study results, the vehicle sector represents the competition between EVs and conventional vehicles (CVs) in the new-car market, and the third sector represents the buildup and drawdown of a state fund that might be used to promote the sale of EVs.

The Phase II research shows that utility incentives for EV sales can be analyzed quickly on a personal computer. While the initial simulation results are only illustrative at this time, it appears that it would be difficult for an electric utility to run an EV incentive program without raising the average electric rate. If utility management and regulatory commissioners consider it important to prevent the average rate from increasing, the utility share of an incentive program will have to be small. The initial AVISS results demonstrate that a state-operated fund could be used to promote EV sales through CV fees or a gasoline tax to fund rebates for EV purchases. The simulations portray the changes in the state fund over time and show how the fund manager should operate the incentive program.

Figure 1. Design of AVISS.



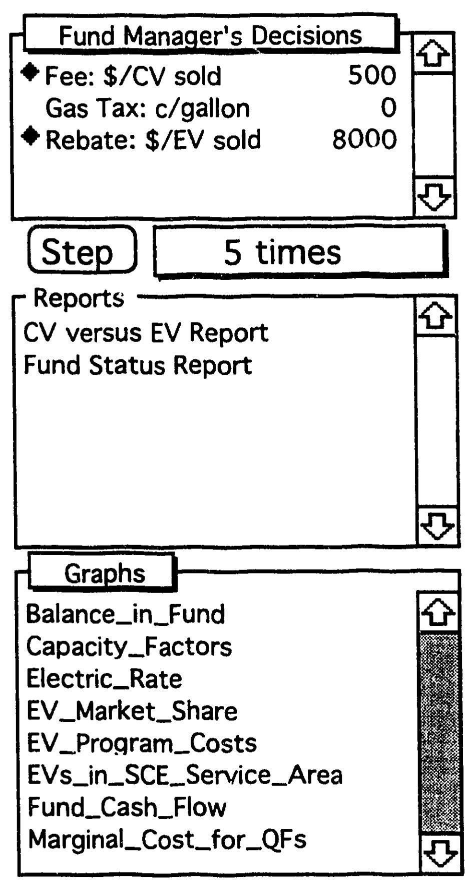
PHASE III: FUTURE DIRECTIONS

Phase III will extend AVISS by adding vehicles fueled by compressed natural gas (CNGVs). The analysis of incentives in the SCE situation will be repeated to learn whether the conclusions change when EVs must compete alongside other alternative-fueled vehicles in Southern California. AVISS will then be adapted to fit the planning situation faced by San Diego Gas and Electric, which is interested in both EVs and CNGVs.

TECHNOLOGY TRANSFER

The computer models developed in the course of the utility-impacts research may be useful to EV planners in state agencies as well as electric utilities. A technology transfer workshop was conducted at the Institute of Transportation Studies at the University of California, Davis, in April 1993; the 22 participants discussed analytical approaches taken in several studies of EV impacts on both the utility generation system and the distribution system. The workshop included a hands-on demonstration of the various models that have proven useful in the CIEE research. Of greatest interest was a MicroWorlds version of AVISS called the Fund Manager, a Macintosh-based program that allows the user to experiment with EV incentive policies through a cockpit like the one shown in Figure 2. In this example, the user has set the fee on the sale of CVs at $500, while the rebate used to lower the purchase price for an EV is set at $8,000.

Figure 2. One view of the Fund Manager's cockpit. The cockpit allows planners to operate AVISS even though they are unfamiliar with the programming details of the model. Workshop participants used the Fund Manager to explore the dynamic implications of different combinations of CV fees, gasoline taxes, and EV rebates.



BUILDING ENERGY EFFICIENCY PROGRAM/COMMERCIAL BUILDINGS

OFFICE TECHNOLOGY EFFICIENCY CONSORTIUM: OFFICE TECHNOLOGIES ASSESSMENT

Morton H. Blatt
Commercial Program Manager
Electric Power Research Institute

CIEE is one of ten sponsors of the Office Technology Efficiency Consortium, organized in early 1992 to encourage the development and increased use of efficient computers, printers, copiers, and faxes. In addition to the cofunders, many other organizations have actively participated in Consortium activities.

Efforts to date have focused on heightening the awareness of specific users and manufacturers of the importance of efficient office equipment, the fastest-growing electrical load in the commercial sector. Slowing load growth in this area helps the utility and their customers by reducing the need to add generation and distribution capability. More efficient equipment helps the individual building owner by reducing electric service requirements as well as energy bills.

Accomplishments include a workshop, held in San Jose in June 1992, to encourage dialog between users, utilities, and manufacturers. Breakout groups discussed imaging technologies, software, LANs, telecommunication, PCs, workstations, and terminals, then joined forces to develop a plan for action. Workshop proceedings (EPRI TR-101945) are available from the Electric Power Research Institute's Research Reports Center, (510) 934-4272.

At the workshop, the U.S. Environmental Protection Agency announced the Energy Star Program, which acknowledges computers and printers that power down to 30 watts or less when not in use. The availability of Energy Star equipment was announced in June 1993, both in Washington, D.C., and at a regional buyers' workshop in New York City.

Consortium-sponsored research has been under way to publicize the availability and virtues of energy-efficient equipment. The American Council for an Energy-Efficient Economy prepared a selection guide for the Consortium, "Guide to Energy-Efficient Office Equipment" (TR-102545). ACEEE and MIT are assessing office technology equipment to identify the state of the art and potential future enhancements to this equipment. They are also developing test procedures to measure energy use for copiers and other office equipment.

A fact sheet, "Electronic Office Equipment" (BR-101965), reviews energy-use characteristics of office equipment, suggests energy-saving options, and profiles three companies that lowered energy costs by changing user behavior and purchasing new equipment.

The Office Technology Efficiency Consortium last met in New York in June 1993 to discuss ongoing research and member activities and to formulate plans for future research.

ENVELOPE AND LIGHTING TECHNOLOGY TO REDUCE ELECTRIC DEMAND: PROJECT OVERVIEW

Stephen Selkowitz
Program Leader, Building Technologies
Lawrence Berkeley Laboratory

More than 40% of the increase in electric demand in California over the next 20 years is projected to come from the nonresidential building sector. Approximately 40% of this demand can be attributed to electric lighting and cooling from lighting and solar gains. While assessment studies and efficiency advocates claim that efficient glazing, daylighting controls, and lighting technologies can substantially reduce energy use and demand growth, in practice the projected savings are not routinely captured.

The problem stems from several factors. First, the traditional mandatory building standards approach to energy efficiency tends to be component-oriented, requiring piecemeal substitution of more efficient components for less efficient components (normally at increased first cost). A better approach is to integrate multiple components and their control network into a single system, thereby reducing the difficulty and risk of designing and specifying the overall set of envelope and lighting technologies. These integrated envelope and lighting systems have the potential to result in higher energy savings with reduced cost. Second, existing energy-efficient technologies, even if fully integrated to meet energy-efficiency goals, often do not satisfactorily accommodate user needs and preferences. Physiological (visual and thermal comfort) and psychological (view, atmosphere) factors must be considered in the envelope and lighting design.

The goal of this multiyear project is to provide designers with cost-effective integrated envelope and lighting systems that meet the full range of occupant needs and to demonstrate their use in built projects, targeting building peak-demand reductions of 15 to 40%.

PROGRESS TO DATE

The primary focus of this second phase of research is to design, build, and test two integrated, dynamic envelope- and lighting-system prototypes that incorporate smart controls to make optimal use of daylight and electric light. An automated venetian-blind system linked to daylighting controls serves as a near-term alternative to *electrochromics*, smart glazings of the future that will be able to modulate transparency from a clear to colored state with an applied voltage. Designing the dynamic system involved exploring various control strategies to actuate the tilt angle of the blinds and to optimize solar and daylighting performance. Core daylighting prototypes included passive optical light-shelf designs using special daylighting optical films and a lightpipe to be installed within the ceiling plenum. These systems were designed to bring daylight to a depth of 30 feet from the window wall.

Expanding on work completed in Phase I, researchers developed these systems iteratively: first using preliminary scale models to evaluate overall daylighting performance, then progressing to more sophisticated numerical simulation models and field tests on a subset of designs. As the designs evolved, the research team worked concurrently with window, shading, control, and lighting manufacturers, trade associations, and architectural and engineering firms to determine manufacturing constraints and potential market barriers. They also continued to pursue new opportunities to demonstrate the prototypes for Phase III and to follow up on demonstration activities initiated in Phase I.

Using a new, experimental method to model optical performance within the DOE-2 building energy simulation program, researchers evaluated the ability of multiple control strategies to achieve the optimal balance between daylighting benefits and solar liabilities. Dynamic systems were found to provide significant savings over typical static glazing systems, with the additional benefit of being able to accommodate user preferences and comfort throughout the day. Both hardware and software components were then assembled and tested outdoors in a reduced-scale-model room to evaluate real-time performance under dynamic sun and sky conditions. The peak cooling performance of the dynamic system was also evaluated using the Mobile Window Thermal Test facility in Reno.

FUTURE WORK

Full-scale demonstrations of the prototypes in occupied buildings will be the major objective of Phase III. Demonstration opportunities initiated during Phases I and II will permit full-scale testing of either elements of these integrated systems or a complete prototype system at a smaller scale within an existing building. Tools to ensure proper design will also be developed during Phase III. The dynamic system will be developed further through more sophisticated control strategies to accommodate other complex criteria, such as occupant preferences and real-time pricing from utilities.

ENVELOPE AND LIGHTING TECHNOLOGY TO REDUCE ELECTRIC DEMAND: INTEGRATING FENESTRATION CONTROLS WITH LIGHTING CONTROLS

Francis Rubinstein
Staff Scientist
Lawrence Berkeley Laboratory

One component of the *Envelope and Lighting Technology to Reduce Electric Demand* project involves developing a building prototype to test the performance of an integrated dynamic envelope and lighting system. Researchers at Lawrence Berkeley Laboratory have designed, built, and instrumented a reduced-scale-model room, part of a prototype that also features a dimmable electric lighting system, a motorized venetian-blind system, associated controls, and a data acquisition system. Located on a rooftop at LBL, the model simulates a single-person office at one-third scale.

The purpose of the prototype is to test various strategies for simultaneously controlling the operation of the venetian blinds and the electric lighting system for improved energy efficiency and to determine whether they can be implemented practically using a few simple sensors and controls (see the table on the following page). While dimming ballasts and control photosensors for electric lighting systems are commercially available (though currently expensive), control sensors that automatically adjust venetian-blind blade angles according to solar position are not available off the shelf; neither are systems that optimally integrate the operation of both the fenestration system and the lighting system to reduce energy use while maintaining occupant comfort.

The inputs to the integrated control system are:

- Internal illuminance (measured with a commercially available ceiling-mounted photosensor).
- Global external horizontal illuminance (measured with a standard photometer).
- Diffuse external horizontal illuminance (measured with a standard photometer equipped with a shadow band).
- Electric lighting power (measured with a watt transducer connected to the dimming ballasts).
- Sun azimuth and altitude (measured with a custom-fabricated sensor designed around a positioning photodiode).

To assess the performance of the integrated control system, researchers are measuring internal workplane illuminance (at varying distances from the window with standard photometers) and electric lighting power.

The prototype integrated control system is being implemented using a Macintosh-based data acquisition and control system (National Instruments' LabView). This system lets the user write programs that process multiple inputs from disparate sensors according to various control algorithms; the user can also produce appropriately scaled outputs to drive the motorized venetian-blind system and the dimmable fluorescent lights. The control strategies being tested can then be implemented in software and the results examined without the need to construct physical electronic circuits. In addition, the LabView system has various output features that allow the graphical display of real-time data.

Fenestration/lighting control strategies.

Strategy	Fenestration Control	Electric Lighting Control
Strategy 1	Blade angles adjusted to block direct sun when sun in window-facing hemisphere. If no sun, maximize openness.	Dimming system adds just enough electric light to provide total illuminance equal to the design light level at workplane stationpoint. Lighting dimmable to 15% of maximum.
Strategy 2	Blade angles adjusted to maximize daylight illuminance at workplane stationpoint. Also block direct sun when sun in window-facing hemisphere.	Dimming system adds just enough electric light to provide total illuminance equal to the design light level at workplane stationpoint. Lighting dimmable to 15% of maximum, then switches off when daylight alone exceeds design level.
Strategy 3	Blade angles adjusted to optimize daylight illuminance at workplane stationpoint.	Dimming system adds just enough electric light to provide total illuminance equal to the design light level at workplane stationpoint. Lighting dimmable to 15% of maximum, then switches off when daylight alone exceeds design level.

NEIGHBORHOOD COOLING BY VEGETATION

Hashem Akbari
Staff Scientist
Lawrence Berkeley Laboratory

It has been widely observed that the climates in urban areas are generally different from those in surrounding rural areas. The magnitude of the difference depends primarily on both anthropogenic factors—degree of urbanization, population density, and land-use patterns—and natural factors, such as the abundance of vegetation, topographic features, and mesoscale/microscale weather patterns.

In most middle and high latitudes, urban air temperatures are usually higher than their rural surroundings due to the *heat-island effect*. This phenomenon has been linked to recent increases in electricity demand, photochemical smog levels, and human discomfort, giving rise to social interest in mitigating its effects.

Strategic planting of vegetation is among the most cost-effective and efficient ways to control the heat-island effect. Urban vegetative systems are usually categorized as trees and grass; trees can provide direct cooling effects (shading) and indirect cooling effects (evapotranspiration), whereas grass can merely provide indirect cooling via evapotranspiration. The goal of this project is to investigate the correlation between surface air temperature and specific humidity—an indication of moisture abundance—in the Los Angeles Basin.

DATA AVAILABILITY

From 1987 to 1992, Southern California Edison operated a short observation tower (about 10 feet tall) at each of 23 weather stations in southern California. Meteorological data, including surface air temperature, dew-point temperature, wind speed and direction, and solar radiation, was recorded every 15 minutes as well as hourly and daily. The value of specific humidity for each hour at each station was derived from temperature and dew-point temperature based on the physical principles of atmospheric thermodynamics (as suggested by the ASHRAE *Handbook of Fundamentals*).

FINDINGS

Researchers have analyzed the temperature pattern and specific humidity distribution and the correlation between them from both averaged seasonal and diurnal variations and case observations. One of the most important findings is that there are distinctive inland sources of moisture, the magnitudes of which have a strong surface air temperature dependency. In other words, there is generally a positive correlation between surface air temperature and specific humidity. This correlation was most obvious in the central part of the Los Angeles Basin, such as the Rosemead and San Dimas stations. The highest specific humidities and surface air temperatures were usually found around noon in the summer and the lowest right before sunrise during the winter. The specific humidity gradients during fall and spring were significant and are attributed, at least in part, to the seasonal succession of urban vegetation.

At far-inland stations, the positive correlation was also verified; however, there were sudden decreases in specific humidity around noontime, especially when the surface air temperatures exceeded 80°F. As many previous studies suggested, the sudden surface drying was attributed to strong vertical mixing caused by intensive heating on the surface.

Among the four major moisture sources—precipitation, sea breeze, anthropogenic activities, and soil/vegetation—the evapotranspiration of soil/vegetation appears to be the only mechanism that would explain most of the findings from both averaged seasonal and diurnal variations and case observations. Short-term traverse measurements of air temperature are planned for several parks in Los Angeles to verify the hypotheses on sounder ground.

ENERGY EFFICIENCY AND FIRE SAFETY ASPECTS OF REFLECTIVE COATINGS

Paul Berdahl
Staff Scientist
Lawrence Berkeley Laboratory

The purpose of this exploratory project is to evaluate the feasibility of developing new, practical materials that can retard the spread of fire through enhanced reflectivity for the infrared radiation emitted by fires. Materials with enhanced reflectivity for solar radiation and for the thermal infrared spectrum are also important in energy conservation applications, creating a synergism between energy efficiency and fire safety. The primary conclusion of this project is that we can develop modified paints that will significantly reduce the absorption of infrared radiation from wooden-structure fires.

BACKGROUND

For various applications of radiant energy control, different portions of the electromagnetic spectrum are important. These portions are identified by the wavelength of the light; the solar spectrum, ranging from 0.3 to 2.5 micrometers wavelength, includes the ultraviolet (UV, 0.3 to 0.4 micrometers), the visible (0.4 to 0.7), and the near infrared (NIR, 0.7 to 2.5). Thus, the ideal window in a hot climate would be reflective in the UV and NIR bands and transmissive in the visible. Other important spectral ranges are those for fire (1,500 K blackbody, 1 to 8 micrometers) and for thermal infrared radiation (300 K blackbody, 5 to 40 micrometers).

LOW-EMISSIVITY COATINGS

The ability to reflect fire radiation is important because of a process known as *differential thermal expansion* (the edges are cooler than the center). This expansion causes the window to fracture, which in turn hastens the spread of fire due to the increased supply of air.

Low-emissivity window coatings are now fairly common in energy-conserving buildings. These coatings are transparent in the visible spectrum but become reflective and consequently low-e in the thermal infrared, thereby reducing infrared heat transfer. It appears feasible to modify conventional low-e coatings to reflect both ordinary thermal radiation and the radiation from fires.

REFLECTIVE PAINTS

Reflective coatings such as white paint have energy conservation benefits in hot climates due to their high solar albedo (reflectivity). White coatings also usually have high thermal infrared emissivities (low reflectance) as well, aiding in the radiation of heat to the environment.

Schematically, typical white paint consists of small particles of titanium dioxide (TiO_2), 220 nanometers (nm) in diameter, in a transparent polymer film. TiO_2 is chosen for its high refractive index (which enhances its ability to scatter light), low cost, and ability to absorb ultraviolet light, protecting the polymer from UV damage. The 220-nm particle size is carefully optimized to reflect visible radiation, with visible reflectance as high as 98%. The solar albedo is fairly high—roughly 80%—despite the UV absorption and reduced infrared reflectance beyond a 2-micrometer wavelength.

Typical white paints don't reflect fire radiation well due to the poor infrared reflectance for wavelengths greater than 2 micrometers. Reflectance is poor because the particles are very small compared to the wavelength, and the scattering cross-section decreases inversely with the fourth power of the wavelength. With larger particles, it should be possible to increase the reflectance of ordinary (white) paint to fire radiation.

The researchers wrote a computer program to evaluate the spectral reflectance of paints with varying pigment sizes. They used the well-known Mie theory to compute the scattering from TiO_2 spheres and a model based on the work of Palmer et al. (*J. Coatings Technol.* 61: 41, 1989) to deal with the mathematics of the multiple scattering problem. First, the program was applied to scattering from particles 220 nm in diameter; this diameter was determined to be best for scattering of visible light. Next, radiation from fire was simulated as 1,500 K blackbody. The average reflectance for this radiation was then computed using TiO_2 particles of larger sizes. With a fixed total amount of TiO_2 in the paint film, the best "fire" reflectance showed a broad maximum of about 75% for particle diameters of 1 to 2 micrometers (compared to 30% for ordinary paint).

Thus, more than half of the fire radiation that ordinary paint would have absorbed can be reflected if the particle size is altered. (The visible reflectance declines from 98% to about 85%.) Furthermore, increasing the pigment in the film or using a thicker film raises the reflectance even further, to roughly 85%. The exact maximum value of the fire reflectance is determined by the infrared absorptivity of the polymer, which is not known precisely.

FUTURE WORK

The logical next step is to acquire windows with suitable low-e coatings and paints with a pigment particle size of 1 to 2 micrometers. The theoretical expectation that the spread of fire can be slowed by infrared-reflective materials can then be verified.

The computer code developed in this project will be used in follow-on work that has been proposed to the U.S. Department of Energy. In this work, to be performed jointly with Kerr-McGee, a pigment manufacturer, pigments are to be optimized for high-solar-reflectance paints.

ADAPTIVE OPTIMIZATION OF INTERNAL COMBUSTION ENGINES FOR FUEL VARIABILITY

J.E. Bobrow, Associate Professor
Derek Dunn-Rankin, Professor
University of California, Irvine

Natural gas is likely to become an important alternative fuel for vehicular internal combustion engines, both because it is inherently cleaner-burning than gasoline and because it can help reduce U.S. dependence on foreign sources of oil. Its composition is variable, however, necessitating an adaptive control strategy to maintain optimal engine operation independent of fuel characteristics. The goal of this project is to apply such an adaptive strategy to a realistic automobile engine using sensors and computer technology.

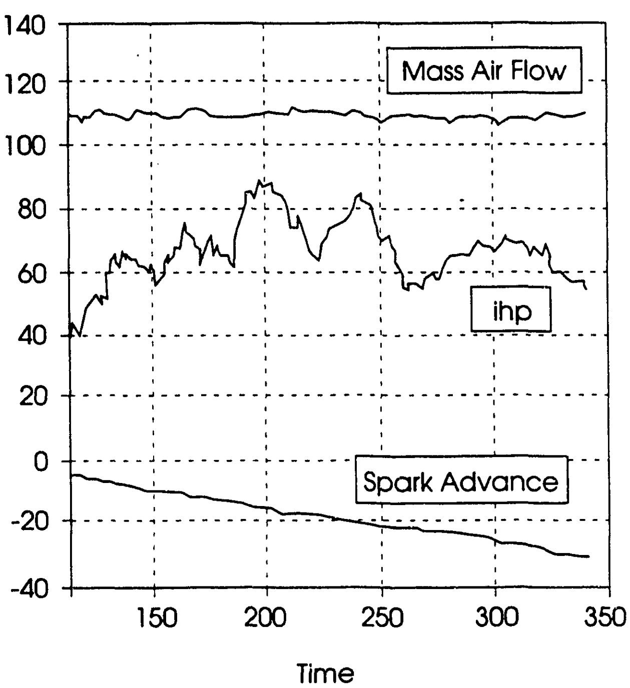
STRATEGY

In this one-year exploratory project, the researchers replaced the stock control unit from a 5.0-liter Ford Mustang engine with their own control software running on a 486/50 computer. After instrumenting the Ford engine with a Kistler pressure transducer on the number-one cylinder, the team used a 16-bit, 48-kHz analog-to-digital converter configured in direct memory access mode to sample the pressure 1,024 times every two revolutions of the crankshaft. These conversions were triggered by a 32,000 count/revolution optical encoder mounted on the crankshaft. The work integral, $\int PdV$, was evaluated during the subsequent two revolutions and used to optimize engine performance. The goal is to maximize fuel economy at any engine speed and load.

For a given engine speed and a set fuel-injection duration, three parameters were adjusted on-line to produce the greatest power output, or $N\int PdV$, where N is the engine rpm. Those parameters are the ignition timing, the intake manifold throttle butterfly valve position, and the time within the cycle at which the injectors deliver the fuel. To vary the throttle plate angle from the computer, the researchers replaced the conventional throttle cable control (open loop) with a high-bandwidth analog servomotor PID position control system. The concept here is that the driver controls the actual fuel flow rate with the "gas pedal," while the controller sets the air and timing to maximize the efficiency of the incoming fuel.

The results show that, due to the cycle-to-cycle variability inherent in the combustion process, care must be taken when developing an efficient numerical search strategy for the optimum values of the three parameters. The figure below is a typical plot of the indicated horsepower $N\int PdV$ versus time as the ignition timing is advanced. It shows the combustion variability problem and the fact that optimum performance for the fixed-load condition is reached at about 18 degrees before top dead center. Changes in the other two parameters—throttle angle and fuel injector timing—also reveal some interesting trends.

As fuel flow is held constant and the ignition timing is varied, the indicated horsepower (ihp) appears to be optimum at about t=200 sec.



To find the best parameter values, the researchers optimized a low-pass filtered version of the power output by a scaled sequential search.

The results are important for today's gasoline engines because the strategy described here can compensate for engine aging and variable-composition gasolines, including those with ethanol additives. In addition, if natural gas is used as the fuel, faster optimization convergence will likely be achieved because the better fuel mixing will decrease cycle-to-cycle variability.

TECHNOLOGY TRANSFER

The research team met with the manager of a natural-gas-vehicle project for Southern California Gas. He expressed interest in the project and indicated that SCG would contribute a natural-gas "fuel maker" and associated tank storage.

The researchers also attended the Society of Automotive Engineers' International Congress and Exposition. The Congress allowed the team to:

- Identify the latest in adaptive control research.
- Interact with automotive engineers from all major vehicle manufacturers.
- Establish a connection with Southwest Research Institute, a major center of automotive research (including natural-gas vehicles). The SwRI connection in turn provided a contact with BKM, a San Diego engineering consulting firm and Clean Air Partners' consultant in the retrofit of Ford 4.3-liter engines for natural gas in turbo-charged, lean-burn operation. BKM will provide one of these retrofit engines to allow the control approach to be tested on a realistic natural-gas engine.

WALKING SYSTEM FOR THE CAL POLY CONTROLLED TRAFFIC FARMING SYSTEM

E. J. Carnegie
Department Head, Agricultural Engineering
California Polytechnic State University, San Luis Obispo

With funding from Pacific Gas and Electric, Southern California Edison, and CIEE, the Agricultural Engineering Department at California Polytechnic State University has for the last few years been working on a Controlled Traffic Farming system. The basic component of the CTF system is an electrically operated movable truss that spans a distance of 100 feet (30.5 m). In operation, the truss is positioned at the starting location in the field and the implement carriage is lowered and powered along the length of the truss. When the carriage has traversed the full span of the truss, it is automatically raised and rotated 180 degrees. The truss is then automatically indexed (moved ahead one field row), the implement is lowered, and the carriage makes a return pass.

Because the indexing and implement motions are controlled by a computer, no operator is required for normal operation of the unit; the operator need only decide, for example, when to start a series of field operations. Several such operations—including scraping, disking, spring tooth harrowing, rototilling, listing, and planting—have been tested. The unit has so far shown great promise, performing these operations with one-fifth the energy of a standard tractor using the same implement. In addition to energy savings, the soil compaction was measured to be about half that of the standard tractor and implement.

During preliminary testing, the accuracy or repeatability of field-implement position on the CTF unit was approximately plus or minus one foot. This inaccuracy was hindering further progress of the system. One major limiting factor was the programmable controller; the original controller used an eight-bit processor with limited I/O capabilities and was too slow to measure six elements and control 13 motors in real time. The other limiting factor was wheel slip, which the walking system was developed to eliminate.

COMPUTER CONTROL

The prime consideration in the design and implementation of the control system was that all components be readily available and obtained locally. For that reason, an MS-DOS 486 PC was chosen as the heart of the controller. The computer controller reads operating conditions, makes decisions, and activates operations. Data received by the computer comes through a Jameco Electronics PC Lab card placed in one of the computer's I/O slots. The control signals come from the computer through a standard parallel card, which is also placed in one of the I/O slots.

The control program was written in Borland C++ using an object-oriented design approach. The use of object-oriented programming allowed the system to be built up in discrete, stand-alone modules, simplifying long-term development. The main program is a real-time control executive that sets up the virtual function for the desired implement, then calls the object functions in the order of desired execution. This has the effect of going through a general command chain that is identical for each task (tilling, plowing, and planting).

WALKING SYSTEM

Each movable leg in the walking system must perform five functions: lower, align, advance, lift, and return. These functions are carried out by three motors under computer control and four linear actuators for each leg. To lower and lift the foot, one motor operates two 2-ton ballscrew actuators. Before the CTF is advanced, the computer determines whether the CTF unit is in the proper position. If a correction is required, the computer operates the align motor and actuator, which change the advance angle to compensate for any misalignment. The advance motor and a long-lead ballscrew actuator advance the CTF one index length. Real-time position feedback tracks the CTF movement and determines when one index length has been completed. The foot is then lifted, and the advance motor and ballscrew actuator return the leg to its starting position in preparation for the next step. During the return operation, the implement carriage is moving across the field; at the same time, the computer is checking the carriage's position the field. Field positioning will be a combination of recorded field movement and computer vision.

METHANE RECOVERY IN ADVANCED INTEGRATED PONDING SYSTEMS: AN UPDATE

William J. Oswald, Professor Emeritus
F. Bailey Green, Graduate Student Researcher
University of California, Berkeley

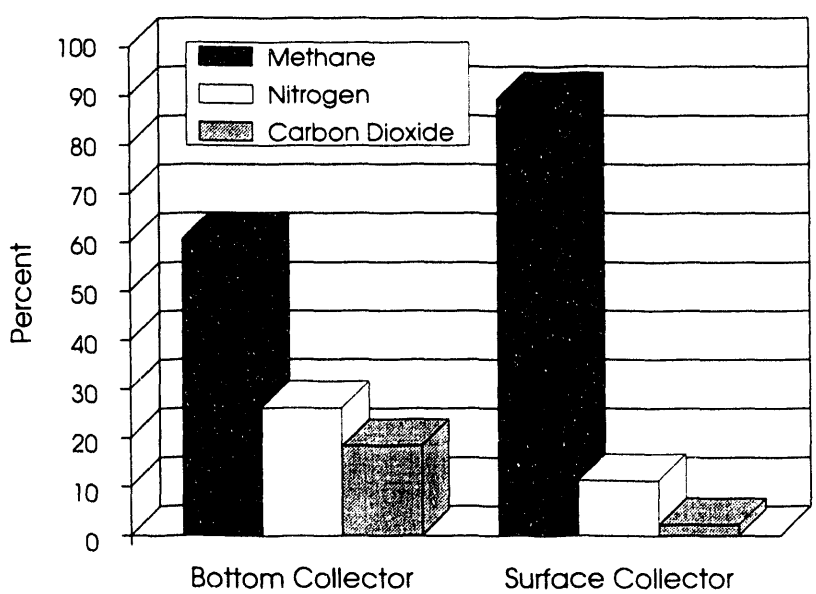
Municipal wastewater treatment accounts for more than 1% of the total electrical energy consumption in the U.S. (approximately 27 billion kWh/yr). Because the need for more complete treatment of increasing amounts of wastewater will compound future demand for energy in this sector, more efficient wastewater treatment technologies are needed.

Advanced Integrated Ponding Systems (AIPSs), developed over the last three decades at the University of California, Berkeley, provide equivalent, if not superior, treatment to conventional mechanical systems at a fraction of the capital and operating costs. AIPSs also reduce the land requirements and eliminate the nuisance conditions associated with conventional waste-stabilization ponds. The economy of first-generation AIPSs, such as those serving the cities of St. Helena and Hollister, result from the complete digestion of sludge and from the photosynthetic production of oxygen by microalgae grown in high-rate ponds.

At the 30,000-gallon-per-day pilot AIPS at UC Berkeley's Richmond Field Station, researchers have increased the efficiency of these first-generation AIPSs by proving the feasibility of recovering methane from in-pond digesters using submerged collectors. Over the past nine months, a second digester and gas collector have been installed to allow an optimal loading rate of the existing facultative pond. Biogas produced in the in-pond digesters is scrubbed as it emerges through the overlying pond, and the Btu content of the biogas is thus increased by nearly 50% (see Figure 1). Using this renewable resource of methane reduces the depletion of fossil fuels (see Figure 2), and recycling the carbon dioxide produced by its combustion to enhance microalgal growth further reduces the level of greenhouse-gas emissions.

Other improvements over first-generation AIPSs are being demonstrated at Richmond; they include the optimal method and velocity for mixing algal high-rate ponds and improved methods of microalgal harvest and reuse. Gentle paddlewheel mixing at a velocity of 0.5 feet per second, as opposed to the lift-pump or screw-pump mixing used at St. Helena and Hollister, greatly reduces the aeration energy requirement. Paddlewheel mixing fosters the growth of microalgae, which will settle when removed from the mixing field. The harvested algal biomass may then be used for animal or fish food, fertilizer, or additional fermentation substrate to increase methane production.

Figure 1. Change in biogas composition due to scrubbing.



TECHNOLOGY TRANSFER

The researchers have completed the preliminary design for a full-scale, second-generation AIPS that will serve a new development in the Central Valley. They are also hosting the Second IAWQ International Specialist Conference on Waste Stabilization Ponds and the Reuse of Pond Effluents, to be held in late 1993.

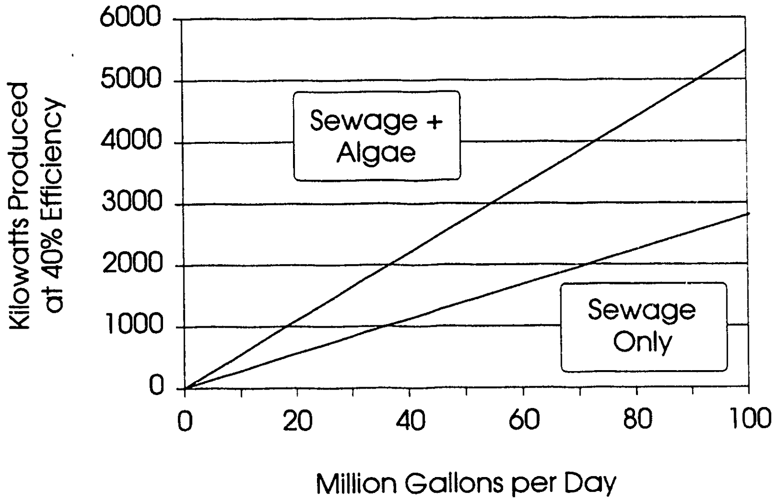


Figure 2. Extrapolated electrical energy production from methane recovery in AIPSs.

ADVANCED REFRIGERATOR/FREEZER DESIGN CONCEPTS

Dariush Arasteh, Staff Scientist
Brent T. Griffith, Senior Research Associate
Lawrence Berkeley Laboratory

The impending phaseout of chlorofluorocarbons (CFCs) used to expand foam insulation, combined with requirements for increased energy efficiency, make the use of non-CFC-based, high-performance insulation technologies increasingly attractive. The majority of current efforts are directed at using advanced insulations in the form of thin, flat, rectangular, low-conductivity gas-filled or evacuated panels, or *advanced insulation panels*. AIPs can be used in conjunction with blown polymer foams to improve insulation performance in refrigerator/freezers (R/Fs) of conventional design and manufacture. This AIP/foam-composite approach is appealing because it appears to be a feasible, near-term method for incorporating advanced insulations into R/Fs without substantial redesign or retooling. However, the requirements for adequate flow of foam during the foam-in-place operation limit the allowable thickness and coverage area of AIPs. This restriction, combined with the thermal bridging effects of elements such as steel outer shells and surrounding foam, allows only relatively small improvements in overall thermal resistance with AIP/foam-composite insulation.

This research is examining design alternatives that may offer a greater increase in overall thermal resistance than is possible with the use of AIP/foam composites in current R/F design. These design alternatives generally involve a basic redesign of the R/F, taking into account the unique requirements of advanced insulations and the importance of minimizing thermal bridging with high-thermal-resistance insulations. The focus is on R/F doors because they are relatively simple, independent components and therefore good candidates for development of alternative designs. A three-dimensional finite difference computer model of an R/F door geometry was used to compare the overall levels of thermal resistance (R-value) for the various design configurations.

One design alternative involves substituting polymer outer-shell materials for conventional steel to reduce thermal bridging and edge losses. The computer modeling of a simplified R/F door indicated that this could improve overall R-values by 13% for foam insulation, 15% for gas-filled AIP/foam insulation, and 18% for evacuated-powder AIP/foam insulation.

Another design alternative uses polymer outer-shell materials but discards foam-in-place insulation in favor of a more comprehensive use of advanced insulation technologies. In this case, a distinction is made between AIPs and advanced insulated components (AICs): While an AIP is an insulating panel made for the inside cavity of a component, an AIC is an entire functional component that incorporates an advanced insulation technology. An AIC is thus a thin-walled, hermetic, barrier part with a modified internal atmosphere and an insert consisting of advanced insulation filler material. In the case of R/Fs, an AIC could be an entire door with accessories attached to it.

The barrier envelope, or outer surface, of an AIC would typically be a formed (or molded) polymer part that includes multiple layers of gas and moisture barrier material. A gas-filled AIC would have an insert consisting of a multilayer reflective baffle and polymer stiffeners as needed. An evacuated-powder AIC would, for example, have an insert consisting of compressed and formed powder. It is unlikely that AICs would employ blown polymer foam insulation.

The polymer-barrier AIC approach offers some significant advantages over using AIP/foam composite in conventional R/F design. One of the most important advantages is better resistance to heat transfer resulting from greater thickness and coverage area of the advanced insulation. The polymer outer shell, in addition to causing less thermal bridging than steel, can offer such advantages as design freedom, parts reduction, weight reduction, scrap recyclability, and process consolidation. Adhesive polyurethane foams make it difficult to disassemble conventional R/Fs; polymer-barrier AICs could be designed for disassembly, improving post-consumer recyclability over conventional foam-core R/Fs.

The individual materials and manufacturing technologies needed to fabricate polymer-barrier AICs are generally well developed; however, it appears that there have been no efforts to apply them directly to the production of AICs. Technologies such as coextrusion and lamination could be used to produce thermoplastic multilayer polymer structures with the necessary stiffness and barrier properties. Twin-sheet thermoforming and coextrusion blow molding could be used to fabricate shaped barrier parts for AICs; thermal or solvent welding could be used to join the barrier parts hermetically.

The major conclusions of this study are:

- AICs could be mass-produced with existing polymer technologies.
- AIC refrigerator components can offer higher levels of thermal resistance than conventional assemblies insulated with foam or AIP/foam composites that have the same thickness.
- A considerable amount of development is required and warranted to assess the energy-efficiency improvements, economics, manufacturing, and reliability of AICs for R/F applications.

Computer modeling of a simplified geometry, representing a refrigerator door two inches (0.05 m) thick, produced the following overall R-values for various configurations of insulation and shell materials.

Refrigerator Door Configuration	**Overall Effective R-value**	
	hr·ft²·°F/Btu	**m²·K/W**
CFC-blown foam with conventional steel outer shell	9.03	1.59
Evacuated AIP/foam composite with conventional steel outer shell	11.14	1.96
Gas-filled AIP/foam composite with conventional steel outer shell	9.71	1.71
Evacuated AIP/foam composite with polymer outer shell	13.09	2.31
Gas-filled AIP/foam composite with polymer outer shell	11.15	1.96
Evacuated-powder polymer-barrier AIC	18.80	3.31
Gas-filled polymer-barrier AIC	13.50	2.38

UTILIZATION OF WASTE OXYGEN FOR LOW-EMISSION COMBUSTION

Ian Kennedy, Associate Professor
Daniel Chang, Professor
University of California, Davis

Recent concern about toxic air contaminants emitted from wastewater treatment processes, haloform formation in water supplies, and storage of chlorine will result in a variety of measures to reduce those emissions and chlorine use. In the case of wastewater treatment plants, continuing conversion to covered pure oxygen activated sludge processes for secondary treatment is likely. Recent studies have demonstrated that nondegradable volatile compounds are emitted from the activated sludge exhaust gas vents. At the same time, it is not uncommon for the oxygen concentration in the exhaust to be as high as 40 to 60% O_2, the balance being CO_2 and N_2 stripped from the wastewater. In both wastewater and normal water treatment plants, conversion from chlorination to ozone disinfection to reduce on-site storage of chlorine and haloform formation in the water results in a waste oxygen stream whose O_2 concentration can be as high as 60 to 80% but that might also contain formaldehyde. Thus far, it has not proven economical to use or recover enhanced-oxygen waste gas streams at either type of water treatment plant.

This project is intended to demonstrate the feasibility of using these humid (enhanced-oxygen) waste gases for combustion in the engines and generators commonly found at water treatment plants. The combustion process itself will reduce the trace concentrations of toxic compounds contained in the waste gas stream to negligible levels and therefore obviate the need for further controls. By applying either exhaust gas recirculation or water/steam injection (or some combination of the two to reduce the oxygen concentration in the waste gas stream) to maintain or reduce peak flame temperatures, it may be possible to significantly reduce the level of N_2 in the combustion chamber. Currently accepted mechanisms of thermal or prompt NO formation indicate linear proportionality of production rates with N_2 concentration. A reduced N_2 mode of thermal NO_x control has not been pursued because of the economics of O_2 production compared to air and a stronger rate dependence on temperature than concentration. However, at water treatment plants using pure-oxygen processes, enhanced-oxygen streams are not captured but simply vented. For example, the Los Angeles Aqueduct Filtration Plant has a 50-ton-per-day (tpd) oxygen plant; a stream containing 60 to 80% O_2 is being vented at about 50,000 standard cubic feet per hour (about 24 tpd of O_2!). Thus, the economics of O_2 availability are not a limiting factor.

The researchers have estimated that as much as 10 to 20 MWe of relatively clean power can be generated in California's urbanized areas as increasing numbers of water treatment plants switch to pure oxygen for disinfection. Peak use of oxygen coincides with peak use of water, typically when additional power-generation capacity is needed. Use of this resource, which would otherwise be wasted, can provide a relatively clean source of energy, become a significant asset for publicly owned wastewater treatment plants and water treatment plants in California's more populous air basins, and negate the requirement for additional pollution-control systems.

SMALL DIESEL ENGINE EXPERIMENT

A small-scale demonstration project has been initiated to determine the feasibility of using waste oxygen in a stationary power-generating engine with reduced NO_x. A single-cylinder diesel engine has been installed in the Combustion Laboratory at the University of California, Davis. The engine is equipped with torque and speed transducers and is loaded with a water pump. The engine is being modified to run a synthetic air produced from engine exhaust and a carbon dioxide/oxygen/methane mixture that is equivalent to the digester gas formed at the East Bay Municipal Utility District. Flow rates of all gases will be measured, and an analyzer is being set up to measure the engine's NO_x emissions. The engine and ancillary equipment have been successfully tested. The NO_x sampling system is being set up, and the flow system for supplying gases to the test engine is being designed and built.

USE OF EMCS TECHNOLOGIES TO REDUCE PEAK COOLING LOADS IN NONRESIDENTIAL BUILDINGS: AN UPDATE

Sukhbir Mahajan and Charles Newcomb
Professors
California State University, Sacramento

The goal of this exploratory project is to optimize the use of energy management and control system (EMCS) technologies to reduce peak load and energy consumption in nonresidential buildings. The research will focus on developing and field-testing a simulation-based, adaptive control methodology for night precooling of thermal mass in a large classroom building.

A campus building (with approximately 77,000 square feet of floor area) has been instrumented to collect the data necessary for thermal performance analysis and development of possible strategies to reduce peak cooling load. The data collection system is fully functional, and data for a full heating season (October through April) has been collected and analyzed for internal consistencies.

A concise computer simulation code based on the existing PSTAR has been developed and tested for a simple building. The cooling season data is being used as input for this code to obtain building thermal parameters, which will then be used to test nighttime cooling strategies for saving energy and reducing peak load. The energy use of this building has been compared to that predicted by the DOE-2.1D computer simulation code. The use of EMCSs for data acquisition and as a diagnostic tool was explored; they were found to be very useful for both tasks. The summer cooling data (for days on which the temperature exceeded 90°F) is expected to be collected during June and July 1993, with the analysis of cooling data and some cooling strategies completed by the end of July 1993.

DESIGN OF HYBRID POWER CYCLES FOR WASTE HEAT RECOVERY APPLICATIONS

Ashish Gupta, Graduate Student Research Assistant
Vasilios Manousiouthakis, Associate Professor
University of California, Los Angeles

Waste heat, such as that from industrial processes or that contained in hot flue gas exhaust of turbines employed in generating electricity, can be converted to power. In a typical waste heat recovery steam cycle application, water is evaporated at constant temperature, whereas heat is available from a source with a graded temperature profile up to a few hundred degrees above the boiling point of water. This gap between the source and the working fluid temperature profile is a measure of the irreversibility of the process or wasted energy. Using a pure component (water) as the working fluid, the cycle involves producing superheated steam from water, expanding it through adiabatic turbines, condensing the turbine exhaust steam by cooling water, and recirculating the condensed water to the boiler through a pump and a preheater.

If the working fluid is a binary fluid mixture, however, the vaporization can be carried out at a temperature much closer to that of the source due to the temperature change the mixture undergoes (from bubble to dew point) as it vaporizes. A design using such a technology can increase power production over the Rankine (steam) cycle.

A typical cycle employing a binary mixture was simulated using the ASPEN simulator. A 75% NH_3/H_2O mixture in the heat recovery section is sent to three staged turbines operating at a temperature profile close to the source temperature curve. This profile is achieved by an intercooler between the intermediate- and low-pressure turbines. The turbine exhaust is condensed and separated into two high- and low-NH_3-concentration mixtures that lose heat to cooling water at ambient temperature. The cooled condensate is reconstituted and pumped back to the heat recovery vapor generator. The simulations show that the working fluid mixture thermodynamics are sensitive to the equations of the state models used. In particular, the ease of flash separation is overestimated.

In this research, the pinch approach—which quantifies the closeness of the working fluid temperature profile to the source temperature profile—was used to analyze the design. This hybrid cycle requires separating a binary mixture and thus involves interactions between mass and heat exchange.

Next, the state-space methodology was used to analyze hybrid cycles that involve both separation and heat-exchange technologies. This approach decomposes the problem into evaluation of an operator, where mass and heat exchange are described, and the distribution network, which contains all the flows to and from the operator. This representation allows consideration of all possible configurations.

Using this representation, researchers analyzed the potential thermodynamic advantages of a hybrid power cycle using an NH_3/H_2O working fluid. For this part of the project, theoretically predicted thermodynamic data from ASPEN was regressed to simplified relations with respect to composition and pressure in the range 2 to 190 atm. These relations are coded as part of the state-space formulation, which includes pressure changes, heat exchangers, and flash operations. The resulting optimization problem is solved using a MINOS optimizer, and chemical processes in which this cycle may be used to recover waste heat or improve process integration are suggested.

Future work on this project will include the simultaneous synthesis of chemical processes and power cycles to achieve maximum integration, investigation of other binary mixtures, and rigorous simulation of state-space designs.

COMPUTER-BASED DESIGN ADVISOR FOR ENERGY-EFFICIENT BUILDING DESIGN

John La Porta
Staff Research Associate
CAD Research Center
California Polytechnic State University, San Luis Obispo

The computer program being developed is a tool for analyzing climatic data and generating architectural building recommendations for energy-efficient design. It is not a simulation program but is intended to be used in the earliest design stages—those in which the site and building type are known but the building form has not yet been developed.

Energy efficiency is an important consideration in these early stages of design if the building form and envelope are to be optimized. If energy issues are left to the design development stage, when a detailed design already exists, major design changes will be difficult or impossible to accommodate.

As building geometry is typically unavailable during the early design stages, input for the program consists of use times of the building (during the day and throughout the year) and climatic data. Normal "means and extremes" data published by the National Oceanic and Atmospheric Administration is used, but the user can also define site-specific climatic occurrences—such as fog, high winds, and thunderstorms—that may not be evident from the data. Although Typical Meteorological Year data provides the most detailed description of the climate, its limited availability would impose too great a restriction on the use of this program.

Once data has been entered, it can be displayed graphically in terms of human comfort on either a psychrometric chart or various 2-D and 3-D temperature and humidity graphs. On the psychrometric chart, the human comfort zone is superimposed on the data along with the effective boundaries of various heating and cooling strategies. This allows the user to see not only why a climatic condition is uncomfortable (too hot, too humid) but also what strategies would be most effective in mitigating a given condition. The user can also incorporate the bioclimatic chart into the comfort zone, shifting its boundaries according to wind and solar radiation.

Design recommendations are generated from the climatic data, the use times, and heating and cooling strategies plotted on the psychrometric chart. For each month, climatic data and the use times of the building are examined to determine heating and cooling needs. Effective strategies are then selected, taking into consideration conflicts in climatic conditions and strategies (for example, heavy fog precludes the use of direct gain heating for that time). After each month has been examined, an iterative process begins in which general characteristics are chosen to accommodate, as much as possible, the requirements of the strategies selected for each month. These characteristics are then mapped to specific design recommendations. Recommendations are made at the site, building, and component levels in the following areas:

- Heating strategies
- Cooling strategies
- Layout
- Form
- Orientation
- Construction system
- Air movement
- Landscaping
- Roof design
- Glazing
- Entry.

Not all of these issues have recommendations for each level; for example, Entry has a recommendation at the building and component levels but not at the site level. The user can view the final recommendations or the optimized recommendations for each month. A limited explanation facility is also available showing why certain strategies were chosen and which factors were significant in generating each recommendation.

The recommendations generated by the program are necessarily general in nature, given the early design stage being addressed. It is hoped, however, that it will be the first step in energy-efficient design considerations and will be carried through in greater detail in later design stages by existing programs, such as DOE-2.

USE OF INTELLIGENT CONTROL TECHNIQUES FOR ENERGY-EFFICIENT SMART BUILDINGS

Anthony V. Sebald
Associate Professor
University of California, San Diego

The goal of this exploratory project is to research smart building controls, focusing on smart control of a variable air volume (VAV) system in spaces containing fume hoods. The analysis is being done in the context of a single air handler feeding a multiple-zone laboratory space in a new building on campus. Of particular interest is the extent to which intelligent algorithms can balance HVAC systems and run the moment-to-moment control of a complicated space, exploiting the energy-efficient VAV approach while maintaining occupant comfort and safety.

The project has been broken down into five tasks:

- Task 1: Generate a dynamic model of VAV ventilation in a multizone environment with fume hoods and a suite of sensors. This will be a reasonably simple model focusing on the variables under study.
- Task 2: Specify both fuzzy and neural controllers oriented toward intelligent control of ventilation and temperature.
- Task 3: Perform computer-aided design on both control strategies to determine the best design of each type of controller and to gain information on the situations in which these designs perform the most poorly.
- Task 4: Analyze the effects of sensor type and placement.
- Task 5: Analyze the smart controllers' ability to do initial building balancing and adapt to changing situations. As in Task 3, computer-aided design will be very helpful.

Task 1 has been accomplished, the fuzzy controller in Task 2 has been designed, and the neural controller has been coded. In Task 3's "fuzzy" area, extensive testing has been done; the neural work is also proceeding.

By the end of the summer, researchers will have completed Task 4, the experiments with the fuzzy controller, and the neural controller design.

WIND MACHINES FOR FREEZE PROTECTION

Richard L. Snyder
Biometeorologist
University of California, Davis

The objectives of this exploratory research project are to:

- Develop a weather-based model for real-time prediction of freezing temperatures.
- Develop a model to help citrus growers determine when to start and stop wind machines based on real-time weather measurements and forecasts.
- Evaluate various ways to start, stop, and monitor wind machines remotely.
- Investigate the possibility of synchronizing the rotation rates of wind machines in an orchard so they blow in the same direction.

REAL-TIME FREEZE PREDICTION MODEL

Since November, weather data from each of the four treatment sites in the Paramount Citrus orchard near Visalia has been recorded each half hour and archived. The wind machines were operated on six nights during the winter; visual observations of the weather on those nights were recorded by the Paramount Citrus co-operators. Because those nights were clear and relatively calm, researchers used that data to develop a freeze prediction model. Data from rainy nights is being eliminated from the complete data set, and the remaining data is being used to verify the model.

STARTING AND STOPPING MODEL

Weather data from the six nights when wind machines were operated is being analyzed to develop a wind machine starting and stopping model. The approach is to use temperature profiles (updated each half hour) and wind information to predict changes during the night. A user-friendly program is being developed to call a weather station, update the database, predict changes in the temperature profile, and provide guidance to the grower on the conditions that should trigger starting or stopping. A batch file was written to tell the telecommunications software to call the weather station each half hour and update the data file; another program is then called to graph the predicted temperature profiles on the computer screen. Eventually, the freeze prediction model and the starting and stopping model will be integrated into this software to provide guidance to the grower.

REMOTE STARTING AND STOPPING OF WIND MACHINES

Turnupseed Electric Services, a subcontractor, is working on the remote starting and stopping of wind machines as part of this project. Researchers have set up and tested an infrared telemetry system to start and stop the wind machines remotely and monitor their performance. The use of radio signals or hard-wiring to controllers at each wind machine has also been considered; the cost-effectiveness of these methods is being evaluated.

SYNCHRONIZING WIND MACHINE ROTATION

Considerable effort has been expended to determine whether wind machine rotation rates can be synchronized. Based on conversations with wind machine manufacturers and distributors, it seems that the mechanical nature of the machines limits the ability to synchronize rotation. Electronic wind machines cost approximately $13,000; a variable-speed drive to control the rotation rate may be as much as $10,000. Consequently, the cost of modifying these machines to control rotation rates is prohibitive. However, it may be possible to control rotation rates of internal-combustion wind machines by controlling the flow of fuel to the engine.

GROWER MEETINGS

Two grower meetings on the use of wind machines for freeze protection were held during the past phase. This project was discussed with growers in both meetings.

ULTRASONIC SILICON-BASED AIR-QUALITY MONITOR

Barat Shah, Graduate Student Research Assistant
Richard M. White, Professor and BSAC Director
Berkeley Sensor and Actuator Center
University of California, Berkeley

This research effort is focused on an ultrasonic vapor sensor for use in room air-quality measurements. This device, made using silicon microfabrication techniques, consists of a thin silicon nitride membrane onto which has been deposited a piezoelectric film and electrodes that form an elastic-wave transducer. After being coated with a sorptive polymer film, this ultrasonic delay line is operated with an electronic amplifier so that self-sustained oscillations are produced. The frequency of the oscillations, which are in the low-megahertz range, is a measure of the phase velocity of the ultrasonic waves and hence the amount of gas the polymer film has absorbed from the atmosphere.

With a knowledge of the partition coefficient, researchers can determine the gas concentration. In prior research, these devices were operated in small laboratory test chambers; the tests showed that the devices are extremely sensitive vapor detectors. Ruggedized versions have been made and will be tested in a metal-lined room at Lawrence Berkeley Laboratory. Vapor indications from this device will be compared with those obtained by standard means (measurement of air samples with a gas chromatograph).

The poster exhibit will detail the device design, operating principles, and initial test results.

MODEL TO SIMULATE THE PERFORMANCE OF HYDRONIC/RADIANT COOLING CEILINGS

Fred Winkelmann
Staff Scientist
Lawrence Berkeley Laboratory

BACKGROUND

Radiant cooling, in which chilled water is circulated through ceilings, may be an energy-conserving, peak-power-reducing alternative to conventional air-conditioning systems. Such hydronic systems are particularly well-suited to dry climates, such as those typical of California. Radiant cooling systems have been used for more than 30 years in hospital rooms because they provide a draft-free, thermally stable environment; however, their energy savings and peak-load reduction characteristics have never been appreciated. Furthermore, lack of adequate guidelines for the design and control of these systems has prevented their widespread application to other building types.

Cooling of nonresidential California buildings is a significant contributor to electrical consumption and peak demand. A large fraction of this cooling energy is attributable to the fans that transport cool air through the ducts; not only is electricity needed to drive the fans, but heat from the fan motor might add to the thermal load. The electrical demand of the motors and their drives also adds to the peak load.

One way to reduce fan energy is to transport only enough air for ventilation and provide thermal conditioning by radiant cooling with a hydronic system. The amount of energy needed to pump chilled water to the conditioned spaces is then small compared to the equivalent fan energy for an all-air system. Moreover, eliminating the return air improves comfort by reducing drafts and improves air quality by reducing interzone pollutant transfer.

The goal of this project is to develop a model that can accurately simulate the dynamic performance of hydronic/radiant cooling systems. This model is being created using the LBL Simulation Problem Analysis and Research Kernel (SPARK, formerly called Energy Kernel System). The resulting model will help analyze the performance of radiant cooling systems for office buildings in different California climates. In particular, occupant comfort will be analyzed by calculating air and surface temperatures, and peak-day cooling energy profiles for radiant cooling systems will be compared to conventional systems.

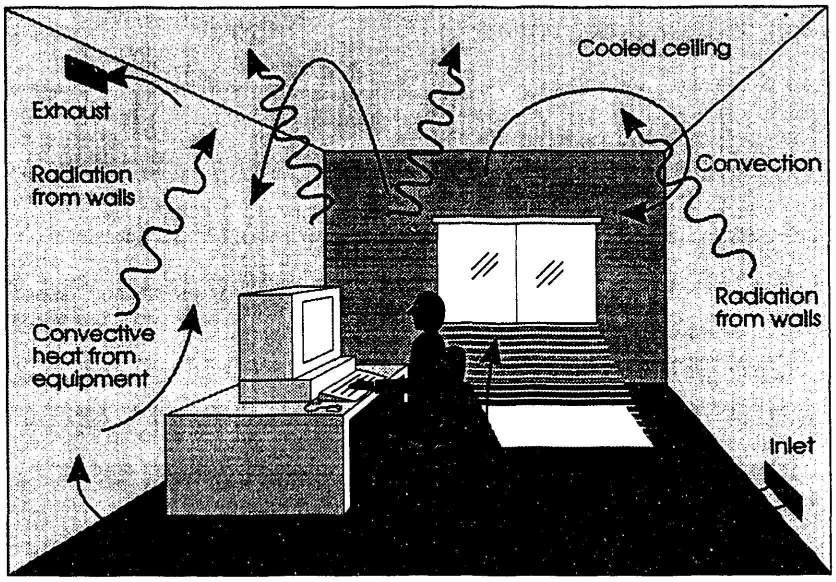
OBJECTIVES AND METHODS

Current energy analysis programs, such as DOE-2, cannot simulate radiant cooling systems. As a result, the expected performance of these systems cannot be analyzed (short of installing and measuring them), inhibiting their use. The primary goal of this project is therefore to develop a computer model that allows users to calculate heat extraction rates and room surface temperature distributions for radiant cooling systems. The model can be used to evaluate such issues as comfort, controls, sizing, system configuration, dynamic response, and energy use.

The model being developed uses SPARK, which provides a methodology for describing and solving the dynamic, nonlinear equations that correspond to complex physical systems. The radiant cooling model will be designed to be included later in DOE-3 (a version of DOE-2 that incorporates SPARK) and will be made available in the SPARK library. It will be used to simulate typical office rooms to show rates of heat removal and determine room air and surface temperatures (which affect thermal comfort).

The DOE-2 model compares overall cooling loads with the overall capacity of hydronic radiant systems currently on the market. Although results indicate that the overall cooling loads for office building construction are low enough to be met by current radiant systems, this simple matching of overall load and capacity is not sufficient to establish the viability of radiant systems. More detailed analysis, including system modeling, is necessary to establish the potential for using hydronic radiant systems in California commercial offices.

So far, the room model containing passive walls and windows has been developed. External loads are taken from DOE-2 simulations, thus reducing the need for a detailed description of the facade. The next step is to develop the active (heated or cooled) components using the two-dimensional finite differences method. Data obtained from in-situ measurements will be used to evaluate the simulation model.



Heat and mass flows in a room conditioned by a cooled ceiling and vented using the displacement ventilation method.

ENERGY-EFFICIENT, LOW-NO_X AND -CO BURNERS FOR RESIDENTIAL, SMALL INDUSTRIAL, AND COMMERCIAL GAS APPLIANCES

RESIDENTIAL EMISSION MODELING AND FORECASTING

Gregory W. Traynor
Staff Scientist
Lawrence Berkeley Laboratory

One goal of many local, state, and federal agencies is to reduce outdoor air-pollution levels in California's South Coast Air Basin and other urban airsheds. Developing gas-fired burners that produce low levels of NO_X and CO could help reduce outdoor air-pollution emissions from gas-fired appliances; measures that reduce the need for gas combustion (such as increased space- and water-heater efficiencies and house insulation) would also help decrease pollutant emissions.

The goal of this project is to develop a quantitative model that can both predict outdoor pollution emissions from residential natural-gas appliances and evaluate various pollutant-reducing strategies on a cost/benefit basis. The model will use detailed information on residential natural-gas-appliance emission factors, usage rates, and market penetration to evaluate the benefits of various pollutant-reducing strategies, rank the strategies, and compare them to similar measures proposed in other pollutant-producing sectors, such as large industrial and mobile sources.

APPROACH

This approach has three components: develop a model that quantifies outdoor pollutant emissions from residential gas appliances, collect the data necessary to run the model, and then run the model. Besides the parameters mentioned earlier—gas-appliance emission rates, usage rates, and market penetration—the model will include usage rates for selected gas appliances (such as space heaters) based on the need for those appliances. For example, residential space-heater usage depends on outdoor temperature, house insulation levels, house air-exchange rates, and other energy-related parameters.

Data for the model will be collected from a wide variety of sources. Pollutant emission-rate data will be collected from published journal articles and reports; to date, researchers have found more than 80 papers reporting pollutant emission rates from some 700 residential gas appliances. Appliance market penetration and residential housing stock characteristics will be collected primarily from local utility surveys, while information on appliance usage rates will be modeled or obtained empirically from surveys.

After gathering the data and developing the model, researchers will run the model to compare its results to current aggregate pollutant emission estimates used by state and local air-quality districts. Discrepancies between the two will be explored. The model will also be run to compare, on a cost/benefit basis, various strategies for reducing outdoor air-pollution emissions from residential gas appliances.

RESULTS

The first phase of this project—the literature survey of pollutant emission rates from residential natural-gas appliances—reveals mixed findings when the resulting literature values are compared with those published by the U.S. Environmental Protection Agency in its *Compilation of Air Pollutant Emission Factors* (AP-42). NO_X and fine particulate emission factors collected in the literature search are consistent with the emission factors in AP-42; however, the CO and methane emissions collected are considerably higher than the AP-42 values. These results may indicate that the impact of residential natural-gas combustion on outdoor CO and hydrocarbon levels has been underestimated. A well-designed field study is needed to test this hypothesis.

ALTERNATIVES TO COMPRESSOR COOLING IN CALIFORNIA TRANSITION CLIMATES

PROJECT OVERVIEW

Joe Huang
Staff Scientist
Lawrence Berkeley Laboratory

This multiyear project is aimed at reducing the unfavorable electricity demand peaks caused by sporadic air conditioning of houses in California transition climates by developing housing designs and control strategies that keep houses comfortable using less energy-intensive cooling techniques. These alternative cooling strategies include improving the housing design for better solar control and thermal storage; using noncompressor cooling systems, such as evaporative coolers or whole-house fans; and installing "smart" systems for improved ventilation control.

Although the ultimate goal is to design and build houses that demonstrate these alternative cooling strategies, the first year of the project has been devoted to:

- Improving simulation methods and gathering field data on the effectiveness of alternative cooling strategies under transition-climate conditions.
- Determining the criteria for indoor comfort.
- Investigating public attitudes toward air conditioning versus alternative cooling strategies.

In subsequent phases, researchers will apply the analysis tools and insights developed to produce model building plans and low-energy cooling systems. They will also collaborate with utility programs and the building industry to construct actual buildings.

The research team consists of eight investigators from Lawrence Berkeley Laboratory (LBL) and five universities representing several diverse disciplines. Ed Arens (Architecture, UC Berkeley) is studying indoor comfort criteria and health conditions. Bruce Hackett and Loren Lutzenhiser (Sociology, UC Davis and Washington State University) are surveying public attitudes toward cooling equipment use and identifying barriers to acceptance of alternative cooling strategies. Baruch Givoni (Architecture, UCLA) is gathering field data on the effects of ventilation and evaporative cooling. Hofu Wu (Architecture, Cal Poly Pomona) is studying evaporative cooler designs and the architectural implications of cooling strategies.

At LBL, Helmut Feustel is improving the ventilation modeling and developing algorithms for ventilation control strategies; Fred Winkelmann is providing simulation support for improvements to the DOE-2 program. Joe Huang, the overall coordinator of the project, has completed a preliminary assessment of cooling strategies and is working to improve an evaporative cooler model.

The following seven summaries describe the work done to date by the individual researchers.

ALTERNATIVES TO COMPRESSOR COOLING IN CALIFORNIA TRANSITION CLIMATES

ANALYSIS OF CLIMATIC CONDITIONS AND PRELIMINARY ASSESSMENT OF ALTERNATIVE COOLING STRATEGIES

Joe Huang
Staff Scientist
Lawrence Berkeley Laboratory

The aims of this research are to characterize conditions in the California transition climates, to study cooling requirements, and to determine the effectiveness of alternative cooling strategies in meeting these requirements for typical houses. The climate analysis will help define design conditions and identify the availability of weather data; the preliminary assessment of cooling loads and the effectiveness of alternative strategies will guide future research and designs.

The study of climate characteristics was based on ASHRAE design temperatures and California Energy Commission hourly weather tapes. Plots made from ASHRAE design temperature data for more than 600 locations suggest that a rough transition climate extends 10 to 30 miles inland from the coast. Compared to the Central Valley further inland, the climate in this zone is more humid (but still semi-arid); it has significantly lower daytime temperatures on most days but occasional peak temperatures that approach those in the Valley. The irregularity of this climate means that the design-day conditions will be highly dependent on the choice of design stringency.

The preliminary analysis of alternative cooling strategies was done using a parametric DOE-2 analysis of two prototypical houses in three transition-climate locations (Santa Rosa, Pasadena, and Riverside). Change in the indoor temperature was the primary criterion for evaluating the impact of several strategies: light-colored roofs, reflective glazing, exposed floor slab, evaporative cooling, and natural and mechanical ventilation. Electricity use was a secondary criterion, assuming the houses had air conditioning. The results indicate that the peak indoor temperature of a typical current-vintage, unconditioned house in Riverside can be reduced from 89 to 79°F using a combination of relatively simple alternative designs and strategies. For a similar conditioned house, the cooling load is reduced by 85%; if the load is met by a direct evaporative cooler, the energy and peak reductions are 82% and 52%.

ALTERNATIVES TO COMPRESSOR COOLING IN CALIFORNIA TRANSITION CLIMATES

COMFORT ANALYSIS

Fred Bauman, Research Specialist
Edward Arens, Professor
Center for Environmental Design Research
University of California, Berkeley

The effect of indoor air motion on cooling the human body is not well-understood, yet it is very important to the success of several energy-conserving approaches to cooling buildings in the summertime. These approaches are:

- Fan-powered ventilation as provided by room fans, ceiling fans, whole-house fans, or the fans in direct evaporative coolers.
- Natural ventilation as induced by wind pressure or thermal buoyancy pressures across the building envelope.

By producing air motion across the body, these approaches enhance the rate of heat transfer from the body; thus, a warmer environment can be comfortable than would be possible under still-air conditions. Because the energy required to move air is usually much less than that required to lower its enthalpy, these approaches are potentially very attractive in terms of saving energy.

The problem is that air movement's effects on body cooling are usually construed in the context of undesirable drafts, the unwanted cooling induced by air movement when the body is already cool. This view has perhaps arisen because of the European and East Coast origins of comfort research, where heating is the primary concern. Standards regulating the indoor thermal environment, such as ASHRAE Standard 55 and ISO Standard 7730, have maximum air-movement limits that essentially prevent the use of air movement for comfort. These are now under debate, and this study is intended to give the standards-writing committees enough information that they will take air-movement cooling into consideration.

The primary objective of this phase has been to test human subjects in the Controlled Environment Chamber at the University of California, Berkeley, under varying combinations of temperature and air movement. Two studies have been completed, one with the air movement coming primarily from the subject's front and the other with the air from the side. In the first study, cosponsored by the Universitywide Energy Research Group, the subjects were tested in residential settings doing residential types of activities. The fan used to provide the air movement was programmed to provide a distribution of velocities representative of natural gustiness. The results of these studies, while not yet complete, show a marked preference for greater air movement than the standards permit. Encouragingly, these results are corroborated by results from a recent field study the researchers carried out in Australia.

With the goal of more accurately predicting air-movement comfort in the future, researchers have met a number of secondary objectives. A multi-segment computer model of the human body has been under development. To calibrate it, researchers took detailed measurements of heat flow and skin temperature with an electrically heated thermal mannequin exposed to the same air flows as the subjects in the chamber. This mannequin was also tested in the wind tunnel under a carefully controlled set of wind speeds, allowing the effects of air movement on clothing insulation to be determined in unprecedented detail. Finally, the mannequin was used to determine the thermal insulation provided by various types of chairs used in offices and residences, helping researchers retroactively assess the findings of earlier field and laboratory studies in relation to air movement and comfort.

A related subproject is a literature review of humidity's effect on human health. This project was initiated because the indoor humidity maxima prescribed in environmental standards are lower than the humidities provided by direct (or direct/indirect) evaporative coolers. The review shows that the effects of higher humidities in buildings that are being cooled evaporatively differ from those in buildings that are being mechanically cooled or that are in a heating mode. The effects also depend to a great extent on the mechanical system features and the finishes and furnishings of the building. The simple prescription of a maximum relative humidity in the occupied space is probably not sufficient to control health problems in buildings and works against the adoption of healthy evaporative cooling systems.

ALTERNATIVES TO COMPRESSOR COOLING IN CALIFORNIA TRANSITION CLIMATES

VENTILATIVE COOLING AND CONTROL STRATEGIES

Helmut E. Feustel
Staff Scientist
Lawrence Berkeley Laboratory

VENTILATIVE COOLING STRATEGIES

During the literature review for *Alternatives to Compressor Cooling*, ventilative cooling was identified as the most likely candidate to replace compressor cooling in California transition climates. *Ventilative cooling* refers to any strategy that uses outdoor air in the cooling process. The two basic ventilative cooling approaches are direct cooling ventilation, in which ventilation air is supplied as cooling is desired, and thermal storage ventilation, in which ventilation air is supplied primarily during off-peak hours to reduce the temperature of the thermal mass in a building.

Direct cooling ventilation works by removing internally generated heat. Its cooling effect is enhanced because people feel cooler when air is moving over them, partially a result of air motion increasing the rate of evaporation from the skin. In climates with diurnal temperature swings of more than 10°C, direct cooling ventilation is typically used when the outdoor temperature has peaked and is subsiding. For transition-climate houses incorporating other significant cooling measures (such as high insulation levels, solar control window glazings, exterior shading, and substantial thermal mass), this ventilation strategy might be unnecessary.

If cooling is required when outdoor conditions are unfavorable, evaporative cooling can be used as the direct ventilative cooling method. In this strategy, outdoor air, cooled by the evaporation of water, is supplied to the conditioned space at a significantly lower temperature than the ambient air temperature.

While direct cooling ventilation has been studied in considerable detail for some time, many aspects of thermal storage ventilation are now being investigated. This method is feasible only in climates with significant diurnal temperature swings. Outdoor air is supplied to the building during cooler hours, storing "coolth" in the structure for later use during warmer hours. The ventilation rate is reduced as the outdoor temperature rises. Because the cool structure absorbs heat from the indoor air, the indoor temperature rises more slowly than the outdoor temperature. Thus, this ventilation method takes advantage of the delay between the availability of cooling resources and the need for cooling.

The charging and discharging of the storage medium used in thermal storage ventilation may be either passive or active. In the passive/passive case, cool night air is used to remove heat from a structure that has absorbed heat during the day. A passive/active combination can be used when night air is too cold for continuous night ventilation of the structure. The cold air is directed to an isolated storage medium, cooling it and preparing it to absorb heat again the following day.

These ventilative cooling methods may be either natural or induced. Induced ventilation must be used when the natural driving forces are inadequate or when the large openings in the building envelope required for natural ventilation would create security or privacy problems. Induced ventilation is also easier to control automatically.

CONTROL STRATEGIES

Many alternative system controls are inherently more complex than compressor cooling controls. Ventilation can be difficult to control manually, necessitating automatic controls in many cases. Ventilation systems without additional cooling sources should be off when the outdoor temperature is higher than the indoor temperature. Thus, automatic control of ventilation requires at least a determination of the outdoor and indoor temperatures, and optimum control requires information about the air humidity, time of day, heat capacity of the building, and so on. The control problem becomes more complicated when ventilation is combined with other cooling strategies (such as evaporative cooling).

A system providing ventilative cooling to a residential building requires a set of "smart" controls to use the supplied energy most efficiently. The system should provide both direct cooling ventilation and thermal storage ventilation. Based on the comparison of temperature differences between the indoor air and ambient air, the capacity of the thermal storage, and the time of day, the system should be controlled either to use minimum outside air flow or to be in the direct ventilative cooling or thermal storage cooling mode. The system may also include the use of ceiling fans. In addition to the basic ventilation system, a direct evaporative cooler can be used as a booster to avoid extreme indoor air temperatures in peak cooling situations and to reduce the supply air temperature for effective night thermal storage ventilation. For reduced water consumption, evaporative cooling should be used only in extreme peak situations.

SYSTEM SELECTION AND DESIGN

To design an optimum ventilative cooling system and determine a complementary control strategy, we must determine the relative performances of various ventilation applications. Computerized building-energy simulations are necessary to obtain such performance data. To simulate ventilative cooling and its effects on the building and its occupants, we must know the quantity and velocity of ventilation air supplied to a building. Accurate calculation of the effects of a structure's air-flow velocities on the convective heat transfer requires determination of the velocity field in each room. However, most building-energy simulation models are currently unable to calculate air-flow distributions in multizone structures. Therefore, a multizone air-flow model, such as COMIS, that provides the air flows and distributions in a building must be linked to a building heat-transfer calculation model, such as DOE-2, to calculate the air-flow rates required for cooling in a zoned structure.

The accuracy of simulation data must be confirmed by measured performance data. Simulations permit the low-cost evaluation of various cooling strategies in different climates, but experience has shown that simulations can produce very questionable results if not grounded in actual measurements.

The development of any "smart" ventilative cooling system must include design of the apparatus and control mechanism. The apparatus must be flexibly designed to facilitate direct ventilative cooling, thermal storage cooling, and some supplemental (such as evaporative) cooling. The control design should be based on the performance evaluation described above. A prototype should be built and used to demonstrate the cooling strategy in a residential building.

Although ventilative cooling has the potential to replace compressor cooling in California transition climates, it is most viable when used in conjunction with building envelope technologies that minimize external heat gains, particularly solar gains.

ALTERNATIVES TO COMPRESSOR COOLING IN CALIFORNIA TRANSITION CLIMATES

NOCTURNAL VENTILATIVE COOLING

Baruch Givoni
Professor
University of California, Los Angeles

MONITORING PLAN

At the Pala Research Facility, three test buildings with different levels of thermal mass are being monitored as part of this research. The objective of this study is to evaluate the effect of ventilation on indoor temperatures as an alternative to compressor cooling. This effect will be quantified and expressed as a function of the thermal mass of the buildings and the ventilation schedule and rate. The monitored buildings have low-mass stud walls, high-mass concrete walls, and medium-mass walls.

Three physical characteristics of the buildings, which will be included in a generalized model of the performance of nocturnal ventilative cooling, are being evaluated: indoor sol-air temperature rise, decrement factor and time lag, and heat-transfer coefficient. These thermal properties can be evaluated from the same measured data. The indoor temperatures are recorded when the buildings are closed (not ventilated or cooled). The measurements in this mode will provide the baseline thermal performance data.

INDOOR SOL-AIR TEMPERATURE RISE

The indoor sol-air temperature rise—in other words, the elevation of the average indoor temperature above the average outdoor temperature ($dT_{s\text{-}Ta}$)—reflects the solar energy absorbed at the building's envelope. It can be correlated with measured solar absorptivities of the external surfaces of the test buildings as well as with measured outdoor climate data. A formula is then derived expressing the indoor sol-air temperature rise of the test building as a function of average albedo, daily solar radiation, and daytime wind speed. This parameter will be included in a generalized mathematical model predicting the expected performance of nocturnal ventilative cooling under different climatic conditions.

The albedo of the test buildings will be evaluated using a pyranometer. Radiation fluxes will be measured either parallel to the surface in question (the impinging radiation, R-i) or facing the surface (the reflected radiation, R-r). The ratio (R-r/R-i) provides an estimate of the surface albedo.

DECREMENT FACTOR AND TIME LAG

The measured decrements of the indoor temperature swing (relative to the outdoor swing) and the time lags of indoor maxima behind outdoor maxima will be correlated with the calculated thermal mass of the three test buildings according to their design details. The measurements taken in the sol-air temperature rise evaluation will also be taken in this series.

HEAT-TRANSFER COEFFICIENT

The buildings will be heated continuously with constant and known convective electrical heating sources for about two weeks. The heat input, Q, and the measured difference between the indoor and outdoor averages minus the sol-air temperature elevation, $(Tin\text{-}Tout)\text{-}dT_{s\text{-}a}$, are used to calculate the overall building heat-loss coefficient (BLC):

$$BLC = Q / [(Tin\text{-}Tout)\text{-}dT_{s\text{-}a}]$$

THE EFFECTIVENESS OF NOCTURNAL VENTILATIVE COOLING AT DIFFERENT THERMAL MASS LEVELS

The effect of ventilation at the three levels of thermal mass is being tested under the following ventilation conditions:

- Buildings closed day and night (control conditions).
- Buildings closed during the day and ventilated at night, with different ventilation rates.
- Buildings ventilated day and night.

Two criteria will be used to evaluate the performance of ventilative cooling: the reduction of the average daytime temperature and the reduction of the peak temperature. The performance will be expressed, at the data-analysis stage, as functions of the heat capacity of the building, the ventilation rate, and the climatic conditions. The effect of ventilation at the three levels of thermal mass will also be tested under the following ventilation conditions:

- Buildings closed during the day and ventilated at night (two or three weeks, each with a different ventilation rate, depending on equipment capabilities).
- Buildings ventilated day and night (two weeks, with two ventilation rates).

This sequence will be performed in the spring and midsummer to obtain data on the effect of changing climatic conditions on the performance of ventilative cooling. The effect of these ventilation modes will be compared with the baseline performance (when the buildings are not ventilated).

In a nocturnally ventilated building, the stored cold is used during the daytime hours to lower the indoor temperature, thus reducing the need for mechanical (compressor or evaporative) cooling. The structural cold-storage effectiveness is expressed by the reduction of the indoor daytime temperatures in the nocturnally ventilated buildings below the indoor daytime temperatures of the same buildings when they are closed day and night or when ventilated day and night.

ALTERNATIVES TO COMPRESSOR COOLING IN CALIFORNIA TRANSITION CLIMATES

IMPROVED DOE-2/COMIS RESIDENTIAL SYSTEM MODEL

Fred Winkelmann
Staff Scientist
Lawrence Berkeley Laboratory

Researchers on the *Alternatives to Compressor Cooling* project are devising approaches to mitigate the large and sporadic electric demand peaks on hot summer days caused by air conditioning of houses in California transition climates. The main tool being used to analyze demand-reducing cooling strategies is the DOE-2 building energy analysis computer program.

An improved DOE-2 residential system model is being developed that will provide increased flexibility and accuracy in simulating alternative cooling strategies, such as natural ventilation, forced ventilation, and evaporative cooling. The key new features of this model are:

- A link to the COMIS air-flow model to allow accurate modeling of wind-induced natural ventilation, taking into account wind direction, wind speed, size and position of window openings, and effects of interzone air flow.
- Calculation of forced night ventilation to precool the building mass.
- Improved calculation of direct and indirect evaporative cooling.
- Simulation of a "smart controller" that will decide what alternative cooling strategy is most appropriate at any given time, depending on the building type and environmental conditions (such as outside temperature, humidity, and wind speed).
- Simulation of duct losses.

The improved model will be used for parametric analyses in this project, validated against measurements from the Pala test buildings, and later released for public use.

ALTERNATIVES TO COMPRESSOR COOLING IN CALIFORNIA TRANSITION CLIMATES

CULTURAL, SOCIOLOGICAL, AND INSTITUTIONAL ISSUES

Bruce Hackett
Associate Professor
University of California, Davis

Loren Lutzenhiser
Associate Professor
Washington State University

This element of the *Alternatives to Compressor Cooling* project is designed to identify potential barriers to the adoption of alternative cooling technologies in new home construction in California transition climates. The first phase of the project has involved in-depth interviews and secondary analysis of existing data. The researchers are exploring both consumer cooling behavior and preferences and market constraints faced by the organizational actors who shape residential design (builders, developers, HVAC installers, realtors, appraisers, lenders, and code officials). The immediate goal is to identify those characteristics and attributes of compressor air conditioning (AC) and alternative technologies that are most salient to buyers and users.

Preliminary analysis has identified a good deal of variability in cooling behavior and cooling energy use in transition climates, with wide variation in saturations of the various types of cooling equipment used (central and room AC, evaporative coolers, and whole-house and attic fans) and the finding of widely variable cooling energy load shapes. Some important dimensions of consumer preference and understanding regarding cooling alternatives have also been identified, although data continues to be collected from both AC users and nonusers living in transition areas.

While some consumers are strongly opposed to compressor cooling (and have developed a variety of strategies for dealing with heat, often in dwellings that are poorly designed for natural cooling), others express concerns about alternatives. These include aesthetics, risk, cost, post-sale support, functionality, fashion, comfort, resale value, and cultural meanings (such as the perception of evaporative coolers as lower-status "swamp coolers"). AC is increasingly questioned by consumers on environmental grounds, however, and few AC users are pleased with its noise and unpredictable costs. Continuing CIEE research may show that AC and noncompressor alternatives appeal to different, and changing, consumer market segments. The work on consumer behavior is being expanded to compare cooling practices, preferences, and desires in different parts of the transition climate area.

Studies of the organizational networks responsible for building design and first purchase of cooling technologies show that AC is, of course, well-established and strongly supported by vendor networks, engineering standards, and sellers' beliefs about buyer preferences. The residential housing industry is changing rapidly, however, and a number of economic and regulatory trends seem to be combining in support of AC alternatives. These include CFC regulation/phaseout and the increasing adoption of new building materials and construction techniques—such as panelized building systems, steel framing, engineered lumber, and increased use of concrete—in response to wood's declining quality and unpredictable prices.

We may be entering a period in which an industry in transition may be more receptive to innovation than in more stable times. A depressed housing industry is also more cautious, and preliminary assessments of builder concerns regarding cooling alternatives point to perceived risks and costs, lack of off-the-shelf and proven designs, and uncertainties about the Title 24 implications. The concerns and interests of HVAC contractors have also been considered, along with those of developers, architects, the lender/appraiser subsystem, utilities, and government. The importance of various factors (critics/opponents of AC, buyer/user knowledge, codes and standards, non-California actors, interest rates and financial conditions, marketing barriers, and subsystems undergoing particularly rapid change) in the development, acceptance, and diffusion of cooling technologies is being investigated.

Until the project team develops a range of prototype designs, industry and consumer informants can only supply fairly generic information regarding barriers to adoption. However, some of the forms of support and resistance that are likely to be encountered by specific design alternatives have been explored; these include evaporative coolers, exposed slab and interior mass, shading, increased albedo levels, insulation, modified window design and placement, forced ventilation, night ventilation, and advanced building/HVAC control systems.

As the project proceeds, researchers are working to supply team members whose expertise lies in building and system design with suggestions regarding design acceptability and alternative design strategies (for example, designs that do not preclude future modification and approaches to design that integrate structure with occupant behavior). Industry and consumer studies are being expanded to build a network of key sources of criticisms and suggestions regarding specific design alternatives.

This effort is being coordinated with other utility-sponsored DSM marketing and building prototype R&D projects. These networks are intended to develop into primary channels through which technology development resulting from this project may be readily transferred to designers, builders, installers, and marketers. Regional and national trends in changing consumer lifestyles and preferences, industry developments, and competing cooling technologies will continue to be closely monitored, with a long-range goal of assuring optimal acceptability and adoption of noncompressor cooling designs by first buyers and end users.

ALTERNATIVES TO COMPRESSOR COOLING IN CALIFORNIA TRANSITION CLIMATES

ARCHITECTURAL INTEGRATION AND PERFORMANCE OPTIMIZATION OF EVAPORATIVE COOLING SYSTEMS

Hofu Wu
Brooks Cavin III
Professors
California State Polytechnic University, Pomona

If alternative strategies for replacing compressor cooling in residential buildings are to be successful, the proposed evaporative cooling systems must provide both adequate comfort level and substantial energy benefits. From the utility's point of view, the system must have drastic peak reduction and no negative environmental impact; from the developer's perspective, the system needs to offer flexible compatibilities for design and construction.

PRELIMINARY ASSESSMENT

Preliminary assessments are being conducted using the existing analytical module in the DOE-2 program. Energy consumption and peak demand of evaporative cooling systems are quantitatively compared with several system design variables: dimensions of the wetted pad, size and type of heat exchanger, air-flow rate, and fan power. After reviewing alternative cooling strategies, researchers decided to focus on ventilation and evaporative cooling systems; system optimization is planned for the transition climate only. The conclusion of the preliminary assessment is that building with better envelope thermal criteria can almost eliminate the cooling load in this region.

VALIDATING THE EXISTING MODEL

Researchers are investigating the factors that determine the effectiveness of evaporative cooling systems in transition climates; these include fan and pump power, part-load efficiency, and water usage. The system performance is validated with field experiments, and system parameters are derived from computer simulations to achieve the most energy-efficient system designs for residential buildings in transition climates.

For example, an evaporative cooler's performance varies greatly depending on the thickness of the wetted media and the speed of the air passing through the media. Once the performance relationship to the pad thickness and air speed is determined, it can be used to derive various design combinations for specific application. Meanwhile, the energy-load profiles and peak-load demands can be closely monitored to confirm the effects of system cycling and seasonal operations.

INTEGRATED DESIGN SOLUTIONS

Optimizing the cooling potential of ventilation, evaporative cooling, and thermal storage requires a smart-control device. Based on the variables monitored between the outdoors and the interior, a smart-control system can choose among various routes to meet cooling needs. Researchers are developing ways to integrate alternative cooling systems with standard architectural elements to allow industry implementation. Because many of the alternative cooling strategies being analyzed require specific architectural changes to the building, the physical constraints imposed by residential construction and system integration are being analyzed. A preliminary collection of architectural design and construction details used by the regional architects and builders is being examined.

CALIFORNIA UTILITY DATABASE ON MONITORED PERFORMANCE OF EFFICIENT END-USE TECHNOLOGIES

Alan Meier
Staff Scientist
Lawrence Berkeley Laboratory

The objective of this project is to uncover and assess the California utilities' "gray literature" pertaining to energy use and conservation. Gray literature is the technical reports, memos, and informal studies undertaken by utilities that are never published, categorized, or disseminated, typically residing in file cabinets and closets. Earlier projects had indicated that this literature contained information that would improve the general knowledge of energy use and conservation technologies. Indeed, some of the studies were unique or would be extremely expensive to duplicate. If such information appeared useful, then the second goal of this project would be to determine the feasibility of establishing a catalog so that other utilities would benefit from the research.

To limit the scope of the study (and to avoid any nervousness among the authors), researchers placed three restrictions on the gray-literature search:

- Only studies containing measured energy use or savings would be included.
- No studies with rate-making implications would be considered.
- A utility may ask that any of its documents not be included in the database.

The response to one of the documents uncovered confirmed the potential value of gray literature. Pacific Gas and Electric (PG&E) had commissioned a detailed study of a stand-alone solar house. The objective was a better understanding of the energy requirements of an ultra-low-energy home. In the course of the investigations, the researchers discovered that the gas stove was a significant consumer of electricity and identified the source as the electric igniter for the oven. Unlike ordinary, pilotless ignitions on range burners, this igniter drew 400 watts whenever the stove burner was on. In fact, when cooking small items, the gas oven consumed more electricity than a microwave oven!

As a result of this revelation, Southern California Gas looked into offering a special rebate on gas ovens not equipped with this option. Another result of this study is that the Department of Energy will probably revise the appliance energy-efficiency standards to discourage the use of this technology.

The PG&E report reflects many aspects of this CIEE project. First, it was truly gray literature: The report was never listed in any collection and lacked an identifying number. (The cover didn't even have a date.) Second, the report had important results that were not available elsewhere. Finally, uncovering these results caused another utility to consider an entirely new demand-side management program.

There is no easy way to identify and collect the gray literature. In fact, one objective of this project was to determine whether or not the gray literature could even be located. It was not possible, for example, to telephone every utility and ask them to mail all their gray literature. Instead, the researchers are visiting each of the utilities and identifying the people who are most likely to know about this kind of research. In the larger utilities, this may involve visiting several departments. The researchers typically give examples of the kinds of information being sought as well as examples from other forays. One result of these discussions is that information is transferred both among the utilities and, even more surprising, among different departments within the same utility.

Hundreds of documents have been reviewed; more than 75 have been entered into an electronic database. Although several sites remain to be visited, some tentative conclusions have been reached:

- The research contained in the gray literature is valuable and should be disseminated.
- It would be difficult to compile and update a comprehensive list of gray literature pertaining to energy use and efficiency;

there are simply too many people involved. Many of those people would not even realize that they were creating the desired gray literature, while others would be much less candid if they knew their reports would be widely disseminated.

- Customer confidentiality could become a major obstacle to wider dissemination. Many documents in the gray literature are case studies that name the customers and unique features of their operations. Utilities are justifiably reluctant to reveal this information to the public.
- Everyone involved would benefit from increased exchange of this information. A database is probably the wrong medium, but an informal conference or an add-on to an existing conference might be suitable.

RESIDENTIAL SECTOR SPACE-CONDITIONING LOAD DATA ANALYSIS

Joseph Eto
Staff Scientist
Lawrence Berkeley Laboratory

Residential space-cooling loads are of particular concern for resource planners; not only are they growing rapidly, but the loads they place on utilities coincide with system peak demands.

The annual energy-demand forecasting models used by California utilities and the California Energy Commission (CEC) rely on an explicit representation of the end-use structure of energy demand. Forecasting peak electricity demand and load shapes requires additional disaggregation of annual forecasts over the hours of the year. These disaggregations are appropriate because policy interventions to improve energy efficiency can only be captured by forecasting tools that incorporate end-use and load-shape detail.

Lack of high-quality end-use data to support these modeling activities has been cited as the most important factor limiting forecasting improvements. Moreover, collecting this data can be very expensive. California is fortunate because its utilities have begun collecting end-use metered data. Analysis of the data for forecasting purposes, however, has been limited.

PROJECT OBJECTIVES AND APPROACH

The objective of the project was to analyze end-use metered data on residential space cooling to develop a common set of inputs for the end-use forecasting models used by Pacific Gas and Electric (PG&E) and the CEC.

PG&E's load research group has been collecting end-use metered data from more than 700 residential customers since 1985. This data was obtained, along with corollary weather data and statistical weighting factors, in a previous CIEE-sponsored project (a subproject of *Integrated Estimation of Load Shapes and End-Use Energy Intensities in Commercial and Residential Buildings*).

Both PG&E and the CEC use a load-shape forecasting model (called HELM) developed by the Electric Power Research Institute to prepare electricity demand forecasts. However, they use different conventions for defining end uses within HELM.

Working within existing PG&E and CEC conventions, the researchers developed HELM input files by applying consistent analysis procedures to the PG&E data. Three types of inputs were developed: weather response functions that allocate forecasts of annual energy use to the days of the year; sets of 24-hour load shapes correlated with measures of daily climatic severity; and an alternative to the use of a single 24-hour load shape that relies on direct estimation of each of the 24 hourly values.

CURRENT STATUS AND FINDINGS

The findings are being summarized in a final report, which should be available about the time of the CIEE Annual Conference. In addition, the results of the analysis will be delivered to PG&E and the CEC in the form of revised HELM input files so that both can incorporate project results into their fall 1993 forecast filings.

FUTURE WORK

At present, all load-shape models operate as post-processors to annual energy-demand forecasting models. In the future, the researchers would like to investigate methods for relating observed hourly end-use electricity consumption directly to physical and other characteristics of metered households. CIEE is also interested in determining how best to leverage expensive end-use metered data with nonmetered end-use data to develop reliable information for forecasts and demand-side management program evaluations.

INTEGRATED ESTIMATION OF COMMERCIAL-SECTOR END-USE LOAD SHAPES AND ENERGY-USE INTENSITIES IN THE PG&E SERVICE AREA

Hashem Akbari and Joe Eto
Staff Scientists
Lawrence Berkeley Laboratory

This multiyear project has three primary objectives. The first is to apply an end-use load-shape estimation model and develop a common set of hourly end-use load shapes and annual energy-use intensities (EUIs) in commercial buildings by building type, vintage, and climate region. The results will be compatible with the energy and peak-demand forecasting models developed by Pacific Gas and Electric (PG&E) and the California Energy Commission (CEC). Load shapes are of special interest for typical weekdays, weekend days, and peak days, by month or by season.

Second, the adequacy of the estimated load shapes and EUIs for the PG&E and CEC forecasting models will be evaluated. The third objective is to analyze measured end-use load data collected by California utilities (such as PG&E and Southern California Edison) for commercial buildings and to validate an end-use load-shape estimation model developed at Lawrence Berkeley Laboratory.

This project, being conducted in two phases, addresses the first and second objectives. The scope of Phase I, which was completed in May 1992, included three building types and up to 10 end uses per building. Phase II began the following September and will study the remaining eight building types. The building types being studied are small office, large office, retail store, restaurant, food store, warehouse, school, college, health, lodging, and miscellaneous. The end uses include space heating, space cooling, ventilation, indoor lighting, outdoor lighting, refrigeration, cooking, and office equipment.

The project addresses both electric EUIs and electric load shapes. The average annual electric EUIs for each vintage are being developed for the conditioning and nonconditioning end uses. Whole-building load shapes have also been developed for all building types. Weather-dependent EUIs are being evaluated for two climate zones: coastal and inland. For each building type, the two building/equipment vintages considered are buildings built before 1979 with pre-1979 equipment and those built after 1979 but before 1982 with post-1979 equipment.

The core data on which the project is focused includes:

- PG&E on-site survey data of 855 buildings, including billing data and weights.
- Load research short-interval (30-minute) load data of more than 1,000 accounts for 1985 and 1986.
- The 1985 and 1988 PG&E commercial-sector end-use mail surveys (roughly 6,000 for 1988).
- Hourly weather data for five climate zones.

The integrated methodology has two major components: reconciliation of initial end-use load-shape estimates with measured whole-building load data to produce intermediate EUIs and load shapes, and data-transfer procedures to transform intermediate outputs into a revised set of inputs for CEC and PG&E forecasting models. In previous presentations, researchers have talked in detail about the reconciliation methodology, which includes initial estimates of end-use load shapes, average whole-building load shapes, and reconciliation of the two sets of load shapes. This presentation will focus on data-transfer issues and adjusting the reconciled EUIs for direct application to CEC and PG&E forecasting models based on the following factors:

- Determining climatic impacts on space-conditioning EUIs.
- Accounting for fuel saturation effects.
- Disaggregating reconciled EUIs by building and equipment vintage.
- Developing EUIs for electric heating and nonelectric end uses.

- Expressing reconciled EUIs relative to a 1975 base year.

The end-use load shapes and EUIs developed through the reconciliation procedure represent a snapshot of 1986 electricity use by building type and end use for two regions of the PG&E service territory. For each building type, this snapshot represents an aggregation of the energy used by buildings in all five PG&E climate zones considered in the CEC's forecasts. Within these zones, the snapshot also aggregates differing saturations of fuels and end-use equipment within each end-use category. It further aggregates energy use over buildings and equipment subject to various eras of building construction and equipment selection practices (including the effects of two generations of mandatory building and appliance minimum-efficiency standards). Each of these underlying dimensions of total energy use (climate zone, fuel choice, vintage, and equipment saturation) is explicitly represented as a separate element within the CEC and PG&E commercial-sector energy-demand forecasting models. In addition, the models' forecasts are based on a common base year, 1975, so that the impacts of energy prices on energy use between 1975 and 1986 must also be taken into account. Finally, both the CEC and PG&E models require information on several classes of EUIs—such as electric space heating and nonelectric space heating and water heating—that cannot be developed directly through the reconciliation procedure.

BUILDING PERFORMANCE MEASUREMENT, OPERATION, AND CONTROL

Anthony V. Sebald
Associate Professor
University of California, San Diego

The goal of this multiyear project is to assess and demonstrate ways to operate and control whole-building systems through intelligent computer control, diagnostic measurements, and feedback. This approach makes commissioning a continuous activity rather than a one-time certification, combines commissioning with operation and maintenance, and integrates building customers with the internal building control system.

Specifically, this project will define a standard set of information that will, if provided by the building's energy management and control system (EMCS), assist utilities, building owners, and building operators by allowing rapid evaluation of building performance and rapid diagnosis of the most important operational and maintenance problems. This standard will address informational needs of owners, operators, and utilities in both energy and economics. Its four main components are the data that needs to be recorded, the data processing and graphics display (for conveying the information to the users), the networking protocol for extracting the information either locally or remotely, and user training. Utilities may decide to require conformance with the standard as a condition for rebates.

This multidisciplinary project, which will begin in August 1993, consists of three phases: research, development of the tools required to demonstrate the utility of the approach, and demonstration of the approach. Specific tasks are to:

- Determine the status and performance of current commissioning techniques and investigate strategies for correcting the worst building performance problems.
- Give building customers clear, up-to-date information on the building's current status and performance.
  - ➢ Investigate how to present relevant information to customers so they can easily understand the current status and performance of the building.
  - ➢ Investigate the degree to which the intelligence of the EMCS should be expanded and how best to distribute that intelligence throughout the building.
- Investigate advanced methods for minimizing energy consumption and maximizing comfort and indoor air quality by integrating occupant (and other customer) cooperation with advanced building control techniques.
- Demonstrate systems that achieve these goals in a commercial building or buildings to be chosen during the first phase of the project.

SUBPROJECT PRINCIPAL INVESTIGATORS

Edward Arens
Department of Architecture
University of California, Berkeley

Samuel Haddad
Department of Mechanical Engineering
Santa Clara University

Harry Misuriello
The Fleming Group

Mary Ann Piette and Alan Meier
Lawrence Berkeley Laboratory

A. V. Sebald (Project Coordinator)
Department of Electrical and Computer Engineering
University of California, San Diego

Dale Seborg
Department of Chemical and Nuclear Engineering
University of California, Santa Barbara

Robert Tatum and Chris Shockman
Department of Civil Engineering
Stanford University

IMPROVED OPTIMIZATION OF ENERGY EFFICIENCY AND LOAD SHAPING THROUGH LIGHTING CONTROLS: A SCOPING STUDY

Mark Rea, Director
Dorene Maniccia, Lighting Application Specialist
Lighting Research Center
Rensselaer Polytechnic Institute

This scoping study was sponsored by CIEE, the New York State Energy Research and Development Authority, Pacific Gas and Electric, and Bonneville Power Administration. Jim Benya of Proven Alternatives, Inc., and Rudy Verderber of Lawrence Berkeley Laboratory served as subcontractors.

The project was designed to evaluate the attitudes and opinions of electric utilities, lighting control manufacturers, and lighting control specifiers regarding:

- The state of the art in lighting control systems and components.
- Barriers limiting the application of the state-of-the-art technologies.
- Energy benefits of lighting controls as they apply to commercial office buildings.

METHODS

Attitudes toward lighting controls were assessed through mailed and telephone surveys and personal visits from utilities, manufacturers, and specifiers. These three groups were contacted because of the significant impact they can have on the penetration of lighting controls into commercial buildings.

Utilities influence the specification of lighting products through their demand-side management programs, including the use of rebates, but they could be much more influential in the specification of lighting controls through these programs. Manufacturers define the marketplace for lighting controls through their products; therefore, it was essential to understand their attitudes toward the state of the art in lighting controls. The specifiers' confidence in and past experiences with products drive their decisions on what, if any, control product to specify. If specifiers have no confidence in lighting control products, those products will never become a prevalent efficient-lighting technology.

RESULTS

The interviews showed that the state of the art in lighting controls has two definitions: what is known to work and is cost-effective and what is being promoted and might be made to work. By the first definition, occupancy sensors, time-of-day scheduling, or a combination of the two strategies was considered cost-effective and state-of-the-art by the specifiers and manufacturers interviewed. By the second definition, "smart" technologies are defined by all three groups as the state of the art in lighting controls.

The three groups identified similar barriers to the application of controls. All three believed that education, first cost, research and development, reliability, and cultural beliefs were barriers to the application of lighting controls, although specifiers most often considered effects on the end user.

This scoping study showed that the identified barriers are inhibiting the specification and use of lighting controls. Although smart technologies are considered state of the art, they are not being specified because of certain barriers. Also, objective data to support convictions by the three groups was scarce. The groups' beliefs were based largely on personal experience or on a narrow perspective of a particular lighting control strategy. Although past demonstrations have reported significant energy savings from using lighting controls, most of the data was collected for combinations of strategies rather than a single strategy. Further, there exist few demonstrations documenting systematic analyses of occupant responses to lighting controls and long-term evaluation of maintenance issues and energy benefits. In effect, the potential for lighting controls to improve lighting and building energy efficiency is not well documented.

A comprehensive research, development, demonstration, and technology transfer program is recommended to overcome the identified barriers and to identify the energy benefits of lighting controls.

The demonstrations should be designed to collect objective data using standardized methods, evaluate new and existing control technologies, and develop application guidelines based on the results of the data collection. Documenting the energy benefits and human-performance issues of new and existing lighting control technologies is critical to gaining wider acceptance and use of lighting controls, and application guidelines are necessary to help users select, specify, and use lighting controls.

RESIDENTIAL VENTILATION SYSTEMS

Helmut E. Feustel
Staff Scientist
Lawrence Berkeley Laboratory

Over the past two decades, rising home heating costs have increased efforts to improve energy efficiency in homes by limiting air infiltration. State energy planners have responded by enacting new building codes and programs requiring builders to construct homes that are better insulated and limit air infiltration. While these efforts have succeeded in reducing home heating costs, homes have now become so "tight" that they don't allow adequate ventilation. Whereas natural air infiltration through the building once provided adequate ventilation, energy-efficient building practices have effectively eliminated that as a means of meeting current ASHRAE ventilation standards.

With state home energy efficiency programs limiting allowable air infiltration and ASHRAE standards recommending minimum air-ventilation rates, it has become obvious to builders that these opposing requirements can only be met by incorporating ventilation systems into the designs of their homes. Builders across the state, as well as across the country, are now faced with the task of identifying and selecting ventilation strategies and products that provide sufficient ventilation without significant impact on the home's energy usage.

OBJECTIVES

The goal of Phase I of this project is to identify and assess effective, economical, energy-efficient ventilation approaches to residential construction. The approaches currently in use will be researched and analyzed to assess their performance, cost-effectiveness, and impact on home energy usage. At the conclusion of this phase, the most appropriate ventilation strategies will be recommended.

The objective of Phase II will be to demonstrate the ventilation approaches determined to be most appropriate for New York state homes to verify their field performance and impact on home energy usage. The ventilation approaches recommended in Phase I will be implemented in 24 New York homes and monitored to verify their ability to provide acceptable ventilation without significantly affecting the home's energy usage. The results of this phase will be used to develop a manual of acceptable design and installation practices for ventilation systems. Additional short-term monitoring shall then be performed to evaluate the design and installation practices outlined in the manual.

PHASE I ACTIVITIES

Phase I consists of the following tasks:

1. Review of ventilation approaches and strategies
Technical literature will be researched to identify the range of approaches available for providing ventilation in homes, review the products used, and compare the results of these studies. Relevant standards for ventilation equipment, building ventilation requirements, and air-infiltration measurements (ASHRAE 62-119, ASTM E779, and NYSE-STAR, for example) will be identified.

2. Review of air-change data for New York state and California homes
Measured data from air infiltration and ventilation studies provided by CIEE will be reviewed and analyzed to characterize the natural infiltration rates of the New York and California housing stock and create a baseline database for subsequent analysis.

3. Product and HVAC contractor survey
Air-leakage data will be acquired from the NORIS study and compared to the New York and California data to examine the similarities in measured air leakage and calculated ventilation rates between these homes and homes in other states.

4. Development of analysis plan
An analysis plan that describes the methods and procedures for determining the most promising ventilation approaches and strategies for New York state and California homes will be developed.

5. Analysis of ventilation approaches
At a minimum, the analysis will determine the following for each ventilation approach:

- Air-change rate
- Uniformity of air distribution
- Energy impact
- Equipment costs
- Operating costs
- Life-cycle costs.

Life-cycle cost analyses shall also be performed for each of the ventilation options based on New York fuel prices, fuel price escalation rates, inflation rates, and length-of-time information provided by the Energy Authority. This analysis shall be performed for new and existing homes of varying tightness in New York and California. The effect of ventilation systems on combustion appliances and heating equipment operation (such as back draft from exhaust) will be analyzed, as will the effects of ventilation systems on moisture buildup and humidity in homes.

6. Development of ventilation guide
A ventilation guide for New York state homes will be developed based on the results of the work completed in Phase I. The guide, which will be suitable for use by building contractors and HVAC contractors, will cover issues related to ventilation in New York state homes; the types of ventilation products available; methods and strategies appropriate for ventilating those homes (including new, existing, NYSE-STAR, and non-NYSE-STAR homes); and a list of products researched in this project, including their performance specifications, purchase costs, and installation issues and estimated costs.

ANALYSIS OF ENERGY EFFICIENCY AND AIR QUALITY

THE ROLE OF VEGETATION AS A SOURCE AND SINK FOR AIR POLLUTION IN THE SOUTH COAST AIR BASIN

Arthur Winer
Director, Environmental Science and Engineering Program
University of California, Los Angeles

The goal of this three-year project is to address the direct and indirect effects of end-use efficiency on reducing photochemical smog in California's South Coast Air Basin (SoCAB). The proposal under study involves modifications to the surface characteristics of the SoCAB, primarily an increase in surface albedo and a massive tree-planting program. These changes in surface characteristics are designed to moderate the urban heat-island effect and reduce the air temperature of the SoCAB during the summer months. An overall decrease in temperature is hypothesized to lead to reduced energy use with an associated decline in NO_x emissions from electric power plants, as well as lower evaporative emissions of reactive organic gases from a variety of mobile and stationary sources. Reducing these photochemical smog precursors would lead to improved air quality without imposing additional emissions regulations.

However, the effects of a massive tree-planting program may not be entirely beneficial. While many trees have been shown to remove airborne pollutants, they also emit volatile hydrocarbons—primarily isoprene and various monoterpenes—that have been shown to contribute to the formation of photochemical smog in both rural and urban areas. Moreover, volatile hydrocarbons emitted from vegetation generally have a greater photochemical reactivity in the atmosphere than a typical urban mix of anthropogenic hydrocarbons. Adding large numbers of trees could therefore increase both the total hydrocarbon emissions inventory for the SoCAB and the reactivity of the atmosphere. The specific focus of UCLA's portion of this collaborative study is to examine the effects of massive tree-planting programs proposed for the SoCAB and the ability of vegetation to act as both a source of and a sink for air pollution.

To determine the effects of additional trees on air quality in the SoCAB, the researchers developed a baseline vegetative emissions inventory using a Geographic Information System. The advantage of a GIS over conventional database management systems is the ability to manage and model large spatial databases. A GIS was used in this study to resolve existing biogenic hydrocarbon emissions spatially and to model the effects of various tree-planting scenarios. The first step in developing a spatially resolved biogenic emissions inventory was to digitize land-use databases compiled for the entire SoCAB by Ellefsen and Sidawi. Most of the urban areas were resolved to a 50 m resolution, while the rural areas were resolved to a 5,000 m resolution. By combining this digitized land-use map with land-use-specific biomass factors estimated by Horie et al., researchers were able to develop a spatially resolved green-leaf biomass inventory. This baseline inventory was modified to correct for seasonal variations in biomass.

The second phase of the study involved estimating hydrocarbon emission rates for all identified tree species in the SoCAB through an exhaustive literature search. Where available, measured emission rates were assigned. Tree species for which emission rates were not measured were assigned rates based on phylogenetic relationships.

Next, these hydrocarbon species-specific emission rates were combined with the spatially resolved biomass inventory to produce a spatially resolved emissions inventory for isoprene and monoterpene in the SoCAB. Correction algorithms, which account for the effects of temperature, light intensity, and humidity, were applied to the emissions database to develop a diurnally corrected emissions inventory.

Existing vegetation in the SoCAB contributes an estimated 250 metric tons per day of hydrocarbon emissions on a typical summer day, as compared to estimated anthropogenic hydrocarbon emissions of approximately 2,000 MTPD. Since the biogenic hydrocarbon emissions are concentrated in the downwind, eastern portions of the SoCAB—namely the forested San Bernardino, San Gabriel, and San Jacinto Mountains—they are likely to have a relatively minor effect on the urban areas in the upwind, western portion of the SoCAB.

Additional emissions contributed by a massive tree-planting program would vary depending on the species of trees planted. For illustrative purposes, estimates of the emissions from two tree-planting scenarios were calculated. Planting 10 million trees, equally distributed among 10 of the most popular species found in the SoCAB, could contribute approximately 50 MTPD of biogenic hydrocarbons on a typical summer day. If those trees represented 10 of the ultra-low-emitting species identified in this study, however, the contribution to current biogenic emissions would be negligible. These simple scenarios emphasize the importance of selecting low-emitting tree species for massive tree-planting programs. However, other factors must also be considered when selecting candidate trees; these include drought resistance, flammability potential, pollutant trapping and resistance, and a broad spectrum of horticultural properties and landscape uses.

In summary, hydrocarbon emissions from existing vegetation do not appear to contribute substantially to the air-pollution problems in the SoCAB relative to current anthropogenic impacts. However, as anthropogenic emissions decline with future control programs, vegetative emissions may define a lower limit on hydrocarbon emissions for the Basin. Thus, greater emphasis may be required in the future on control of NO_x smog precursors. In addition, proposed massive tree-planting programs may have positive or negative impacts on air quality depending on the species of trees planted; investigation of the role of vegetative hydrocarbon emissions will take on greater importance as mandated emission-control strategies reduce overall inventories of anthropogenic hydrocarbons.

ANALYSIS OF ENERGY EFFICIENCY AND AIR QUALITY

METEOROLOGICAL MODELING INVESTIGATION OF MITIGATION STRATEGIES FOR THE SOUTH COAST AIR BASIN

David J. Sailor
Graduate Student Research Assistant
Lawrence Berkeley Laboratory

In the previous year of this project, an initial series of meteorological simulations was conducted to investigate the potential of several mitigation strategies to cool the Los Angeles Basin. This study included a complete two-dimensional sensitivity analysis and a preliminary investigation of three-dimensional simulations. The sensitivity study revealed the importance of accurate specification of surface characteristics when modeling a heterogeneous domain. These simulations also provided an initial indication that high-albedo and tree-planting strategies could cool cities by several degrees.

In the current phase, a number of advances have been incorporated into the meteorological model and a series of improved three-dimensional simulations has been conducted. Analysis of these simulations indicates a substantial potential to cool Los Angeles through citywide implementation of tree-planting and high-albedo programs.

SURFACE CHARACTERIZATION

The computational domain covers the Los Angeles Basin with an array of 5 km grid cells stretching over 320 km east-west and 200 km north-south. The modeling domain extends vertically to 9 km using variably spaced vertical levels. Initial profiles of meteorological variables were obtained from sounding data for August 1987.

The boundary condition of most interest in this study is the land surface. Specification of surface characteristics—such as albedo, roughness length, moisture availability, and substrate properties—is necessary so that parameterizations of the surface energy balance can accurately predict surface temperatures and heat fluxes. It is common practice for meteorological modelers simply to specify domain-wide average values of all surface characteristics. In this study, a land-use database was used to determine the composition of each grid cell (such as percentage urban core, grassland, and low-density housing). Each cell consists of various percentages of 23 terrain types. Based on data in the available literature and professional judgment, reference values of each surface characteristic were assigned to each land-use category. Simple area-weighted averages of these characteristics were then used to represent each grid cell.

MODELING ADVANCES

The original version of the meteorological model used for this project did not allow for explicit representation of vegetation within the modeling domain. In all previous studies, the effects of vegetation were indirectly accounted for through the available input parameters. Since the investigation of vegetation modification (tree planting) was of interest in this project, a method for explicitly including vegetative changes in the modeling was required.

Several vegetation parameterization schemes were investigated. A simple, previously validated scheme known as *bulk layer parameterization* was eventually chosen for this study. As implemented, the BLP requires specification of only one additional parameter for each grid cell: the fractional vegetative cover.

The model also lacked the ability to include the effects of anthropogenic (man-made) heat release into the environment. This required a simple modification to the energy balance of the first air layer and the specification of a nominal diurnal profile function. The peak value of daily anthropogenic heat release was then assigned to each grid cell as a function of the land-use characterization. The simulation results indicate that inclusion of this term produces moderate air-temperature differences with virtually no impact on the local flow patterns.

MITIGATION SCENARIOS

The mitigation scenarios developed in the previous phase of this study were refined and tested using a land-use database to identify 394 grid cells (out of the 2,600 cells in the modeling domain) for albedo and/or vegetation augmentation. Two nominal levels of each mitigation strategy were investigated for both individual and concurrent application. The moderate-level modification specified a nominal 0.15 increase in the albedo or vegetative fraction, while the extreme-level modification was exactly twice this value. The modified grid cells are highly concentrated in and around the city of Los Angeles. These 394 grid cells correspond to regions that are significantly developed and have low existing values of albedo and/or vegetative cover.

METEOROLOGICAL RESULTS

After developing and investigating several base-case simulations, the researchers evaluated the mitigation cases. The results indicate a potential for moderate application of high-albedo surfacing to cool Los Angeles by as much as 2°C (3.6°F). The corresponding application of a moderate tree-planting program was predicted to have a peak-temperature impact of roughly 1°C (1.8°F). The extreme mitigation scenarios investigated a doubling of the mitigation level relative to the moderate cases; the impacts on air temperatures were approximately a factor of two larger for the extreme cases.

The complex interactions between the surface modifications and the local meteorology give rise to several conflicting air-quality implications. The lower air temperatures will clearly result in lower biogenic and anthropogenic emissions from the surface and lower rates of photochemical reaction. At the same time, however, these simulations revealed that mixing heights will also be reduced. Reduced mixing height is a mechanism for increased photochemical smog in Los Angeles because it reduces the effective volume into which surface emissions are mixed, resulting in higher concentrations of photochemical precursors. The quantitative effect of the two mechanisms can only be evaluated by analyzing the photochemical simulations; this analysis is currently under way.

ANALYSIS OF ENERGY EFFICIENCY AND AIR QUALITY

URBAN AIRSHED MODELING OF THE SOUTH COAST AIR BASIN: PRELIMINARY SENSITIVITY ANALYSIS

Haider Taha
Staff Scientist
Lawrence Berkeley Laboratory

Many strategies have been proposed to reduce the emission and formation of atmospheric pollutants in urban areas. These strategies directly or indirectly involve a broad range of regulations and standards, such as those related to transportation emissions or energy efficiency in buildings. In this project, researchers are examining the impacts of yet another potential pollution-reduction strategy, this one involving large-scale surface albedo and vegetation modifications. The impact of these modifications on the urban meteorology and air quality of the South Coast Air Basin (SoCAB) is being studied with the aid of numerical models. Output from a prognostic mesoscale meteorological model will be used in a three-dimensional mesoscale photochemical air-quality model to quantify the implications of these strategies on urban air quality.

The Urban Airshed Model (UAM) is used to simulate the effects of surface property modifications on meteorological conditions and regional air quality in the SoCAB, with particular emphasis on ozone formation. The simulations will account for existing anthropogenic and biogenic emissions as well as the additional biogenic emissions that will result from the proposed increase in vegetation cover. Instead of performing the simulations for hypothetical and purely theoretical conditions, researchers are simulating UAM sensitivity using SoCAB-specific data to provide more insightful clues to real conditions.

At the current stage of this project, the UAM is being used in preliminary sensitivity simulations to analyze the basinwide air-quality changes following modifications in major parameters. These include near-surface air temperature, mixing height, emissions, roughness, vegetation fraction, and wind field resulting from modifications in surface albedo and vegetation cover. In these simulations, surface characteristics, emissions, and meteorological data from August 26-28, 1987, were used as input to the UAM.

The conditions in all 2,340 cells at the bottom boundary of the 180-by-325-km modeling domain are modified in a similar fashion (equal or proportional amounts of change with respect to a certain variable). For example, temperature-sensitivity simulations were performed by modifying the near-surface air temperature in every surface cell by 2 and 4°C (4 and 7°F). The mixing-height simulations, on the other hand, were performed by increasing or decreasing the mixing height over each cell by 25% of the base-case mixing height at that location and time.

As expected, the large space and time variation in thermophysical, emissions, and meteorological conditions within the domain results in a range of possible space- and time-varying conditions, combinations, and concentrations. It is inherently difficult to formulate one simple, descriptive statement as to the direct impacts of certain parametric variations on basinwide air quality. Therefore, the figures presented here should be interpreted cautiously at this stage.

The preliminary temperature-sensitivity simulations indicate that lowering the air temperature near the surface by 2°C (3.6°F) can reduce the ozone by 10 to 15 parts per billion (ppb) in areas such as Riverside, the Los Angeles Civic Center, and Burbank during times of peak concentrations (about noon to 4:00 p.m.), when the baseline concentration is between 100 and 170 ppb at these locations. (Site-specific reductions can be larger or smaller, but the numbers given here are representative of these areas.) For a decrease of 4°C (7.2°F) in air temperature, reductions in ozone of 20 to 30 ppb are possible in these areas and for the same times of day. Note that cooling the Los Angeles area by 2 to 3°C (up to 5°F) is feasible according to mesoscale meteorological simulations that account for the effects of large-scale increases in surface albedo and vegetation cover.

In terms of mixing height, the results are still being analyzed; however, it appears that the chemistry of ozone removal may add a complicating factor to this case. If the mixing height is decreased—as would happen when albedo is increased, for example—ozone concentrations in various areas of the SoCAB would increase or decrease depending on several factors. Based on preliminary UAM simulations, a 25% change in mixing height typically increases or decreases ozone by 5 to 20 ppb in the areas and time frames mentioned earlier. Changes in basinwide air quality as a function of changes in other parameters are still being analyzed.

Following this stage of preliminary simulations, the UAM will be run using extensive output from the meteorological model so that specific times, meteorological and surface conditions, and albedo/vegetation modification scenarios may be evaluated. The results will help researchers formulate implementation guidelines for these strategies.

REDUCING PUMPING POWER IN HYDRONIC DISTRIBUTION SYSTEMS THROUGH THE USE OF FLUID ADDITIVES

Eric F. Matthys
Associate Professor
University of California, Santa Barbara

Recirculating water (hydronic) systems for cooling and heating in buildings are very attractive because of their efficiency, compactness, and comfort level. For large systems, however, the pumping power required to circulate the water can be a significant part of the overall energy consumption of the system.

To minimize the pumping energy used, researchers on this project have proposed the use of surfactant additives to reduce the pressure drop in the system pipes. These additives affect the turbulence intensity of the flow, resulting in decreased friction at the wall compared to pure water at the same flow rate. This phenomenon is often referred to as *viscoelastic drag reduction*, and polymeric additives showing this effect have been studied for some time. A common problem with these additives, however, is that they are very susceptible to degradation caused by the fluid motion itself and by hydraulic components and are therefore generally not usable in long-term recirculation systems.

Unlike these drag-reducing polymeric additives, the surfactant additives being examined in this study do not degrade rapidly, making them a potentially more viable option for recirculating applications such as hydronic HVAC systems. Because very little was known about the flow characteristics of these solutions at the beginning of this project, the properties of these fluids are being investigated to quantify the potential energy savings they may yield and to solve possible problems pertaining to their implementation in hydronic systems.

PREVIOUS WORK

The first phase of the project consisted of a theoretical feasibility study based on a literature survey. The known properties of these fluids were reviewed and analyzed in light of typical hydronic system characteristics. A good match was determined to exist between the expected fluid properties and the system requirements. Estimates suggested, for example, that using the additives could save on the order of 50% of the pumping power in typical large hydronic systems. This feasibility study also allowed researchers to identify the main issues in need of further investigation: degradation, the effect of hydraulic components on the fluid and vice-versa, diameter effect, material compatibility, and the effect of the fluid on heat exchangers.

The aim of the second phase of the project was to develop an experimental installation that will help researchers answer these questions. Accordingly, a large-scale experimental installation has been built to quantify the savings achieved with the additives and to investigate their flow properties. Several subsystems have also been built to test the flow characteristics of the fluid in pipes, heat exchangers, pumps, fittings, valves, and other components. Experiments conducted with a generic additive have confirmed that friction reductions of about 60 to 80% are readily achieved for velocities normally used in hydronic systems. It was also determined that typical pumps and valves do not result in serious degradation and that the fluid will reconstitute fully less than 150 diameters after a pump or valve. Other studies have been conducted to investigate the effects of concentration, degradation, entrance, and other factors on flow behavior. A large, nonlinear effect of the tube diameter on friction was also observed and quantified for these fluids.

In summary, no major difficulty was encountered in these hydrodynamic experiments, and the results obtained have confirmed the validity of the assumptions made in the feasibility study.

CURRENT PHASE

Given that the basic hydrodynamic premises of the proposed approach were satisfactorily validated, some additional issues need to be explored before the approach's potential can be accurately quantified. The goal of the current research is to address those points.

The question of the additives' effect on heat exchangers is naturally very important to implementation of these fluids in HVAC hydronic systems. The researchers are therefore focusing on measurements in both commercial and laboratory heat exchangers to quantify and control the degree to which heat transfer may be reduced with these fluids. Preliminary investigations of heat exchangers have suggested that heat transfer may be reduced but that the degree of reduction varies greatly depending on the exchanger's geometry and configuration. Research has also shown that the reduction can be controlled or even eliminated.

Another significant effort involves characterizing the fluid and its variations in nature and behavior. Clearly, if an HVAC system is recirculating these additive solutions, we need to know how the fluid is faring as time goes by or as other additives are added. One way to do this is to monitor the overall flow characteristics of the system. Because this measurement may not be enough to characterize the fluid behavior fully, a system of high-pressure capillary viscometers has been built to allow rheometric measurements. Not only do such measurements provide information on change in the fluid properties, but they may also indicate at what point the fluid becomes drag-reducing. In addition, this system—together with direct measurements of friction and heat transfer in the main test loops—is being used to quantify the extent to which the fluid may be sensitive to air exposure and mechanical degradation over long recirculation periods. These viscometer units will also be used to investigate disposal methods for the fluids.

PLANNED ACTIVITIES

The current studies are aimed at understanding the behavior of these fluids. With this understanding, researchers will be able to optimize the use of the additives in hydronic systems. The hardware used in existing installations will need to be defined more accurately in terms of the pertinent parameters—tube diameters, flow rates, shear stresses, and heat-exchanger configurations, for example—leading to identification of a suitable large-scale test site. This test should allow direct measurement of savings in a typical hydronic commercial system.

EFFICIENT THERMAL ENERGY DISTRIBUTION IN COMMERCIAL BUILDINGS

Fred Bauman, Research Specialist
Charlie Huizenga, Research Specialist
Edward Arens, Professor
Center for Environmental Design Research
University of California, Berkeley

Mark Modera and Helmut Feustel
Staff Scientists
Lawrence Berkeley Laboratory

The overall goals of this project are to identify the best energy-savings opportunities in thermal energy distribution (TED) systems used in commercial buildings in California and to research the measures needed to achieve those savings.

The objectives of the first-phase effort are to:

- Identify the prevalence of each major type of thermal distribution system in existing and new commercial buildings.
- Quantify the typical energy performance and peak-load impacts of those systems.
- Use available energy analysis methods and performance data, along with a survey of design engineers, to identify the significant factors (such as inadequate design tools, construction practice, or operating strategies) contributing to poor TED system performance.
- Identify research and technology transfer needed to achieve the identified savings.

BACKGROUND

The first two phases of the multiyear research project *Thermal Energy Distribution in Buildings* consisted of four subprojects: one directed toward residential buildings and three toward commercial buildings. As the residential building population is fairly homogeneous, the only major difference being between single-family and multifamily, the appropriate direction for research has been relatively easy to define.

In the commercial sector, however, the variability in building types, system types, and operating characteristics is dramatic; thus, the prioritization of research topics has been less than systematic. Moreover, due to the large number of options for TED systems in commercial buildings, new ideas for savings opportunities continually arise. At this stage of the project, it seems appropriate to step back and look at the larger picture with the objective of identifying the most cost-effective savings opportunities.

The term *thermal distribution system* refers to all equipment and pathways between the source of heating or cooling and the point of use (such as the delivery of air to a room or water to a coil). Typical distribution media are air, water, steam, and refrigerants. Of these, air systems are by far the most popular and have the largest number of variations.

There are several reasons to evaluate these systems more systematically in commercial buildings:

- The issue of thermal distribution efficiency has not received adequate attention by the building energy research community.
- Anecdotal stories and case studies indicate that small commercial buildings suffer from many of the same inefficiencies that have been uncovered in residential systems.
- The potential for energy savings associated with increasing thermal energy transport efficiency is much greater in commercial buildings than in residential buildings. For example, approximately 35% of the energy consumption associated with large air-distribution systems is due to transport energy; a hydronic system transporting the same thermal energy would require less than 5% of the energy used to transport air.
- Many options are available for commercial building TED systems, and we need a way

to identify and prioritize the energy-savings opportunities.

CURRENT-PHASE ACTIVITIES

The current phase consisted initially of characterizing TED systems in California commercial buildings. Data from several sources, including studies by California utilities, the California Energy Commission, the Electric Power Research Institute, the U.S. Department of Energy, and the Energy Information Agency, was collected to identify the types and quantities of TED systems used in existing commercial buildings. The data, which clearly shows that constant-volume air systems are by far the most common, will be very useful in projecting the potential savings of the various strategies being explored.

The next activity is to determine the most significant causes of energy inefficiencies in commercial TED systems found in California construction. The technical approach will include a literature review, an industry survey, and energy analyses of a full range of thermal distribution systems in commercial buildings. This effort will lead to an assessment of the research and development opportunities for saving energy in the design and operation of commercial-building TED systems.

Based on the current understanding of the situation, the technologies that researchers expect to examine in detail include:

- Various forms of hydronic distribution systems as replacements for or supplements to air-distribution systems (such as flexible hydronic piping for localized thermal distribution systems, radiant panel heating and cooling with hydronic distribution, and distributed water-to-air heat pumps tied to a hydronic distribution system).
- Retrofits of small commercial-building TED systems, including conversion of constant-volume to variable air volume (VAV) systems and duct insulation retrofits for exterior duct work.
- Improved control and operating strategies for TED systems.
- Conversion of constant air volume to VAV and reduction of operating pressures in large duct systems.
- More efficient TED components, including fans, motors, and pumps.
- Reduced friction losses for both air and hydronic systems through improved design, more efficient fittings, and additives for hydronic systems.
- Integration of design and energy simulation tools for large commercial buildings.
- Improved commissioning practices for TED systems and controls.

Subsequent phases will involve additional energy analyses and development of new approaches to improving the energy performance of commercial TED systems, including design tools, construction practices, retrofit options, and operating strategies. Field measurements will be made to support the researchers' assessment of energy performance and demonstrate the effectiveness of proposed energy-conserving measures. Research needs will be identified and pursued to achieve the identified savings. Energy-efficiency guidelines and other recommendations will be disseminated to the building industry, utility companies, and other users of TED technology.

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