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Research & Development Conference

CALIFORNIA INSTITUTE FOR ENERGY EFFICIENCY

A branch of the University of California's Universitywide Energy Research Group, administered by Lawrence Berkeley Laboratory

CIEE

PROGRAM

1991

AUGUST 27–29, 1991 · UNIVERSITY OF CALIFORNIA AT SAN DIEGO, LA JOLLA, CALIFORNIA

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

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WELCOME
to CIEE's 1991 R&D Conference

CIEE's first Research and Development Conference will introduce you to some of the results achieved to date through CIEE-sponsored multiyear research performed 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 will also be featured.

We at CIEE wish to thank the Pacific Gas and Electric Company, Southern California Edison Company, Southern California Gas Company, San Diego Gas and Electric Company, the Los Angeles Department of Water and Power, the Sacramento Municipal Utility District, the California Public Utilities Commission, the California Energy Commission, University of California, and Lawrence Berkeley Laboratory for supporting and guiding CIEE's 1990-1991 research program.

Acknowledgements

Special thanks go to: Ed Vine - Conference Chair, Denise Thiry - Conference Coordinator, Cindy Polansky - CIEE Administrator, Ellen Ward - CIEE Technology Transfer Coordinator, Ralph McLaughlin - CIEE Computer Specialist, Louise Millard and Peggy Little - LBL Conference Coordinators, and Cindy Lawrence - University of California at San Diego (UCSD) Conference Coordinator. Thanks to Jim Cole for his encouragement and support, to UCSD for hosting the Conference, and to the rest of the CIEE staff for helping to make this happen.

MASTER

CIEE's Background and Mission

The California Institute for Energy Efficiency (CIEE) was established in 1988 by the University of California (UC) in cooperation with California's electric and gas utilities, the California Public Utilities Commission (CPUC), the California Energy Commission (CEC), and the U.S. Department of Energy's (DOE) Lawrence Berkeley Laboratory (LBL). CIEE's mission is to coordinate, plan, and implement a statewide program of medium to long-term (five to fifteen 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 research and development (R&D) has the following goals:

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 quality of the indoor built environment, while remaining sensitive to global warming issues.

Improve the data and analytical tools related to the end-use of energy, in order 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 guidance from the CIEE Research Board, technical support from CIEE's Planning Committee, and ongoing input from Project Advisory Committees (PACs) as part of research management.

CIEE's R&D approach emphasizes sponsor input throughout all phases of multiyear research planning and project selection, research management, and the rapid transfer of promising research results.

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AGENDA

TUESDAY, AUGUST 27

11:00 am - 12:00 am: REGISTRATION — **WARREN COLLEGE**

5:30 pm - 7:30 pm: OUTDOOR BARBECUE — **PRICE CENTER**

7:30 pm - 8:00 pm: OPENING REMARKS — **PRICE THEATER**

Ed Vine, CIEE Conference Chair
Jim Cole, CIEE Director
Virgil Rose, CIEE Research Board Chair (PG&E)

8:00 pm - 9:00 pm: PLENARY — **PRICE THEATER**

S. David Freeman, SMUD General Manager

WEDNESDAY, AUGUST 28

7:00 am - 8:45 am: BREAKFAST — **MUIR CAFETERIA A**

9:00 am - 10:30 am: FIRST MORNING SESSION — **PRICE THEATER**

Mark Modera (LBL), *Improving the Energy Efficiency of Residential Air Distribution Systems*
Ed Arens (UCB), *Localized Thermal Distribution Systems for Office Buildings*
Eric Matthys (UCSB), *Reducing Losses in Hydronic Distribution Systems with Fluid Additives*

10:30 am - 11:00 am: BREAK

11:00 am - 12:30 pm: SECOND MORNING SESSION — **PRICE THEATER**

Ashok Gadgil (LBL), *Cold-Air Distribution Systems for Office Buildings*
Halil Guven (SDSU), *The Field Performance of Thermal Energy Storage and Conventional Chillers*
Preston Lowrey (SDSU), *Thermal Energy Storage Commissioning Guidelines*

12:30 pm - 2:00 pm: LUNCH — **MUIR CAFETERIA A**

2:15 pm - 4:00 pm: AFTERNOON SESSION — **PRICE THEATER**

Joe Eto (LBL), *Residential End-Use Energy Data and Load Profiles*
Hashem Akbari (LBL), *Commercial End-Use Load Shape and Energy Utilization Intensity Data*
Mary Ann Piette (LBL), *Office Equipment Energy Use, Load Profiles, Efficiency, and Trends*

4:00 pm - 6:30 pm: POSTER SESSION — PRICE THEATER

Leo Rainer (LBL), *Integrated Estimation of Commercial Load Shapes and Energy Use Intensities*
Dariush Arasteh (LBL), *Low Heat Loss, Non-CFC-Based Appliance and Building Insulation*
Carl Blumstein (UCB), *Alternatives to Compressor Cooling in California Climates*
Nancy Brown (LBL), *Sensitivity Analysis of RAPRENO$_x$*
Ahmad Ganji (SFSU), *Comparative Evaluation of the Impacts of Domestic Gas and Electric Heat Pump Heating on Air Pollution in California*
Ralph Greif (UCB), *Flow and Energy Transfer in Enclosures*
Joe Huang (LBL), *An Assessment of Residential Evaporative Cooling Technologies in California*
Francis Rubinstein (LBL), *Lighting Audit Tool: A Precursor to an Expert System for Specifying Energy-Efficient Lighting*
Marc Schiler (USC), *Interactive Graphic Input to Superlite*
Osman Sezgen (LBL), *Analysis of Energy Use in Building Services of the Industrial Sector in California*
Haider Taha (LBL), *High-Albedo Materials for Reducing Building Cooling Energy Use*
Kenneth Train (UCB), *Customer Participation and End-Use Load Response to Voluntary DSM Programs*

7:30 pm - 9:30 pm: DINNER — FACULTY CLUB

THURSDAY, AUGUST 29

7:00 am - 8:45 am: BREAKFAST — MUIR CAFETERIA A

9:00 am - 10:30 am: FIRST MORNING SESSION — PRICE THEATER

Dan Sperling (UCD), *Market Potential of Alternative Transportation Fuels*
Cathy Kling (UCD), *Market Incentives for Natural Gas and Electric Vehicles*
Andy Ford (USC), *Utility Impacts of Natural Gas and Electric Vehicles*

10:30 am - 11:00 am: BREAK

11:00 am - 1:00 pm: SECOND MORNING SESSION — PRICE THEATER

Steve Selkowitz (LBL), *Integrated Envelope and Lighting Technology to Reduce Electric Demand*
Joe Huang (LBL), *Impact of Shade Trees and White Surfaces on Building Peak Power and Cooling Energy Savings*
Scott Samuelsen (UCI), *Formation of Nitrogen Oxides in Industrial Gas Burners*

1:00 pm - 2:00 pm: LUNCH — MUIR CAFETERIA A

2:15 pm - 4:00 pm: AFTERNOON SESSION — PRICE THEATER

Harry Misuriello (The Fleming Group), *Advancing the State of the Art of DSM Impact Measurement*
Al Gough (Lighting Research Institute), *Supply and Demand of Efficient Lighting Technologies*

Jim Cole (CIEE), *Future Directions for CIEE*

ABSTRACTS

ACRONYM LIST

ACH	Air Changes per Hour
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CAAD	Computer-Aided Architectural Design
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
C-EC	Controlled-Environment Chamber
CEC	California Energy Commission
CFC	Chlorofluorocarbon
COP	Coefficient of Performance
DFWM	Degenerate Four-Wave Mixing
DOE	Department of Energy
DSM	Demand-Side Management
EC	Evaporative Cooler
EDA	End-use Disaggregation Algorithm
EF	Efficiency
EM	Source Emission Factor
EPA	Environmental Protection Agency
EPDM	Ethylene-Propylene-Diene Terpolymer Membrane
EPRI	Electric Power Research Institute
EUI	End-Use Intensity
EV	Electric Vehicles
GFP	Gas-Filled Panels
HVAC	Heating Ventilating and Air Conditioning
IES	Illuminating Engineering Institute
LBL	Lawrence Berkeley Laboratory
LEAR	Lighting Energy Analysis for Retrofits
LRD	Load Research Data
LRI	Lighting Research Institute
LS	Load Shape
LTD	Localized Thermal Distribution
MSI	Moderately Strongly Implicit
NALMCO	National Association of Lighting Management Companies
NGV	Natural Gas-powered Vehicles
ORNL	Oak Ridge National Laboratory
PC	Personal Computer
PEM	Personal Environment Module
PG&E	Pacific Gas & Electric Company
PSP	Precision Spectral Pyranometer
R&D	Research and Development
SAIC	Science Applications International Corporation
SCAQMD	South Coast Air Quality Management District
SCE	Southern California Edison
SDSU	San Diego State University
SERI	Solar Energy Research Institute
SMUD	Sacramento Municipal Utility District
TAM	Task Air Module
TES	Thermal Energy Storage
TOU	Time of Use
UCB	University of California, Berkeley
UCLA	University of California, Los Angeles

COMMERCIAL END-USE LOAD SHAPE AND ENERGY UTILIZATION INTENSITY DATA

Subproject of the Integrated Estimation of Load Shapes and End-Use Energy Intensities in Commercial and Residential Buildings Project

Hashem Akbari
Staff Scientist
Energy Analysis Program
Lawrence Berkeley Laboratory

ABSTRACT

SUMMARY

This project draws upon the modeling and database expertise at Lawrence Berkeley Laboratory (LBL), Pacific Gas & Electric Company (PG&E), and the California Energy Commission (CEC) to improve the quality of commercial sector end-use energy and load data for demand forecasting (and related demand-side planning purposes) in California. The main objective is to integrate commercial end-use intensity (EUI) and end-use load-shape estimates, using a combination of measured load data and simulation modeling of on-site survey data. The second, longer-term objective is to identify further data collection and analysis needs, and assist PG&E and the CEC in developing cost-effective strategies for improving data quality and thus the reliability of forecast results.

In this project, we review and assess the quality and adequacy of the existing databases and for selected PG&E stocks of commercial buildings, apply an integrated approach to estimate hourly end-use load shapes by building type, vintage, and climate region. Typical monthly or seasonal weekday, weekend, and peak load shapes will be developed for both conditioning and nonconditioning end uses.

BACKGROUND

It is generally acknowledged that one of the weakest empirical links in the end-use forecasting arena is the absence of reliable data on electricity end uses in the commercial sector. For several years, the CEC and Southern California Edison (SCE) have supported development of a model by LBL for estimating end-use load shapes and EUIs, using whole-building 15-minute interval load and on-site surveys of building and equipment characteristics for a sample of commercial buildings.

For the SCE service area, data used by the model included on-site surveys, whole-building load research, billing data, mail surveys, and hourly weather data (Akbari *et al.* 1989). A comparable data set is available for PG&E. PG&E has collected whole-building load data at 15-minute intervals for many commercial buildings in their service area. Furthermore, they have obtained on-site surveys for over 800 commercial buildings. These two sources of data, supplemented by records from mail surveys can be used in combination to develop better estimates of EUIs and hourly electric load profiles for commercial building end uses. The model, developed with CEC and SCE sponsorship, will be applied to the PG&E service territory to develop a common set of commercial sector load shapes and EUIs.

SUBPROJECT OBJECTIVES

The overall objectives of this multiyear project are:

1. To analyze measured, end-use load data in commercial buildings collected by California utilities such as PG&E and SCE to validate an end-use load shape estimation model that has been developed at LBL.

2. To apply the validated model to develop a common set of reconciled hourly end-use load shapes and annual EUIs in commercial buildings, by building type, vintage, and climate region. The results will be compatible with PG&E's energy and peak demand forecasting models. Of special interest are load-shapes for typical weekdays, weekend days, and peak days, by month or by season.

3. Evaluate the adequacy of the estimated load-shapes and EUIs in the PG&E and CEC energy and peak demand forecasting models.

This project is designed in two phases. The specific goals of the first-year Phase I subproject are:

1. To apply LBL's end-use load-shape estimation model to obtain a common set of reconciled hourly end-use load shapes (LSs) and annual EUIs for four commercial building types.

2. Initiate work with PG&E and CEC to resolve issues related to the transfer of data for application in forecasting models.

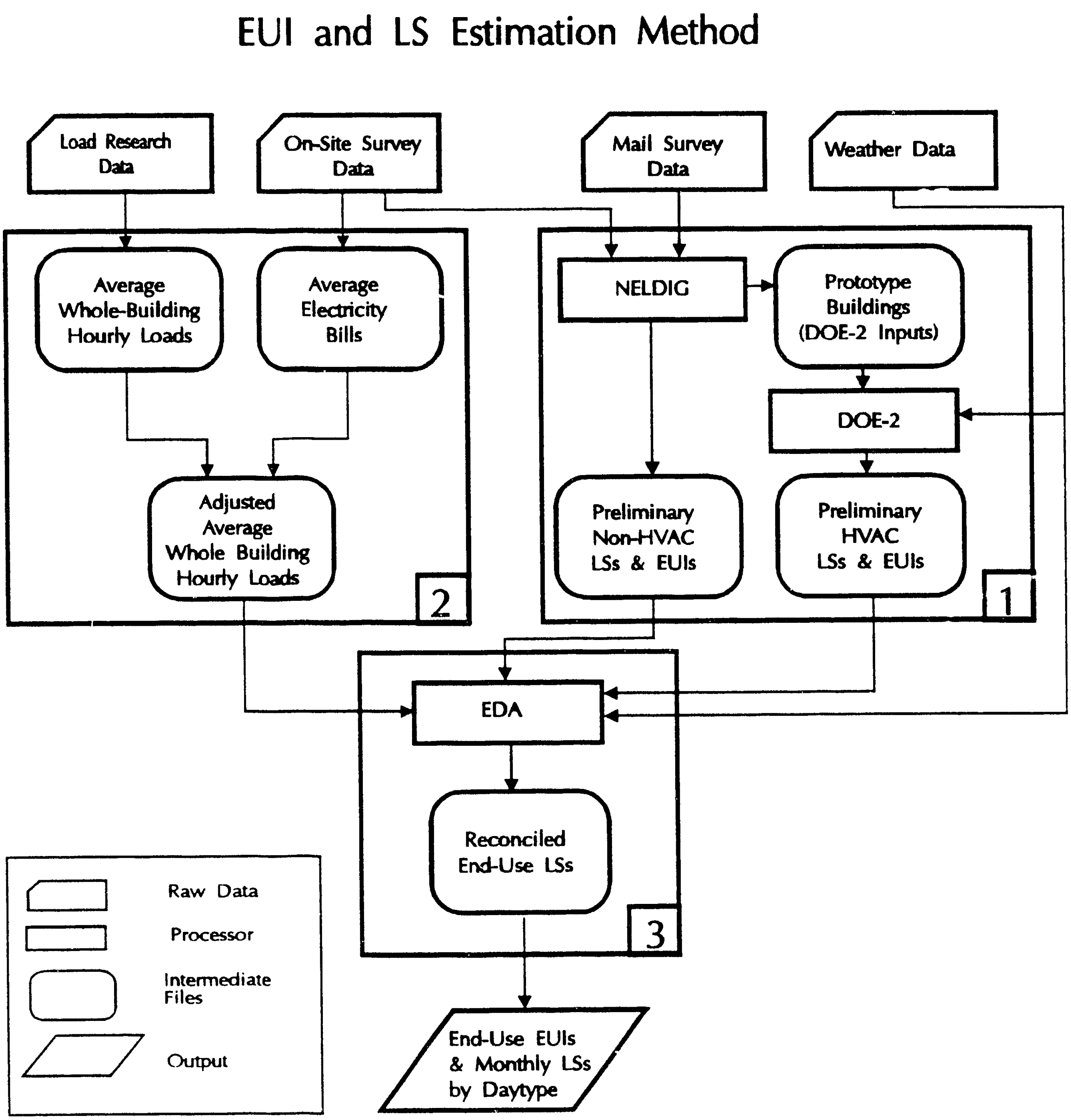
EUI AND LOAD-SHAPE (LS) ESTIMATION METHOD

The LBL model is an integrated method for the estimation of EUIs and LSs, which relies explicitly on measured load research data (LRD) to reconcile preliminary engineering estimates. The method consists of three steps and three major software tools (see Figure 1). First, we develop preliminary prototypical EUIs and LSs for the premises of interest, using the integrated on-site survey data, the non-HVAC EUI/LS and DOE-2 Input Generator (NELDIG), and the DOE-2 building energy analysis program. NELDIG performs two functions: 1) it estimates LSs and annual EUIs for non-HVAC end uses, and 2) it prepares prototypical building input data. The prototypical buildings are then simulated, using DOE-2, to obtain EUIs and LSs for the HVAC end uses.

Second, using the LRD and monthly billing data from the on-site surveys, we construct average whole-building hourly load shapes for each premise type.

Third, using the initial building loads by end use from the first step and the average hourly loads from the second step, we apply the End-use Disaggregation Algorithm (EDA) to obtain adjusted, reconciled end-use load profiles for all building types. The corresponding EUIs are simply the integration of the hourly profiles for the entire year.

Figure 1.


EUI and LS Estimation Method
Load Research Data
On-Site Survey Data
Mail Survey Data
Weather Data
Average Whole-Building Hourly Loads
Average Electricity Bills
NELDIG
Prototype Buildings (DOE-2 Inputs)
DOE-2
Adjusted Average Whole Building Hourly Loads
2
Preliminary Non-HVAC LSs & EUIs
Preliminary HVAC LSs & EUIs
1
EDA
Reconciled End-Use LSs
3
End-Use EUIs & Monthly LSs by Daytype
Raw Data
Processor
Intermediate Files
Output

LOW HEAT LOSS, NON-CFC-BASED APPLIANCE AND BUILDING INSULATION

Brent T. Griffith, Dariush Arasteh, and Stephen Selkowitz
Research Associate, Staff Scientist, and Program Leader
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ABSTRACT

This CIEE exploratory project initiated the development of a new high performance non-CFC-based insulating material, Gas-Filled Panels (GFPs). Applications for GFPs are widespread, with a primary focus on refrigerator/freezer appliances and building walls. While this project has proven the thermal performance potential of GFPs, further development is necessary to optimize designs for cost, manufacturing, and performance.

GFPs evolved from applying the successful approaches used to manufacture highly-insulating windows towards the production of an opaque insulation. The use of low-emissivity surfaces and multiple, low-conductivity, gas-filled cavities results in a highly-insulating panel fabricated using existing materials and technologies. GFPs are not a homogeneous insulating material such as fiberglass or foam but rather an assembly of two specialized components. The first component is a barrier envelope that contains a gas, or gas mixture, at atmospheric pressure. Placed inside the envelope is the second component, a baffle consisting of multiple, low-emissivity, coated, nonpermeable layers. The baffle effectively eliminates radiative and convective heat transfer, leaving primarily conductive heat transfer through the gas and baffle. Figure 1 is a conceptual schematic of a GFP. Panel geometries and physical properties can be tailored for specific applications. GFPs can be constructed with mechanical properties ranging from flexible but self supporting to stiff and supportive.

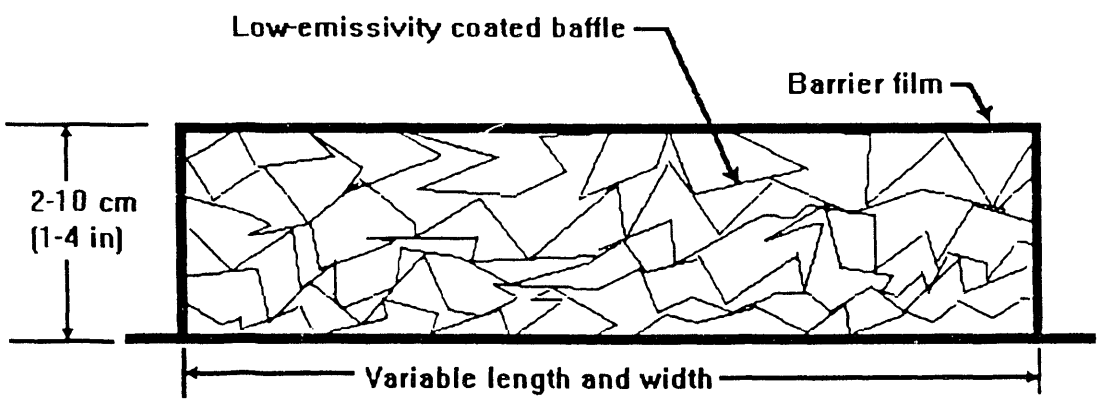

Figure 1. Gas-filled panel schematic cross-section. This figure shows a random orientation of baffle layers; other configurations are possible.

The thermal performance of GFPs has been independently tested (per ASTM C518) at Oak Ridge National Laboratory (ORNL) and predicted thermal performance values were supported. Results are summarized in Table 1. [Note that the predicted R-values given in Table 1 assume a 0°C (32°F) mean sample temperature (representative of building and refrigerator/freezer operating temperatures) while the ORNL-measured R-values are based on a mean temperature of 24°C (75°F). In theory, one would expect performance values at the lower temperature to be roughly 10% better than those at the higher temperature. The remaining small differences between measured and projected R-values for the argon and krypton GFPs are primarily attributed to solid conduction through the large numbers of baffle layers.]

Table 1. Measured R-values from the ORNL R-Matic and Projected R-values in m-K/W (hr-ft^2-F/Btu-in.)

	ORNL Measured	Projected
Air GFP	36.1 (5.2)	38(5.5)
Argon GFP	49.3 (7.1)	55(8)
Krypton GFP	86.7 (12.5)	105(15)

As Table 1 shows, air-filled panels perform as well as styrene foam. Argon-filled panels perform as well as CFC-blown foams or at a level twice that of fiberglass. Krypton-filled panels offer much higher performance levels than any commercial insulation currentlyavailable.

GFPs are an alternative non-CFC high performance insulating material for refrigerator/freezer appliance applications. Such potential materials are in high demand due to the phase-out of CFCs and increasing energy-efficiency standards. In the near-term, appliances could be manufactured with composite insulations consisting of GFPs foamed-in-place with non-CFC foams. This would not require significant changes in manufacturing methods. In the long run, advanced plastics and processing techniques used in conjunction with GFP technology may produce high performance appliance components without the use of any foam. Current research is aimed at developing GFPs for both of these applications.

Energy-efficient building walls can also benefit from the use of GFPs. Low-cost flexible GFPs (i.e., air- or argon-filled) could be used to improve overall wall thermal resistance without increases in wall thickness. For example, 2x4 ft stud walls could be filled with air GFPs to achieve R109 m^2-K/W (R19 hr-ft^2-F/Btu) or with argon GFPs to achieve R136-159 m^2-K/W (R24-28 hr-ft^2-F/Btu). Such designs would eliminate the need to begin using 2x6 ft studs and fiberglass insulation in moderate climates such as California's Central Valley. Direct research on these embodiments has temporarily halted with the completion of this CIEE exploratory project.

GFPs are relatively easy to manufacture and can be produced at low cost. Costs for flexible argon GFP batts 0.076 m (3 in.) thick are estimated at \$5.90-7.50/m^2 (\$0.55-0.70/ft^2). GFPs can be assembled from roll-stock polymer films on equipment from the packaging industry. Very high production rates are possible without the development of new, untried production techniques.

LOCALIZED THERMAL DISTRIBUTION FOR OFFICE BUILDINGS

Subproject of the Efficient Systems for Thermal Distribution Project

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Director, and Research Specialist
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University of California, Berkeley

William Fisk and David Faulkner
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Lawrence Berkeley Laboratory

ABSTRACT

The goal of this project is to quantify and improve the effectiveness and energy efficiency of localized thermal distribution (LTD) systems for office buildings. LTD systems have the potential to improve the energy efficiency of air distribution by distinguishing between the energy and comfort requirements of local workstation environments and those of less critical surrounding spaces. It is possible, however, to design LTD systems in ways that are substantially less energy-efficient than conventional systems. In surveys office workers report that LTD systems significantly improve environmental satisfaction; one might anticipate a measure of increased worker productivity as a result. Because of this, the technology is now spreading rapidly, driven more by the interest in occupant satisfaction than by concern for LTD energy performance. California would benefit if it were able to increase the levels of its worker productivity while saving energy at the same time, rather than by having to pay an energy penalty over present practice.

This project is examining LTD systems in order to quantify their performance in energy terms compared with similar conventional systems. The systems' ability to control temperature and air quality at the workstation is also being quantified, in order to provide the data needed for modeling LTD systems in building energy simulation programs, and to identify key areas where LTD system efficiency might be improved. The project has also reviewed the applicable state and national energy and indoor environment building codes to identify where changes may be required to encourage energy efficiency in the deployment of such systems. It has supported participation in the standards writing process to promote such changes. Finally, the results are intended to serve the utilities in projecting the future energy-use implications of this new development in office space conditioning.

During this first year, work was carried out in four task areas.

Task 1. Laboratory Experiments
This task contained most of the work performed this year. Two LTD systems were tested: the Task Air Module (TAM), a through-floor supply fan and diffuser manufactured by Tate Access Floors; and the Personal Environment Module (PEM), a desk-mounted unit manufactured by Johnson Controls Corp. These units were tested for a range of realistic configurations and operating conditions in the Controlled Environment Chamber at UCB. The tests were performed

collaboratively by researchers at the University of California at Berkeley (UCB) and Lawrence Berkeley Laboratory; UCB studied the thermal performance (distributions of temperature, velocity, and computed comfort) and LBL studied the ventilative efficiency (air flow patterns, age of air, and particulate transport) throughout the space. In short, the systems were found to be able to modify the workstation environments over a wide range, should the occupant so desire.

Task 2. Field Study Experimental Plan
Developing an experimental plan for field studies included selecting two buildings for on-site testing, arranging for cofunding from PG&E and SCE, and making arrangements to monitor the buildings for their environmental conditions, occupant comfort responses, and energy conditions. A portable instrumentation system has been devised and tested on a parallel project. The field studies will be conducted in the second year.

Task 3. LTD System Energy Modeling Issues
Examining system energy modeling issues included evaluating LTD systems under various modes of operation using a building energy simulation program. Here the interactions between the LTD units and the central system were assessed. One key conclusion is that the central system should be designed with LTD system operation in mind. Energy consumption was minimized for systems with the following characteristics: increased supply and return temperatures, minimum possible local fan load, use of an occupancy sensor at each workstation, reduced central fan static pressure, and an economizer cycle. Systems operating in mild climates also demonstrated reduced energy consumption.

Task 4 . Building Standards and Codes
Applicable California building codes and ASHRAE standards (energy, thermal environment, and ventilation) were reviewed for compatibility with LTD technology. In this year, changes were recommended and adopted in the new version of ASHRAE Standard 55-81, currently nearing the end of its revision process, to allow for better definition of the thermal comfort zone under the different types of air movement provided by LTDs. When applied to LTDs, the revision will reduce the energy required to condition workspaces.

ALTERNATIVES TO COMPRESSOR COOLING IN CALIFORNIA CLIMATES

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ABSTRACT

California's electricity use for cooling residential buildings in 1987 was about 4200 gigawatt hours (GWh), contributing about 5.8 GW to peak utility demands. These figures indicate that residential air conditioning has a very poor load factor (about 0.08). As a very rough estimate, residential air conditioning requires an investment of about $6 billion in generation, transmission, and distribution capacity while generating only about $400 million in sales. It is an unprofitable load; if an allowance of $160 million is made for operating costs, the return is about 4%.

As part of its planning process, CIEE initiated a study of more efficient methods of meeting the demand for cooling. Since most energy used in air conditioning is for operating compressors, the study focussed on alternatives that do not require the use of compressors with an emphasis on eliminating compressors in California's transition climates. These climates—moderately warm areas located between the cool coastal regions and the hot central regions—were emphasized because the load factor for residential air conditioning is probably lower in these climates than the statewide average for air conditioning and because non-compressor cooling is technically easier in these climates.

The study reviewed a number of alternatives to compressor cooling including: evaporative cooling, natural and induced ventilation, reflective coatings, shading with vegetation and improved glazing, thermal storage, radiative cooling, and absorption cooling. It was concluded that many of these alternatives, used either singly or in combination, are technically- and economically-feasible for meeting the demand for cooling in transition climates. However, it was also noted that compressor-driven cooling enjoys a number of advantages such as familiarity, low first cost, ease of control, and reliability. A number of areas were identified where additional research and development could strengthen the competitive position of the alternatives to compressors. These included simulation and design methods, field performance measurements, control strategies, use of adjustable speed drives for ventilation fans, improved heat exchangers for indirect evaporative coolers, use of phase-change materials for thermal storage, environmental impacts, and consumer behavior.

SENSITIVITY ANALYSIS STUDIES OF THE RAPRENOX PROCESS

Nancy J. Brown
Senior Scientist and Program Leader
Jeronimo N. Garay
Chemical Engineering Undergraduate Student
Environmental Research Program
Lawrence Berkeley Laboratory

ABSTRACT

The objective of this research is to use modeling and sensitivity analyses to investigate the suitability of the RAPRENOx process for potential application to natural gas-fired engines in the state of California. RAPRENOx[1] is a selective reduction process for NOx which is based upon the after-treatment of combustion exhausts. A parametric sensitivity analysis is being used to suggest strategies for optimizing the RAPRENOx process.

We have successfully duplicated the modeling calculations of RAPRENOX reported by Miller and Bowman[2,3] which give reasonable agreement with the experimental studies of Siebers and Caton[4] and Caton and Siebers.[5] We are currently unable to model the later experiments of Caton and Siebers[6] who examined the effects of hydrogen addition on the removal of nitric oxide by cyanuric acid. We suspect that lack of knowledge of branching ratios of critical reactions is responsible for this. We are currently modifying the mechanism to obtain better agreement. Mechanism integrity becomes especially critical in a sensitivity analysis study because sensitivities are calculated with respect to nominal values of the rate coefficients. The Caton/Siebers experiments were conducted very close to the lean flammability limit; the sensitivity analysis indicates that reactions responsible for the generation of radicals are most crucial to NO reduction. Since natural gas burning is so very clean, sufficient radical generation to support RAPRENOX chemistry will be a problem unless additional fuel is added with the cyanuric acid. We are considering the addition of H_2 as a prototypical additive.

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RESIDENTIAL END-USE ENERGY DATA AND LOAD PROFILES

Subproject of the Integrated Estimation of Load Shapes and End-Use Energy Intensities in Commercial and Residential Buildings Project

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ABSTRACT

RELEVANCE TO CALIFORNIA END-USE ENERGY EFFICIENCY

The demand forecasting models used by California utilities and the CEC rely on an explicit representation of the end-use structure of energy demand. To forecast peak electricity demand, additional disaggregation of end-use electricity consumption over the hours of the year is required. These disaggregations are appropriate because policy interventions to improve energy efficiency can only be captured by models that incorporate end-use detail.

However, the lack of high quality data to support these modeling activities is widely acknowledged as the single most important factor limiting improvements to this modeling approach. This limitation is of particular concern because obtaining these data is often very expensive. California is fortunate because its utilities have begun collecting end-use metered data. Nevertheless, analyses of these data for forecasting applications has been limited.

SUBPROJECT OBJECTIVE

This subproject's objective is to analyze end-use metered residential electricity consumption data collected by PG&E in order to develop a set of reference end-use electricity hourly load shapes for common use by CEC and PG&E forecasters.

APPROACH

PG&E's load research group has been collecting end-use metered data from a sample of over 700 residential customers since 1985. LBL will obtain these data, verify their appropriateness for use in developing load shapes for electricity demand forecasting, and then develop load shapes suitable for direct use by CEC and PG&E electricity demand forecasting models. For space-conditioning end uses (including central air conditioning, room air conditioning, and heat pumps), the CEC forecasting model relies on a unique representation that expresses energy use as a function of time of day and climate severity. LBL will also develop and test an analytic formulation of this representation. For non-space-conditioning end uses (including refrigeration, freezing, cooking, clothes washing, and clothes drying) LBL will develop monthly load shapes for two types of days per week. Throughout these analyses, LBL will work closely with PG&E and CEC forecasters, and the PG&E load research group.

CURRENT STATUS AND FINDINGS

The first set of hourly space-conditioning electricity and weather data collected in 1989 was received from PG&E in March 1991. An additional data set of weather data was received from the CEC shortly afterwards. LBL has completed its initial review of these data to verify data completeness, check internal consistency and out-of-range values, and to visually inspect them for reasonableness. These findings have been summarized in a memo to PG&E and the CEC. We are currently awaiting their comments on the memo prior to proceeding with our analyses of the data.

We have also started to develop a FORTRAN program to represent observed space-conditioning electricity consumption in the time-temperature format used by the CEC electricity forecasting model. We are examining alternative functional forms to fit the data and are developing criteria to evaluate the goodness of fit as well as the accuracy of the fitted data for forecasting space-conditioning electricity consumption.

FUTURE WORK

In addition to developing a reference set of electricity load shapes for current CEC and PG&E forecasting models, the current project will also examine the reliability of the time-temperature representation used by the CEC model to forecast space-conditioning electricity consumption. In the future, we plan to explore alternative methods for representing these data and to compare these methods to the original CEC method as well as to those used in other forecasting models. In the long-run, we would also like to investigate methods for relating observed hourly end-use electricity consumption to the physical and demographic characteristics of the metered households.

UTILITY IMPACTS OF NATURAL GAS AND ELECTRIC VEHICLES

Subproject of the Assessment of Natural Gas and Electric Vehicles Project

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ABSTRACT

This paper reports the results of an analysis of the impacts of extensive use of electric vehicles (EVs) in southern California. The analysis focuses on the Southern California Edison Company (SCE) which provides electric service for approximately 60% of southern California. The analysis is conducted in a "what if" fashion in which the numbers and attributes of EVs are treated as scenarios rather than forecasts. The paper summarizes the impacts on SCE's loads, plant operations, production costs, level of service, and air pollution from scenarios with one and two million EVs in operation by the year 2010.

Each scenario begins by specifying the fraction of annual sales captured by EVs in five classes: large vans, small vans, large cars, small cars, and light trucks. The market penetration assumptions employed in the one to two million EV scenarios go well beyond the recent regulations for "zero emission vehicles" issued by the California Air Resources Board.

A "vintaging" model is then used to keep track of the magnitude and age structure of the EVs in operation in southern California. The age structure information is important when considering the performance characteristics of both the EVs and the conventional vehicles that are displaced. The one to two million EV scenarios typically end up with the EV population dominated by young vehicles whereas the population of conventional vehicles will be dominated by vehicles nearing the end of their useful lives.

The electric loads from the mix of EVs in operation are then calculated by a "stacker program" which estimates the hour-by-hour loads from nighttime charging as well as daytime opportunity charging. Nighttime charging profiles are specified for each of the five classes of EVs based on the miles per day of travel, the miles per kilowatt hour (kWhr) efficiency of the vehicle and the nighttime profile of the charger. The EV loads from the five classes are estimated, combined, and then stacked on top of SCE's regular load to allow the analyst to visualize the daily load shapes that would result under different charging strategies. Through interactive experiments with the "stacker" one can learn whether it is important for the utility to control the timing of nighttime charging.

Each scenario concludes with an analysis of changes in utility operations due to the extra loads from EVs. This analysis was conducted with SCE's version of ELFIN, a computer simulation model originally developed by the Environmental Defense Fund for analysis of electric utility system operations and resource planning. The impact of EVs is estimated by comparing ELFIN projections from each EV scenario with the projections from a benchmark resource plan similar to the CEC's 1990 Electricity Report (ER'90). Of particular interest is the ELFIN projection of the

particular resources which supply most of the energy needed to run the one to two million EVs in the SCE service territory.

The scenarios analyzed to date show that SCE can accommodate a large number of EVs in their service territory without having to add new resources to the existing resource plan. The analysis also shows that the charging strategy can play an important role in accommodating the additional EV load. We find that the bulk of the extra energy to supply the EVs will come from gas-fired generating units. These units are a mix of existing gas boilers in southern California, several gas units scheduled for repowering, and new, combined-cycle, gas-fired units.

COLD-AIR DISTRIBUTION SYSTEMS FOR OFFICE BUILDINGS

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ABSTRACT

Directly supplying cold air to occupied zones of commercial buildings is a cooling option that may partially (or in some cases, fully) offset the higher first cost and higher energy use associated with the installation of Thermal Energy Storage (TES) systems in place of conventional air conditioning. However, there are concerns regarding occupant comfort and the ventilation effectiveness achieved when directly supplying cold air to office spaces. This project is intended to address these issues through experiments and coordinated numerical modeling efforts which will tie in with building energy simulations in the second and third years.

Research efforts undertaken during the first year of this three-year project included both experimental and numerical modeling research.

The experimental effort began with a critical review of diffusers claimed suitable for cold-air distribution, and the selection of one diffuser for performance testing in the Controlled-Environment Chamber (C-EC). Subsequently, the performance of the selected diffuser was measured in the C-EC under two different supply rates of cold air to the room. Each test was replicated three times. Temperatures and velocities were recorded at more than 80 points in the occupied region of the space. Data were also recorded for later input to the numerical model.

A critical review of existing numerical models led to the selection of a suitable model for simulation of indoor air motion in the presence of cold air supply. This model was modified and tested in two dimensions under various configurations to understand its convergence and stability characteristics. Satisfactory agreement with data from an experimentally-validated model was obtained in the laminar and transition regimes. Further work has led to model extensions for simulation of indoor air motion in office spaces with internal loads cooled with cold air supply. The simulation method has also been extended to accept inputs from experimental data regarding the near-field flow from diffusers to predict the room (i.e., the "far-field") air flow.

Work planned in the second year includes analysis of data from the C-EC experiments, extension of the model to three dimensions, and comparison with room air motion data collected experimentally. We would also like to initiate processing of air temperature and motion information predicted numerically to obtain predictions of occupant comfort.

COMPARATIVE EVALUATION OF THE IMPACTS OF DOMESTIC GAS AND ELECTRIC HEAT PUMP HEATING ON AIR POLLUTION IN CALIFORNIA

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ABSTRACT

Residential space and water heating account for approximately 15% of the United States' (U.S.) and 13% of California's energy consumption. Three of the prevalent modes of heating are natural gas, electric resistance, and heat pump heating.

Concern for the costa, eventual depletion of nonrenewable sources of energy, and the air pollutant emissions associated with fossil fuel combustion (such as NOx and CO_2) introduce new dimensions in the choice of end-use equipment for residential heating.

Electric heat pumps have demonstrated their potential to offset the generation and transmission losses of electricity. Advancements in electric heat pump technology are continually increasing this potential. Many electric heat pumps have energy efficiencies which are comparable, or even superior, to the most advanced natural gas heating equipment. Energy source efficiency and pollutant emission of heat pumps depends on three important factors: 1) generation heat rate and pollutant emission, 2) transmission and distribution efficiency, and 3) the heat pump coefficient of performance (COP).

It has been the specific objective of this project to perform a comparative evaluation of the energy source efficiency and emissions (including CO_2) of residential gas and heat pump heating; and to evaluate the effect on air pollution in California of the replacement of gas heaters with heat pumps. In order to perform such a comparison, energy *source efficiency* and *emission factor* have been defined as:

Efficiency (EF) = Heating Energy Delivered/Fuel Energy Input

Source Emission Factor (EM) = Pollutant Produced/Heating Energy Delivered

Based on these definitions, the values for EF and EM have been analyzed for the gas path and the electric path from the energy source to the end-use energy which in this case is heating energy. The paths are shown in Figure 1.

Figure 2 shows the energy efficiency of heat pumps with respect to heat pump COP and power plant heat rate variation. It shows that the combination of the current technology heat pumps (with COP of about three) and electric power generation achieves an energy efficiency value comparable to that of the highest efficiency gas heaters. This combined energy efficiency value is about 25% higher than the efficiency of an average gas heater. Figure 3 shows the effect of heat pump COP and the electricity generation heat rate and mix on the NOx emission factor of heat pumps. The South Coast Air Quality Management District (SCAQMD) standard for NOx emission from domestic gas heaters (40 nanograms per kilojoule of heat output) is the basis for this comparison. The figure shows that considering the U.S. mix, energy source NOx emission from heat pumps can be more than two times

higher than from natural gas heaters. For the California mix, effective NOx emissions from heat pumps will be slightly higher than from natural gas heaters. Other major conclusions from this work are listed below:

- The combination of advanced electric heat pumps and electric power plants can be approximately twice as efficient as natural gas heaters.

- Heat pumps have less than 50% effective CO emission compared to natural gas heaters.

- With the current California electricity generation mix, the effective CO_2 emission from heat pumps is less than 70% of the CO_2 emission from natural gas heaters.

- With the present state of technology, replacing natural gas heaters with heat pumps will slightly increase overall NOx emission, and considerably reduce CO and CO_2 emissions in California.

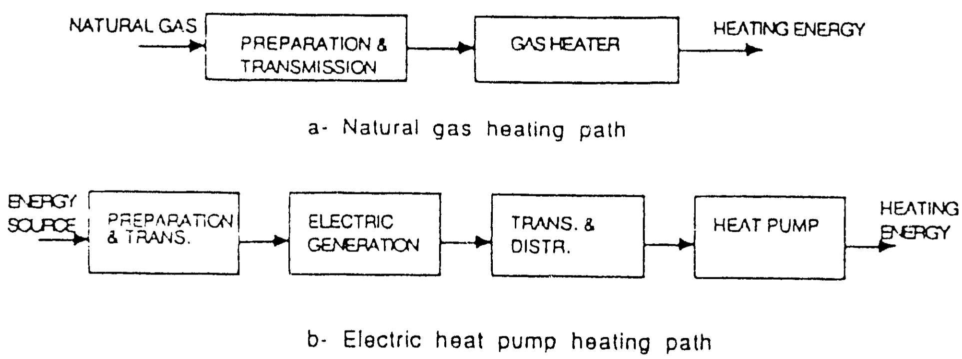

Figure 1. Two distinct paths for domestic heating appliances.

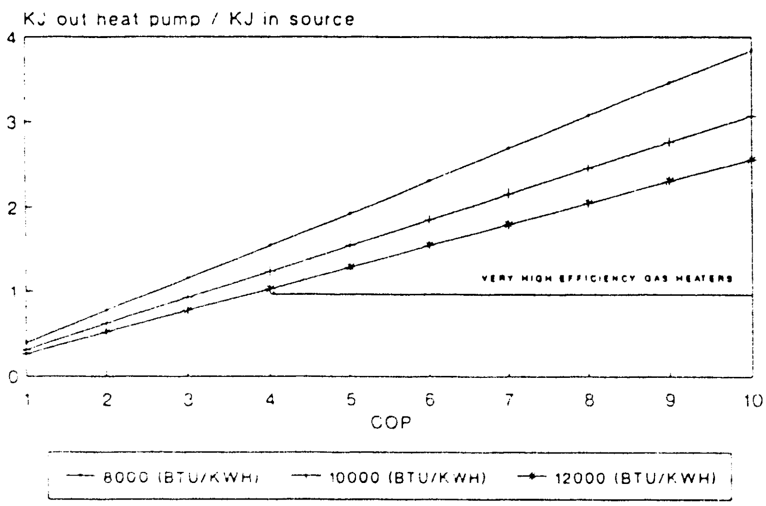

Figure 2. Energy efficiency of heat pumps in terms of coefficient of performance (COP) and electricity generation heat rate.

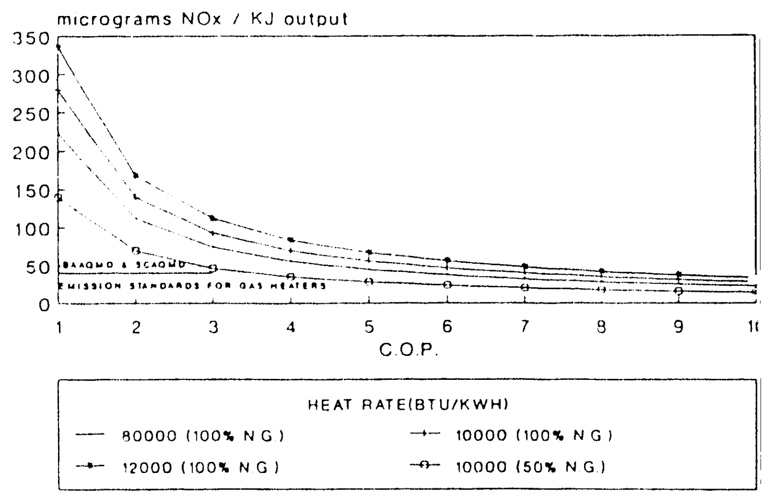

Figure 3. Source emission factor of NO_x for heat pumps in terms of COP, electricity generation heat rate, and generation mix.

SUPPLY AND DEMAND OF ENERGY-EFFICIENT LIGHTING PRODUCTS

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ABSTRACT

BACKGROUND

The market demand for energy-efficient lighting products has grown so rapidly in recent years that some types of lighting products are now, or may soon be, in short supply. Some of the strongest demand stimulation comes from the lighting incentive programs sponsored by electric utilities, and the efficient-lighting programs and standards implemented by federal, state, and local government agencies. One of the major factors complicating the adequate supply of efficient-lighting products is the uncertainty that product suppliers have concerning the ultimate market effects of these programs. On the other side, the utility and government agencies are concerned with when, and if, certain manufacturing industries will be in a position to meet this demand.

The Electric Power Research Institute (EPRI), the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and CIEE are jointly sponsoring a project intended to address this issue. They have contracted with the Lighting Research Institute (LRI) and Plexus Research Inc. to collect and analyze data from a selected set of utility and agency efficient-lighting programs, and from a selected set of lighting-product manufacturers. The preliminary survey (Phase I) has been completed. Later this year there are plans to conduct expanded surveys (Phase II) that will capture data from a broader base of programs and suppliers.

DEMAND STIMULATORS FOR ENERGY-EFFICIENT LIGHTING PRODUCTS

Three major external stimulators of energy-efficient lighting product demand were considered in this Phase I effort: the lighting promotion programs of electric utilities, the "Green Lights" program under way at the U.S. EPA, and the Federal Relighting Initiative being pursued by the U.S. DOE. It should be noted that the three stimulators addressed in this Phase I study do not represent pure "additive" product demand. Both the DOE and EPA programs will utilize utility rebates. Additional marketplace stimulators not surveyed in Phase I include federal, state, and local building codes and standards presently in force or under consideration.

Electric Utility Programs

Twenty-seven utilities conducting large lighting-promotion programs were surveyed. The 27 sample utilities together account for nearly one-fourth of the electricity sales in the U.S. and for about one-fourth of the U.S. utilities with lighting programs. These utilities were asked to provide detailed, aggregate historical data on the numbers and types of efficient-lighting products installed, the numbers and types of customers that installed products (by device type), and the total incentive payments made (by device and customer type) under each efficient-lighting program. Utilities were also asked to provide summary data for the year 1990 and forecasts for the years 1991 through 1994 at the same level of detail as the historical data. Although the data sets originally received from the utilities were fairly robust from a

historical perspective, they were seriously limited in usefulness for directly forecasting lighting-product requirements. Few utilities were able to provide near-term (1991-1992) forecasts of specific lighting product needs, and even fewer were able to forecast product needs for the midterm (1993-1994). A series of assumptions combined with a mix of the "official" and "unofficial" data provides the basis for the forecast and projections. Projections extrapolated for all U.S. utilities indicated 1991 incentives in the range of $232 million to $309 million with the national median at $270 million. The 1994 estimates had the median projections at $546. Also included are forecasts of product mix by dollars and units as well as utility comments and listed needs.

EPA "Green Lights" Program

The EPA's Green Lights Program promotes the adoption of energy-efficient lighting by large commercial and industrial corporations. Each of the "Green Lights Partners" signs a Memorandum of Understanding with the EPA which commits the "Partner" to survey all of its U.S. facilities, to consider a full set of lighting options that can reduce energy use, and to install all cost-effective options that maximize energy savings without compromising lighting quality. Based upon the goals of achieving 300 partners and allies by year-end 1991, and 1500 by year-end 1992, various scenarios (with assumptions and probabilities) were estimated at meeting 25%, 50%, and 100% of the goals. These estimates translate to total annual lighting retrofit expenditures of between $1.1 billion and $9.2 billion during the 1993 through 1996 period.

Federal Relighting Initiative

The objective of the Federal Relighting Initiative is to relight all Federal facilities with life-cycle cost-effective lighting technologies. It is estimated that about 25% of the Federal energy use is for facility lighting. Available lighting technologies have been shown to have significant savings with short-term paybacks. Using these technologies to reduce Federal lighting energy requirements by only 25% would save as much as $600 million per year and reduce Federal energy consumption by more than 6%. The Federal government owns or leases buildings and facilities totalling more than 3.3 billion square feet of floor space in the U.S. The government owns approximately 93% of this square footage and leases the remaining 7%. The largest single use of Federally-owned and -leased buildings is housing, which accounts for over 24% of the total use. Storage, office space, and service-related space are the next largest uses, together totaling 56% of the building space.

FORECAST OF MARKETPLACE SUPPLY OF ENERGY-EFFICIENT LIGHTING PRODUCTS

Phase I studies were conducted in four high priority areas: fluorescent lamps (full-size and compact), ballasts for fluorescent lamps, installation of energy-efficient lighting products and components, and an analysis of the retrofit and renovation market potential for energy-saving products.

In the **Fluorescent Lamp** area seven lamp companies representing more than 95% of the supply to the U.S. market were included in the confidential survey. Compact fluorescent lamp shipments to the U.S. trade were estimated at 13.6 million in 1990, growing to 25.2 million in 1991 and 71.8 million in 1995. Further details in the compact fluorescent category include construction size, packaging with integral or separable ballasts, electronic versus magnetic ballasts, and lamp-only shipments. Full-size energy-efficient fluorescent lamp categories included eight-foot slimline and high output, circular, 17 to 40 watt rapid-start straight T-8 and T-12, other rapid-start, and U-bent and single-ended lamps. The most-repeated items in the "comments" and "needs" categories included "stronger two-way partnering between utilities and the individual lamp companies," "recognition and utilization of trade channel strengths and capabilities," and "critical need for valid utility forecasts, summed nationally, by dollars and by unit volume and mix of lamp products."

In the **Fluorescent Lamp Ballast** segment ten ballast companies representing more than 95% of the U.S. market supply participated in this Phase I survey covering only high-power-factor ballasts. Details for both electronic and magnetic ballasts included: slimline, preheat, and four rapid-start categories (800 milliamps and up, 28 to 40 watts with and without integral dimming capability, and other). Total estimated demand for all grew from 59.4 million units in 1991 to 71 million in 1995. Electronic model demand was forecasted to grow from approximately 11% of the total in 1991 to 40% in 1995. Forecast data is also provided on unit mix demand and the ability of the industry to meet that demand. The ballast company comments followed very closely those of the lamp companies.

From a **Lighting Maintenance and Management Company** viewpoint, 14 of the 135 member companies of the National Association of Lighting Management Companies (NALMCO) trade association were included in the Phase I survey. From the extensive six-page survey, key trends, concerns, and needs are outlined; two are listed here:

1. In the controls area only passive occupancy sensors were used because "user/installer friendly," "cost effective," and "reliable" daylighting and dimming systems were not readily available.

2. Utilities did not take advantage of existing trade channels and, in fact, actually went around them.

Renovation and Retrofit Market Potential

This market research and analysis utilized publicly-available information concerning the lighting industry and the building "stock" in the U.S. Key references are noted and assumptions are documented. In the fluorescent ballast area, 350 million 40 watt ballasts and 60 million slimline ballasts are the estimates for retrofit potential. In the commercial building category (defined as nonresidential, nonagricultural, and nonindustrial) the estimates include 4.5 million buildings, 64 billion square feet, and 20% government-owned buildings (federal, state, and local). Of the non-government-owned buildings, approximately 63% are owner-occupied. The top five usage applications of the 64 billion square feet are mercantile (22%), office (16%), warehouse (15%), education (13%), and meeting/assembly (13%).

SUMMARY

A summary and overview section is also provided as a basis to open the discussion portion of presentation.

FLOW AND ENERGY TRANSFER IN ENCLOSURES

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ABSTRACT

Work on the determination of the energy transfer and flow in enclosures has been carried out. Very few results are available that are applicable to complex configurations and a special emphasis has been placed on attic spaces as well as on enclosures having sector and rectangular shapes.

To develop the capability to obtain results for different geometries over a range of conditions it is necessary that calculations be carried out for nonorthogonal systems. Specifically, a code must be able to solve the governing equations of mass, momentum, and energy, subject to the required geometrical shapes and conditions. This effort is accomplished by using finite differences to discretize the derivatives on a numerically-generated body-fitted nonorthogonal curvilinear coordinate grid. A nonstaggered grid system is employed and the QUICK scheme is used to evaluate the convective fluxes at the control surfaces. The resulting discretized linear equations are solved by using the Moderately Strongly Implicit (MSI) method.

Validations of the resulting code have been made. Excellent agreement has been obtained with benchmark results that have been published for the energy transfer for buoyantly-driven flow of air in a rectangular enclosure. Benchmark results have not, as yet, been published for attic spaces. Calculations are presently being carried out in an attic-shaped configuration and comparisons are being made with experiments which are being carried out by M. Nansteel in water. By using water it is possible to conduct laboratory scale tests and obtain the flow and energy transfer at the desired high heating and cooling rates. Preliminary results show the correct trends for the velocity and temperature profiles. Once the code has been validated for this geometry at the high heat fluxes in water, calculations will then be carried out for high fluxes in air. It is also planned to carry out studies for several practical systems including partitions and different thermal conditions at high heat fluxes.

THE FIELD PERFORMANCE OF THERMAL ENERGY STORAGE AND CONVENTIONAL CHILLERS

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ABSTRACT

HOW DO TES AND CONVENTIONAL CHILLERS COMPARE IN THE FIELD?

One of the objectives of the CIEE-sponsored Thermal Energy Storage (TES) project was to develop methods to accurately quantify the impacts and benefits of TES to utilities and customers. Preceding this study there were reports of very high field-measured kilowatt per ton values for TES systems. These were compared unfavorably to the much lower manufacturers' kilowatt per ton quotes for conventional chillers. It was suspected that the manufacturers' quotes for conventional chillers were somehow optimistic. More realistic values were therefore sought based on field data for conventional chillers, more comprehensive simulation of conventional chillers, and more study of the available TES field data.

CONVENTIONAL CHILLER DATA ANALYSIS

Field data from 31 different sites for a total of 49 conventional chillers were acquired by the San Diego State University (SDSU) Energy Engineering Institute, and the data from 23 sites were determined to be consistent and of good quality. These were analyzed and then reduced to charts showing the field performance (kilowatt per ton versus percent of load) and load frequency (number of occurrences versus percent of load).

Most of the data collected are for water-cooled centrifugal chillers since centrifugals dominate the market. Manufacturers' performance curves for some of these chillers were gathered. The field performance of these centrifugal chillers was, in general, found to closely follow their manufacturers' performance curves. This field data also indicated, however, that chillers frequently operate at loads of 20%, 30%, or 40%. Centrifugal chillers perform near their optimum efficiency when the load is 70% and part-loads below 40% should be avoided because efficiency drops steeply. In conclusion, chillers do often use up to twice the electricity that is required. This is not due to errors in the manufacturers' curves but rather to gross oversizing of chillers. This represents a major source of energy inefficiency and corrective research should be initiated.

CONVENTIONAL CHILLER PERFORMANCE SIMULATION

This task was to develop models to determine kilowatt per ton values for different types of compressors and condensers at various loads and water temperatures using the DOE-2 program. Conventional chillers with centrifugal, reciprocating, and screw compressors have been modeled. This also includes air-cooled and water-cooled condensers. The screw compressors

were simulated by using curve fits and replacing appropriate default values in DOE-2. The existing version of DOE-2 does not include evaporative condenser and screw compressor models.

Simulations were performed for a generic office building operating with both weekday and weekend/holiday schedules in San Diego using the meteorological year. The building has a volume of 900,000 ft^3 and 258 occupants. The ratio of the condenser inlet temperature to the normalized cooling load was the same for all chillers. The outlet temperature, however, depended on ambient conditions; it was therefore different for the same load in different months. All chillers are simulated with economizers. Additional documentation on the variations in the load profile, peak demand, and number of occurrences was developed.

The simulations generally confirmed what had been discovered with the conventional chiller field data; the load percentages for conventional chillers are surprisingly low, often 20%-40%. This is a major source of inefficiency which new research should correct.

In addition, it was planned to add new realistic performance curves to DOE-2 if discrepancies were found between the conventional chiller field data (discussed above) and manufacturers' curves. This was not pursued since large discrepancies were not found. In conclusion, it is accurate to use the manufacturers' performance curve fits built into DOE-2 in all the simulations.

TES FIELD DATA ANALYSIS

TES field data from six monitored sites around the U.S. were analyzed to evaluate the performance of installed TES systems. These data were obtained from EPRI and Science Applications International Corporation (SAIC). The actual kilowatt per ton value of TES systems varies between 1.5 and 2.0 kilowatts per ton, and the storage tank efficiency is typically 80%. Hourly and monthly graphs of electric consumption, cooling load, and chiller operation have been developed. Because of the volume of data, software had to be written to manipulate the files. Because of inconsistencies in the data format this software had to be customized for each building's data file. Generally, TES systems have been treated like special chillers with extra energy losses from the storage tanks. Several important TES system performance indicators have been identified by comparing TES with conventional chillers. In addition, TES systems and conventional chillers were compared under the same operating conditions using a combination of data and simulation. The kilowatt per ton value for TES is higher than for conventional chillers, but this analysis confirmed that TES shifted electric demand from on- to off-peak hours in accord with the design strategy.

IMPACT OF SHADE TREES AND WHITE SURFACES ON BUILDING PEAK POWER AND COOLING ENERGY SAVINGS

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ABSTRACT

SUMMARY

To combat the adverse effects of the summer "urban heat island," the Sacramento Municipal Utility District (SMUD) is implementing a heat island mitigation program that includes planting half a million shade trees over the next ten years to shade homes, schools, and places of business. Such neighborhood-scale conservation strategies save cooling energy, allow for compressor down-sizing, lower air conditioning peak demand, and reduce the emission of CO_2 and other pollutants from electric power plants. SMUD predicts that a concerted heat island mitigation effort in Sacramento can yield savings of 20% to 40% in the air-conditioning costs of residential and small commercial buildings by the years 2000 and 2010, respectively.

The current SMUD plan, which runs through December 1991, emphasizes tree planting and collecting basic information about the benefits of using light-colored surfaces. Based on this information, SMUD will decide on possibly expanding their plan to include implementing a light-colored surfacing program similar to the ongoing tree planting program. In this project, we will monitor the impact of shade trees and light-colored roofs on the air-conditioning electricity use in a few buildings, analyze the measured data, and document the savings. In addition, we will gather samples of, and literature about, light-colored surfacing materials and prepare a report on how to implement a program using this strategy. All aspects of the monitoring and analysis project are being carried out in close collaboration with SMUD's engineering staff.

BACKGROUND

Man-made changes to the city landscape have inadvertently created "heat islands" that are from 5° to 9°F hotter than the countryside. During the summer, this "urban heat island" effect increases air conditioning loads and adds to discomfort. Two important factors contributing to the urban heat island are the reduced albedo, or ability to reflect solar radiation, and the loss of vegetation in cities. Although there is increased absorption, reflection, and scattering in the urban atmosphere, the urban surface albedo, typically 0.15 compared to 0.25 in rural areas, results in a net 10% increase in solar heat gain. This increased heat gain is compounded by the lower amount of vegetation in urban areas, which causes a higher portion of this gain to be channeled into sensible heat, i.e., increased air temperatures.

The LBL research team has been studying how to reduce the "summer heat island" effect in U.S. cities by increasing urban vegetation and albedo. Each of these strategies has a *direct* and an *indirect* effect. *Direct effects* are those that accrue only to the immediate area where the strategy is implemented, a single building, for example, or a shaded plot. These benefits are independent of the city conditions as a whole, and can be viewed as ways to counteract the heat island by keeping oneself cool. *Indirect effects* accrue to larger areas, for example, a neighborhood or even a whole city, through the widespread implementation of the same heat island mitigation strategies. These benefits require a concerted community effort and are a way to reduce or eliminate the heat island effect.

Preliminary results from computer simulations show that, in Sacramento, shading homes with trees can save as much as 34% of residential peak cooling demand on a hot summer day. Even more promising results were obtained by simulating a change in the overall albedo of the city, from an existing 0.15-0.20 to a lighter-colored 0.40 corresponding to whitewashed walls and roofs, and light-colored paving. Under such conditions, the peak cooling demand will drop by 40-50% in Sacramento.

Computer simulations provide a way to estimate the theoretical benefits of heat island mitigation strategies in terms of their cooling energy savings. However, the complexity of the urban landscape, the large variations in how buildings are operated, and numerous practical impediments and concerns make it dangerous to proceed to community-scale heat island mitigation efforts based solely on computer results. In order to understand the realistic savings potential of each mitigation measure, it is necessary to carry out field experiments to document actual savings as well as to identify any unforeseen problems.

OBJECTIVES

The objectives of this multiyear project are:

- To measure the albedo of various building and paving materials, and to recommend how they can be promoted in an incentive program.

- To document the energy savings from shade trees and albedo changes in selected residential and public buildings in Sacramento by instrumenting and monitoring their air-conditioning energy use.

- To compare computer simulation results to the monitored data and to refine and validate existing computer models.

- To analyze the energy saving benefits of trees and light-colored surfaces and provide technical assistance to SMUD for their ongoing community program.

POTENTIAL BENEFITS

The project team has used the DOE-2 building energy simulation program to estimate the savings in peak and total electricity use in a typical Sacramento single-family house from heat island mitigation. The preliminary results suggest that nearly half of the residential peak cooling demand in Sacramento can be eliminated by an extensive greening and whitening program. If an extensive implementation program is able to reach 250,000 unshaded Sacramento houses, the savings in peak residential cooling energy use will be about 600 megawatts (MW). These energy savings can be delivered at comparatively low cost. If lightened during routine resurfacing, light-colored surfaces have no incremental costs. Trees are estimated to cost about $10 each. If the costs for purchasing, planting, and watering are added, the present-valued cost per saved peak kilowatt (kW) of these measures would still be under $150 per kW in Sacramento, ignoring the many other benefits of trees, including aesthetics and outdoor comfort.

The algorithms, analytical methods, and input data developed under this project are directly transferable to other California locations and will be made available to SMUD and CIEE.

METHOD

This project is a collaborative effort with SMUD to assess, monitor, and document the energy saving benefits of shade trees and light-colored surfaces in Sacramento. The LBL project team provides technical guidance to the monitoring effort and will be responsible for the data analysis and computer simulations. The SMUD engineering staff will be responsible for installing the monitoring equipment and for gathering data.

As mentioned earlier, heat island mitigation strategies have both direct and indirect effects in reducing building cooling energy use. As a pilot project covering only a few buildings, this project can focus only on measuring the *direct effects* of trees and light-colored surfaces on the selected buildings. These will be studied by temporarily modifying the existing conditions through adding trees or painting the existing roofs with high-albedo materials.

As of June 1991, the project has selected seven single-family residences and two public schools as candidate monitoring sites. The project team and the SMUD engineering staff have ordered the monitoring equipment and are now finalizing the monitoring protocols and the agreements with the occupants or staff of the prospective sites.

AN ASSESSMENT OF RESIDENTIA' EVAPORATIVE COOLING TECHNOLOGIES IN CALIFORNIA

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ABSTRACT

The use of evaporative coolers (EC) is an energy conserving alternative to air conditioning that is particularly suited to the semi-arid climates of California. Since they require power only to drive fans and pumps, evaporative coolers consume far less electricity than do air-conditioners. Evaporative coolers also reduce indoor air quality problems since they use 100% outside air at high ventilation rates. In addition, evaporative coolers are environmentally benign since they do not use chlorofluorocarbons known to damage the ozone layer.

The objective of this exploratory project was to investigate the applicability of evaporative coolers in residential and small commercial buildings in California. The project team included several visiting scholars—Professors Hofu Wu of the California State Polytechnic University at Pomona, and Peilin Chen and Huimin Qin of Tongji University in Shanghai—in addition to LBL staff and a consultant. This project was an extension of previous work by the team in developing analytical models of evaporative coolers and in monitoring EC performance in typical houses.

The project included the following research activities: 1) simulating the energy performance of different ECs for prototypical houses in the 16 California climate zones, 2) analyzing the interior comfort conditions maintained by different EC configurations, 3) calculating the water consumption of ECs and analyzing whether this represents a potential problem for California, 4) conducting a survey of engineers, contractors, and manufacturers to determine the institutional and nonenergy-related engineering barriers that impede the proliferation of EC technology, 5) investigating new configurations to extend the use of ECs in humid climates or larger buildings, and 6) making a preliminary assessment of the life-cycle costs and cost-effectiveness of ECs in California residential buildings.

The engineering analysis was performed by installing numerical models developed by Professors Chen and Qin for different evaporative cooler designs into the DOE-2.1D energy simulation program, and then by using this developmental DOE-2 program to simulate whole-building performance. This program calculates the energy and water consumption, as well as the indoor temperatures and humidity levels produced by various direct and indirect/direct EC models. The program can also simulate a backup air-conditioner that is turned on when the EC is unable to adequately cool the house.

Computer simulations have been completed with this model for two types of houses (pre-1973 and current Title-24 construction) in all 16 California climate zones. The results showed that direct ECs used on average only 16% of the electricity of a standard air-conditioner, but could not maintain indoor comfort during hot summer months in either the inland climate zones (Santa Rosa or Riverside), or the San Joaquin valley (Sacramento or Fresno). More advanced two-stage indirect/direct ECs were shown to use 50% more electricity (still only one-quarter

that of a standard air-conditioner), while maintaining indoor temperatures at 78° for all except the extreme peak hours. For example, the model indicated 15 "undercooled hours" in Sacramento and 30 in Fresno as compared to 200 and 360 hours, respectively, for a simple, direct EC.

Since ECs introduce water vapor into the air stream, the issue of indoor humidity levels becomes very important. Plots of the hourly indoor temperatures and humidity ratios from the simulations indicated that in arid California climates ECs would not produce intolerably high relative humidity ratios; the primary comfort concern would be their ability to maintain cool indoor temperatures. However, the results for ECs with air-conditioner backup suggested that an enthalpy rather a temperature-driven control strategy would be more effective.

The simulations also quantified the amount of water consumed in hot valley climates, which varied from 3000 gallons a year in inland Santa Rosa to nearly 7000 gallons a year in Fresno. This might be a concern in drought-plagued California, but it should be weighed against overall residential water usage as well as against the water consumed for power generation.

The project team is currently compiling the results from a survey mailed to various people familiar with EC technology. So far, there have been 21 responses, roughly half were from engineers and one-third were from HVAC manufacturers. Thirty-five percent of the installations were simple direct systems, while nearly 60% were either indirect or two-stage systems. Negative responses on indoor comfort conditions were surprisingly small (one out of 20 on noise, one out of 15 on humidity, and none on temperature). The chief benefits cited were the savings in operating costs, followed by improvements in indoor comfort and air quality. The major problems cited were the lack of design guidance, improper or poor maintenance, and improper use in inappropriate climates. Unexpected benefits cited included improved air quality and their use as humidifiers during the heating season. Out of 21 responses, 11 were extremely favorable and seven were favorable.

The study of innovative EC configurations evaluated the effectiveness of recapturing through a heat exchanger the "coolth" of the secondary air from an indirect EC, and the use of EC to precool incoming air to conventional air conditioning HVAC systems. These preliminary studies were done using the available EC models and described in two technical papers now in draft form.

The remaining tasks on this project are to finish the preliminary cost-benefit analysis of ECs, comparing first costs—including installation—to the expected savings in operational costs, to document the project findings, and to make a preliminary assessment of the benefits and drawbacks of using ECs in California buildings.

ECONOMIC INCENTIVES FOR THE INTRODUCTION OF ELECTRIC AND NATURAL GAS VEHICLES

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ABSTRACT

MOTIVATION FOR THE RESEARCH

This research project addresses the form of government intervention needed to introduce electric and natural gas vehicles (NGVs). The primary social benefits of these vehicles is their potential for contributing to large-scale reductions in urban air pollution, reduced reliance on imported oil, and reductions in greenhouse gases. Since these benefits accrue to society at large rather than to individual consumers or producers, government intervention to encourage the use of EVs and NGVs is likely.

Current emission standards apply uniformly to each and every vehicle; they provide no incentive to market a cleaner-burning vehicle. An alternative approach, and the one that is the focus of this study, is to create markets for the reduction of pollution. In this approach, firms are required to meet a standard, but there is flexibility in how they must meet it. Specifically, if they more than meet the standard, they earn credits which can be sold to other firms. Alternatively, if they do not meet the standard, they can purchase credits from other firms to meet their statutory obligation.

In fact, current regulatory changes indicate substantial interest in such marketable credit schemes. The 1990 Federal Clean Air Act has such a scheme for the reduction of SO_2 from power plants. Of more direct interest, the California Air Resources Board (CARB) is requiring that vehicles sold in California meet an average emission level. CARB's low-emission vehicle program allows vehicle emission averaging, banking, and trading. NGVs and EVs with inherently low-emission characteristics will certainly earn emission reduction credits for manufacturers. There is also a requirement that 2% of manufacturers' sales be "zero-emission" vehicles between 1998 and 2000, 5% between 2001 and 2002, and 10% by 2003.

The primary objective of this study is to estimate the cost savings associated with the marketable credit schemes for the attainment of vehicle and fuel emission standards. The potential advantages of a marketable credits scheme include the following: 1) large emission reductions and energy shifts can be achieved without imposing large taxes or fees, 2) the approach is inherently more efficient that uniform standards, 3) credits are politically more palatable than taxes, and 4) the approach is more amenable to region-specific solutions.

MARKETABLE CREDITS SCHEME FOR VEHICLE EMISSIONS

The marketable credits scheme analyzed in the first phase of this project is based on the average emission requirements instituted by CARB for vehicle manufacturers. These requirements are based on hydrocarbon emission standards and the program includes two sources of efficiency gains. First, firms must meet an average emission level rather than a standard on

each vehicle, allowing firms to produce some clean-burning vehicles to offset emissions from higher-emitting vehicles. Second, firms are permitted to comply with the regulation by purchasing emission reduction credits from other producers who have more than met their requirements. Our research estimates the cost savings associated with these components both separately and in total. In addition, we are examining the costs of such a system if CO and NO_x are included as well as HC.

On the fuels side, CARB had proposed that fuel suppliers be required to provide a certain percent of "clean" fuels in accordance with sales of clean-fueled vehicles. Firms that more than satisfy their fuel distribution requirement would earn credits which could be banked for later use or sold to firms not meeting their distribution requirement. Although CARB did not adopt this proposal, the potential cost savings associated with such an approach will be examined in future stages of the project.

RESEARCH METHODS

To estimate the cost savings associated with a marketable credits scheme, economic models of the automobile industry's behavior are constructed. Production costs, emission characteristics, and emission control cost data for electric, natural gas, and methanol-powered vehicles have been collected. In addition, emission control costs and emission characteristics of gasoline-powered vehicles have also been collected.

Preliminary analysis of the data suggests that, on average, consumers are spending about $1200 - $1600 per vehicle on emission control components (without accounting for on-board computer systems and fuel injection systems). These figures suggest that there may be large cost saving advantages from a marketable credit system and from the use of EVs and NGVs.

To model the market equilibrium in a marketable credits scheme, manufacturers are assumed to minimize the costs of meeting emission requirements by choosing the mix of vehicles (gasoline-, electric-, natural gas-, or methanol-powered) and the emission control components to add to these vehicles. A programming model is used to find the solution to this problem assuming that a marketable credit scheme is in place. This solution provides an estimate of the costs of compliance with the requirements of a marketable credit scheme. This solution can be contrasted with the cost of meeting the standards, assuming uniform emission requirements. The difference represents the cost savings attributable to the use of the marketable credits scheme.

Another result from the study will be the value of emission reduction credits earned by EVs and NGVs. These results can be used to determine whether the emission reduction credits combined with the Corporate Average Fuel Economy (CAFE) credits they earn will be powerful enough incentives to induce manufacturers to initiate large-scale production of these vehicles.

PROGRESS AND PRODUCTS

A number of researchers are involved in this project. In addition to the two principal investigators, six graduate students and an additional faculty member are involved. Regular meetings are held and have been attended by representatives of the California Energy Commission. The first year of this project has already produced a number of concrete outputs, including the following publications:

> "Marketable Emissions Literature Review: An Annotated Bibliography" by Mark Evans, Institute for Transportation Studies report.

"Emissions Permits and Pigouvian Taxes Under Monopoly" by Robert Innes, Catherine Kling, and Jonathan Rubin, May, 1991.

"Economic Instruments for Vehicle Emission Reductions in California," testimony by Daniel Sperling before the California Energy Commission, May 21, 1991

"Alternative Fuel Technology and Policy," testimony by Daniel Sperling before the Subcommittee on International Cooperation, Committee on Science, Space, and Technology, U.S. House of Representatives, February 16, 1991.

"Toward Alternative Transportation Fuels" by Daniel Sperling, Issues in Science and Technology, Fall 1990 (and letters to the editor, Spring 1991).

"Marketable Credits for Vehicle Emissions in California" by Daniel Sperling, presented to the OECD/IEA Berlin, Germany, March 25-27, 1991.

SUMMARY AND FUTURE WORK

Despite the high level of interest in incentive-based controls of motor vehicle emissions, there has been very little study of these mechanisms as they apply to transportation. This study is intended to help remedy that situation. Specifically, we are empirically examining the cost savings from employing a marketable credits scheme rather than a command and control regulatory mechanism. A marketable credits scheme is expected to provide large incentives for the introduction of alternatively-fueled vehicles such as EVs and NGVs, the cleanest-burning transportation options now available. Preliminary analysis of the data collected confirms that EVs and NGVs have a large cost advantage over gasoline-powered vehicles in meeting emission reduction goals.

During the first year of this project, we have focussed on collecting data and analyzing a marketable credits scheme for vehicle manufacturers. The second year of the project will focus on examining alternative marketable credits programs and examining the sensitivity of the results to assumptions about the cost functions. In addition, a study of a marketable credits scheme for fuels will also be fully initiated in the second year of the project and will be completed in the third year (if funding is available).

THERMAL ENERGY STORAGE COMMISIONING GUIDELINES

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ABSTRACT

THERMAL ENERGY STORAGE COMMISSIONING GUIDELINES

Version 1.0 of the CIEE Thermal Energy Storage (TES) Start-up Testing and Commissioning Guidelines has been written. These guidelines will be continuously improved and upgraded in this and subsequent years based on field experience. The guidelines include the following sections:

1. An introductory section.

2. A design review section.

3. A checklist section comparing the designed and installed TES facility's components.

4. A section on testing the major components.

5. A testing section to evaluate the performance of a TES by its kilowatt per ton ratio, kilowatt shift, and cooling delivery rate.

6. A section on retesting, if a test is failed.

"Penalties" for second test failure are included as an example that could be appropriately adjusted. The guidelines include a series of easy-to-use forms for the different tasks. The guidelines also include diagrams clearly isolating the different responsibilities and components of the complete commissioning procedure.

The checklist section was designed to catch most of the simple errors that have plagued TES sites in the past. The initial step in developing this checklist was to compile a super case-study or a list of all such errors learned from TES manufacturers' representatives, operators, EPRI reports, and utility companies. A total of 37 TES sites were reviewed to find possible problems. Every failure on this list was checked against the guidelines to verify that the failure could have been caught by the guidelines. In addition, two detailed case-studies were undertaken at LBL as part of this project, and added perspective to the commissioning guidelines.

The guidelines have been directed by three principles:

1. For various HVAC components, cooling towers, compressors, etc., there are already a variety of performance checklists and commissioning procedures. But, in practice, many of these procedures don't get used at the final job-site. To get used, guidelines must be

sufficiently simple and generic for a diversity of sites. The procedures in the commissioning guidelines must be swift enough and of acceptable cost.

2. Related to this, the guidelines must be designed so that there is a party with a very strong self-interest in seeing them used properly. These guidelines are, consequently, oriented toward third-party commissioning. It is envisioned that future TES contracts would require a commissioning test by small qualified engineering companies. There is already good precedent for this with quality control companies in the construction industry.

3. As we interfaced with different commissioning experts, we discovered that it was important to clarify how they defined commissioning. We wanted to restrict our efforts to TES commissioning and avoid the much larger, though worthy, task of HVAC commissioning and the even larger worthy task of building commissioning. Similarly, it is important to distinguish between start-up procedures, performance testing, and commissioning.

The guidelines have been checked at two initial sites in San Diego, but much more extensive testing is planned for the coming year. The remaining exceptions to this simplified testing procedure will be addressed in the coming year. These include methods for testing a TES site during the non-cooling season, testing of TES sites which operate on weekly rather than daily cycles, and testing of partial storage TES systems where the storage facility and chiller plant run simultaneously.

REDUCING LOSSES IN HYDRONIC DISTRIBUTION SYSTEMS WITH FLUID ADDITIVES

Subproject of the Efficient Systems for Thermal Distribution Project

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ABSTRACT

INTRODUCTION

This work aimed at evaluating the feasibility of using surfactant additives to reduce the pumping power used in hydronic heating and cooling systems in buildings.

Laboratory and field tests have shown that surfactant additives reduce pressure drop in turbulent flow by up to 80% if temperature and shear stress are below critical values. If the critical temperature or shear stress is exceeded, temporary degradation occurs. After the flow conditions are normalized, however, the solution regenerates without any permanent loss of drag-reducing ability. This regeneration is in sharp contrast to the permanent degradation suffered by polymeric additives and makes the surfactants particularly well-suited for recirculation applications.

The drag-reducing concept has been successfully applied under field conditions to many industrial situations, including a large district heating system. In that work, a series of experiments were performed to determine the potential pumping power savings that can be achieved in district heating systems with surfactant additives. Very impressive results were achieved. Not only was the expected drag reduction verified (with savings in pumping power of up to 250 kW), but there was also no major problem encountered in terms of system performance, long-term stability, or corrosion. Clearly, the concept of using drag-reducing additives in building heating and cooling systems appears to be very promising indeed.

RESULTS OF OUR FEASIBILITY STUDY

Fluid and System Characteristics

We have analyzed the properties of the additives and of the systems in order to ascertain the potential match between these two aspects. Our analysis showed that there are indeed surfactant additives that cover temperatures ranging from 2°C to 150°C and that cover the range of shear stress expected in building systems. There should also be few control, corrosion, maintenance, toxicity, and disposal problems.

Building systems applications would, however, differ from laboratory tests and from district heating field tests in that the former involve many singularities such as valves, fittings, heat exchangers, etc. It is therefore possible that the shear stress in these singularities might exceed the critical stress for the solution in question and might cause some level of temporary degradation. This would mean that the drag reduction in the fittings might be lower than in a

straight pipe. Accordingly, we have identified two time parameters quantifying this temporary degradation: a degradation time and a regeneration time. These may be functions of the additive type, the additive concentration in water, the shear stress, etc. Once measured in the laboratory, these parameters should allow us to predict the level of drag reduction in the singularities and immediately downstream.

Heat Exchangers

There are typically many heat exchangers in a building hydronic system. This makes any additive-related heat transfer reduction potentially important. To address this concern, we have analyzed typical heat exchangers in buildings and found that the efficiency of most of them—and in particular terminal air-water heat exchanger—will likely not be affected much, because the total heat resistance for these units is dominated mostly by the gas side. Nevertheless, some means for minimization of any heat transfer reduction may be an important aspect of the implementation of drag reducers, and intentional degradation appears to be very promising as a simple way to achieve this control. The best way to achieve this temporary degradation will depend on the regeneration time parameter, and may in fact take place naturally in the heat exchanger.

Quantification of Power Savings in a Building

In order to quantify more accurately the savings that could be achieved with the additives, we conducted an analysis of some cooling and heating systems, and calculated the expected pumping power savings as a function of the size of the building and type of flow control. We found that pumping power in large cooling systems (serving more than 100,000 ft^2, say,) typically amounts to 10% to 15% of the total system power consumption (i.e. including thermal load). We calculated then that the pumping power can be reduced at full load by about one-half, if additives are used. This means that savings of over 5% of the total power consumption could be achieved at full load.

The savings at reduced loads will depend on the type of flow control, i.e., variable-speed pump or constant-speed pump. It is interesting in this respect to compare the drag-reducing additives approach with another pumping power savings technique: the use of variable-speed pumps. We expect that even for smaller systems (pumping power less than 20 kW, say,) operating at an average load of 50% and above, the use of additives will provide savings comparable to the use of a variable-speed pump, but at much lower costs. For larger systems, the additives could also be used alone, or—better yet—both techniques could be used simultaneously to provide maximal savings. It is important to emphasize in this respect that variable-speed pumps provide savings only at reduced loads, whereas additives provide the savings at all loads, including full load. The latter may be particularly attractive to utility companies in terms of reduction of peak demand.

Implementation

Our experiments will allow us to measure the fluid and flow characteristics necessary for the prediction of drag reduction in circulating loops, and will also give us the information necessary to modify the design of hydronic systems so as to maximize this drag reduction effect and the system performance.

We expect the implementation of the additive approach to be very simple and cost-effective. In the case of a variable-speed pump system, it may be sufficient to put additives in the system and to adjust the pump control. In the case of a constant-speed pump, the pump characteristics must be changed by impeller diameter reduction or by speed reduction. We believe that these investments would pay for themselves within one year, and that very large savings could be achieved thereafter.

State and National Energy Savings

Our analysis suggests that there will indeed be large savings in the average commercial building. Naturally, these savings will then be multiplied at the state or national level. Looking only at hydronic systems in commercial buildings, we estimated that the savings at the national level if these additives were used would be on the order of $285 million per year. We estimate that the use of additives in industrial and large residential hydronic systems might increase this figure to about $350 million per year, and perhaps to much more. In addition, it should be emphasized that there are many other industrial applications involving thermal loops that could also benefit from the approach. For example, power plants typically spend enormous amounts of energy on pumping water for cooling.

As far as California is concerned, we estimate that the savings on heating and cooling loops in buildings alone could be on the order of $30 million per year and maybe much more.

ADVANCING THE STATE OF THE ART OF DSM IMPACT MEASUREMENT

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ABSTRACT

INTRODUCTION

This scoping study was commissioned by CIEE as part of its research mission to advance the energy efficiency and productivity of all end-use sectors in California. Our specific goal in this effort has been to identify viable research and development opportunities that can improve capabilities to determine the energy use and demand reductions achieved through demand-side management (DSM) programs and measures.

We surveyed numerous practitioners in California and elsewhere to identify the major obstacles to effective impact evaluation, drawing on their collective experience. As a separate effort, we have also profiled the status of regulatory practices in leading states with respect to DSM impact evaluation. We have synthesized this information, adding our own perspective and experience to that of our survey respondent colleagues, to characterize today's state of the art in impact evaluation practices.

This scoping study takes a comprehensive look at the problems and issues involved with DSM impact estimates at the customer facility or site level. The major portion of our study investigates three broad topic areas of interest to CIEE:

1. *Data analysis issues*: These include engineering calculations and other methods used to estimate DSM impacts, methods for analyzing measured energy performance data, experimental design and sampling, and persistence of energy savings.

2. *Field monitoring issues*: These include innovations in metering and field measurement technologies, and ways to reduce the cost of field measurement.

3. *Issues in evaluating DSM measures*: These include technical and behavioral factors that are difficult to assess for specific DSM measures.

SPECIFIC RECOMMENDATIONS

Across the three topic areas, we have identified 22 potential research opportunities to which we have assigned three priority levels.

The *Priority 1* projects, in our opinion, would initiate research that addresses the most basic concerns of the impact evaluation community:

1. A major California persistence study to determine the long-term reliability of DSM resources. We recommend a cooperative project involving all stakeholders. Since this

is an important national technical and policy issue, we would also recommend coordination with, and cooperative funding by, national research organizations.

2. A concerted effort to improve engineering calculations. We believe that engineering calculations are a permanent feature of DSM activities and that research investments in this area will pay long-term dividends.

3. Integration of statistical engineering and behavioral models. This is recommended because of the widespread use of regression analysis methods in DSM evaluations and the potential benefits of incorporating engineering and behavioral factors into the analyses.

4. Better use of field-monitored data for impact evaluation. We feel that this potential has barely been tapped. Five recommended projects can overcome current barriers: 1) systematic value engineering could address problems with the high cost of field monitoring, 2) advanced short-term monitoring techniques could provide timely evaluation results, 3) special monitoring approaches, such as "field kits," could provide reliable data on hard-to-measure DSM parameters, 4) innovative field-testing methods could provide better data on HVAC systems, and 5) evaluation methods specifically tailored to whole-building data could leverage the considerable capabilities of load research departments.

5. Addressing low-impact and low-frequency measures. We recommend two research initiatives in this area primarily due to the relatively high aggregate DSM savings attributed to these measures, and the perceived lack of knowledge about exactly what measures they are.

Our *Priority* 2 recommendations, to a large extent, promote technology transfer as well as initiate development of new methods:

1. In the technology transfer area, we acknowledge the expressed needs of our survey respondents by recommending better information on experimental design, simulation model calibration, site measurement plan preparation for monitoring projects, and improved data on motor performance. All these will contribute to the improved effectiveness of practitioners.

2. A statewide cooperative baseline data compilation study would be designed to address key topics such as new construction (the parameters of which are addressed in the Title 24 standards) and appliance efficiency. A statewide approach should also implement systematic procedures for periodic updates.

3. Collinear variables may pose a growing problem for practitioners as DSM impact evaluations may increasingly rely on regression analysis techniques. We recommend that advanced sampling techniques, which mitigate multicollinearity, be explored.

4. Artificial intelligence and expert systems have shown their potential in other facets of the utility industry. We think DSM impact evaluation can benefit as well. Some of the repetitive, rule-based activities in field monitoring projects, such as measurement plan development, are good candidates for R&D.

5. Intrabuilding sampling for energy monitoring purposes has not, to our knowledge, been tested. We are unsure of its chances for success, but the potential cost reduction benefits lead us to recommend it. However, this concept may presume a higher level of knowledge of building energy use than we have at the present time.

The *Priority 3* recommendations could enhance some of the methods we use today:

1. Oversights in planning data collection projects are still being reported. Standardized protocols could be of assistance to many practitioners.

2. Tracking system improvements are needed. Administrative tracking systems will be a permanent part of DSM activities. Improvements to provide more accurate reporting of savings and to support other evaluation activities (i.e., sampling frames) are worth further development.

3. Interactive and secondary effects are unclear. We agree with our respondent colleagues that the magnitude of these effects is uncertain, but will likely be small in most cases. We think these issues should be resolved.

4. The idea of self-monitoring appliances, and the approach of using DSM market clout to bring it about, is too intriguing not to include here.

The results and recommendations from this CIEE study are first and foremost intended to identify priority R&D opportunities to improve estimates of the energy and demand impacts of DSM measures. Viewed narrowly, these R&D opportunities could conceivably be restricted to the specific needs of California utilities and their implementation of DSM measurement plans. However, many of the shortcomings in DSM impact evaluation are common to evaluation efforts nationwide. Cooperative research in these areas of recommended improvements is in the interest of the entire DSM community and should be pursued in that context. The authors hope that this effort contributes to this end.

IMPROVING THE ENERGY EFFICIENCY OF RESIDENTIAL AIR DISTRIBUTION SYSTEMS IN CALIFORNIA

Subproject of the Efficient Systems for Thermal Distribution Project

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ABSTRACT

SUBPROJECT GOALS AND OBJECTIVES

This presentation describes the results of the first phase of a multiyear research project to investigate means for improving the efficiency of air distribution systems in single-family detached residences in California. The objectives of the planned three-year research effort are to:

1. Obtain representative data on the impacts of air distribution systems on residential energy consumption, peak power demand, and ventilation in California.

2. Develop, test, and evaluate the cost effectiveness of alternative approaches to the problems related to residential air distribution systems, both for new and existing buildings (including duct installation standards, sealing technologies, and non-air distribution systems).

3. Deliver a field-tested retrofit package for residential air distribution systems to California utilities and other residential audit and retrofit groups.

4. 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 first year's efforts focused primarily on the first objective, the results and implications of which are discussed.

BACKGROUND

Approximately 50% 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 represent the vital link between houses and their space-conditioning plants, the energy and comfort effectiveness of residential duct systems 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, and in particular the duct leakage problem, is particularly important in California where a little over 50% of residences presently contain a total of approximately 100,000 miles of ductwork, and virtually all new construction employs air distribution systems. The particular importance of duct leakage in California stems principally from the fact that California ductwork is almost invariably contained in unconditioned attics and crawlspaces (due to the scarcity of basement construction in the state). Earlier studies have suggested that the air leakage from a typical duct system in a Sacramento house represents between 1 and 2 kW (depending upon the location of the ducts) of peak-hour demand and 20-40% of the peak cooling day consumption, as well as approximately 1 kW of peak heating demand and 2000-3500 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 demonstrated to double air infiltration rates when the distribution system is turned on, representing between 20% and 40% of the average annual ventilation of residences. These results provide a strong case for carefully examining the impacts of residential air distribution systems on the following: 1) the energy consumption and peak demands in California, 2) the effectiveness of the Title 24 energy code, 3) the accuracy of state energy and demand forecasts, and 4) the ventilation rates providing indoor air quality in California residences.

RESULTS

This first year's efforts included a survey of HVAC contractors in California, a 31-house field study of distribution-system performance based on diagnostic measurements, and the development of an integrated air-flow and thermal simulation tool for investigating the performance of residential air-distribution systems. The field-study results generally agreed with the findings in earlier limited studies, provided field confirmation of improved diagnostic tools, and provided additional system/house characterization data that will be used for input and verification of simulation codes, as well as in the development of retrofit protocols. The field results include some of the following highlights: 1) building envelopes appear to be approximately 30% tighter for houses built after 1979, 2) duct system tightness showed no apparent improvement in post-1979 houses, and 3) distribution-fan operation added an average of 0.45 air changes per hour (ACH) to the average measured air change rate of 0.24 ACH.

The simulation tool developed is based upon DOE-2 for the thermal simulations, and MOVECOMP, an air-flow network simulation model, for the duct/house leakage and flow interactions. The first complete set of simulations performed (for a ranch house in Sacramento) indicated that the overall heating-season efficiency of the duct systems was approximately 65-70%, and that the overall cooling-season efficiency was between 60% and 75%. The large range in cooling-season efficiency represents the difference between systems with attic return ducts and crawlspace return ducts, the former being less efficient. The simulations also indicated that the overall thermal conductance (UA) value of the building envelope did not have a large impact on the overall efficiency of the air distribution system.

MAJOR ACCOMPLISHMENTS

The major accomplishments of the first year's efforts are:

1. The development of an automated diagnostic instrumentation package and measurement protocol to characterize the performance of residential air distribution systems.

2. The collection of a unique set of primary data from 31 houses on the performance characteristics of residential air distribution systems.

3. Development of a simulation tool that is capable of analyzing the interactions between the building and the loss mechanisms associated with residential air distribution systems including duct leakage, duct conduction, and return-flow imbalances.

4. Preliminary application of the simulation tool and field data to analyze the performance of a typical air distribution system in a ranch house in Sacramento.

OFFICE EQUIPMENT ENERGY USE, LOAD PROFILES, EFFICIENCY, AND TRENDS

Subproject of the Integrated Estimation of Load Shapes and End-Use Energy Intensities in Commercial and Residential Buildings Project

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ABSTRACT

RELEVANCE TO CALIFORNIA ENERGY EFFICIENCY

The demand forecasting models used by California utilities and the CEC rely on an explicit representation of the end-use structure of energy demand. To forecast peak electricity demand, additional disaggregation of end-use electricity consumption over the hours of the year is required. These disaggregations are appropriate because policy interventions to improve energy efficiency can only be captured by models that incorporate end-use detail.

However, the lack of high quality data to support these modeling activities is widely acknowledged as the single most important factor limiting improvements to this modeling approach. This limitation is of particular concern because obtaining these data is often expensive. The need for better data is particularly critical for the office equipment end use (including computers, printers, faxes, etc.), because the growth in energy use within this end use is believed to be a major source of uncertainty in current forecasts of future energy demand. The objective of this subproject is to redesign and revise the data used by a PG&E-developed submodel for forecasting office equipment energy use for common use by energy forecasters.

APPROACH

The project will review, analyze, and synthesize data from a variety of sources. These sources include detailed on-site surveys of 800 PG&E commercial premises, end-use metering and other studies that have focussed on office equipment energy use, office equipment trade journals that report on office equipment trends, and examinations by researchers of the technical options for improving energy efficiency. The project will then redesign an existing spreadsheet model developed by PG&E. The redesign will focus on defining precise categories of office equipment and on clarifying the procedures used to forecast energy as a function of the following types of data: installed, annual hours of use, the ratio of average to rated power, and equipment saturation. Finally, the project will revise the data used by the model for each of these categories.

CURRENT STATUS AND FINDINGS

A prototype of the redesigned spreadsheet model has been completed and submitted to PG&E and the CEC for review. The data inputs in the original spreadsheet have been revised to reflect more recent findings. Important revisions have been made to the values used to relate

nameplate capacity to the much lower energy actually drawn while operating and to the installed capacity of different categories of equipment over time. We have also developed a series of indices to allow the user to check the reasonableness of the forecast; these indicators include the number of pieces of equipment per employee, and the total installed equipment intensity (watts per square foot).

FUTURE WORK

The projections of future equipment saturations remain an important unknown in estimating future energy use by office equipment. Several projects are currently underway that will generate improved data needed as inputs for the model. For example, we look forward to the incorporation of end-use metered data collected by PG&E both to validate our energy use estimates and to develop representative load shapes for forecasting. Additional component monitoring is needed to verify our estimates of on-time and average power use for several categories of equipment.

INTEGRATED ESTIMATION OF COMMERCIAL LOAD SHAPES AND ENERGY USE INTENSITIES

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ABSTRACT

SUMMARY

Reliable electric end-use load shape and intensity data are essential for accurate load forecasting. End-use metering of buildings to obtain these data is very expensive and, consequently, is difficult to justify for the collection of large amounts of data. Using analytical techniques to obtain these data is a promising alternative to end-use metering because it is far less costly. Nevertheless, validation of these techniques must rely ultimately on metered data. LBL has developed an analytical technique for estimating end-use load shapes called the End-use Disaggregation Algorithm (EDA). In this project, we have used hourly end-use metered data collected from two buildings in Southern California to refine and validate EDA.

BACKGROUND

In 1988, SCE and the CEC jointly sponsored a unique project at LBL to develop an analytical technique to estimate commercial sector load shapes (LSs) and energy use intensities (EUIs) using a combination of whole-building load research data, on-site audit data of individual premises, and mail survey data from many premises (Akbari and Eto et al. 1989). The project was unique because it produced a new method for performing this analysis, which was based on a combination of engineering simulations and reconciliation with measured whole-building load data (Akbari et al. 1988).

An important missing piece of the project was the absence of high quality end-use metered data to validate the technique. The objective of this project was to validate and refine EDA, using one year of hourly end-use metered data from two buildings in Southern California.

END-USE DISAGGREGATION ALGORITHM (EDA)

EDA is a deterministic method that primarily utilizes the statistical characteristics of the measured, hourly, whole-building load and its inferred dependence on temperature. Simulation is only used to supply information that is not evident from the load/temperature relationship. In the EDA, the sum of the end uses is constrained, at hourly intervals, to be equal to the measured whole-building load. This constraint provides a reality check that is not always possible with pure simulation. In addition, the load/temperature relationship helps to characterize the HVAC end use, providing an additional constraint on the remaining end uses and preventing some of the errors possible with simple proration. Finally, EDA also attempts to deal with the fluctuations of hourly loads by incorporating observed statistical variation.

For each building, the inputs to the EDA are the following:

- The actual hourly whole-building load during a given period of time.
- The actual measured outside weather conditions during this same period of time.
- Statistics from the regression of load with the selected weather variables.
- Schedules of non-HVAC end uses derived from on-site audit data.
- The results of simulating the building at the base weather condition.

The primary component of the EDA is regression of hourly loads with climatic variables. Because the weather dependency of the building load changes with season, we separate the data into two seasons (summer and winter) in order to obtain two sets of weather regression coefficients. The weather regression equations are used to separate the load predicted by the regression into a weather-dependent part, and a weather-independent part. We assume the weather-dependent load is attributable to HVAC equipment. The weather-independent load is assumed to be the sum of such loads as lighting and miscellaneous equipment, as well as the weather-independent portion of the HVAC at base weather conditions. Because the regression provides no information about how to break down the weather-independent load, we simply prorate it according to the loads predicted by the simulation. A detailed description of the EDA and a comparison of its performance versus pure simulation is reported in Akbari et al. (1988).

RESULTS

Figure 1 compares monitored end-use profiles with those estimated using EDA for a 117,600 ft office in Southern California for an average of all standard days during one year. The estimated lighting profile displays a reasonable fit to the monitored data, only diverging in the evening. The HVAC profile, on the other hand, overestimates the peak load by about 50%. This is due to the mismatch between the audit estimate of miscellaneous loads and the actual monitored load. The audit showed installed miscellaneous equipment loads of 0.6 W/ft^2 which, when combined with the operating hours and our estimated usage factors, resulted in a peak power density of 0.15 W/ft^2. However, the monitored plug loads showed a peak average energy density of 0.4 W/ft^2 and in addition, the peak average energy density of the unmonitored loads (the difference between the total of the monitored end uses and the monitored total) was 0.5 W/ft^2. This underestimate resulted in the excess being applied to the HVAC end use since it was the largest in magnitude during the daytime.

Errors of this type can not be prevented by EDA at this time; accurate end-use disagregation still depends on accurate audit data. In the future we hope to be able to give EDA some insight into the expected shape and magnitude of end-use profiles so that it can automate the human analysis and engineering presently needed to keep the end uses within realistic limits.

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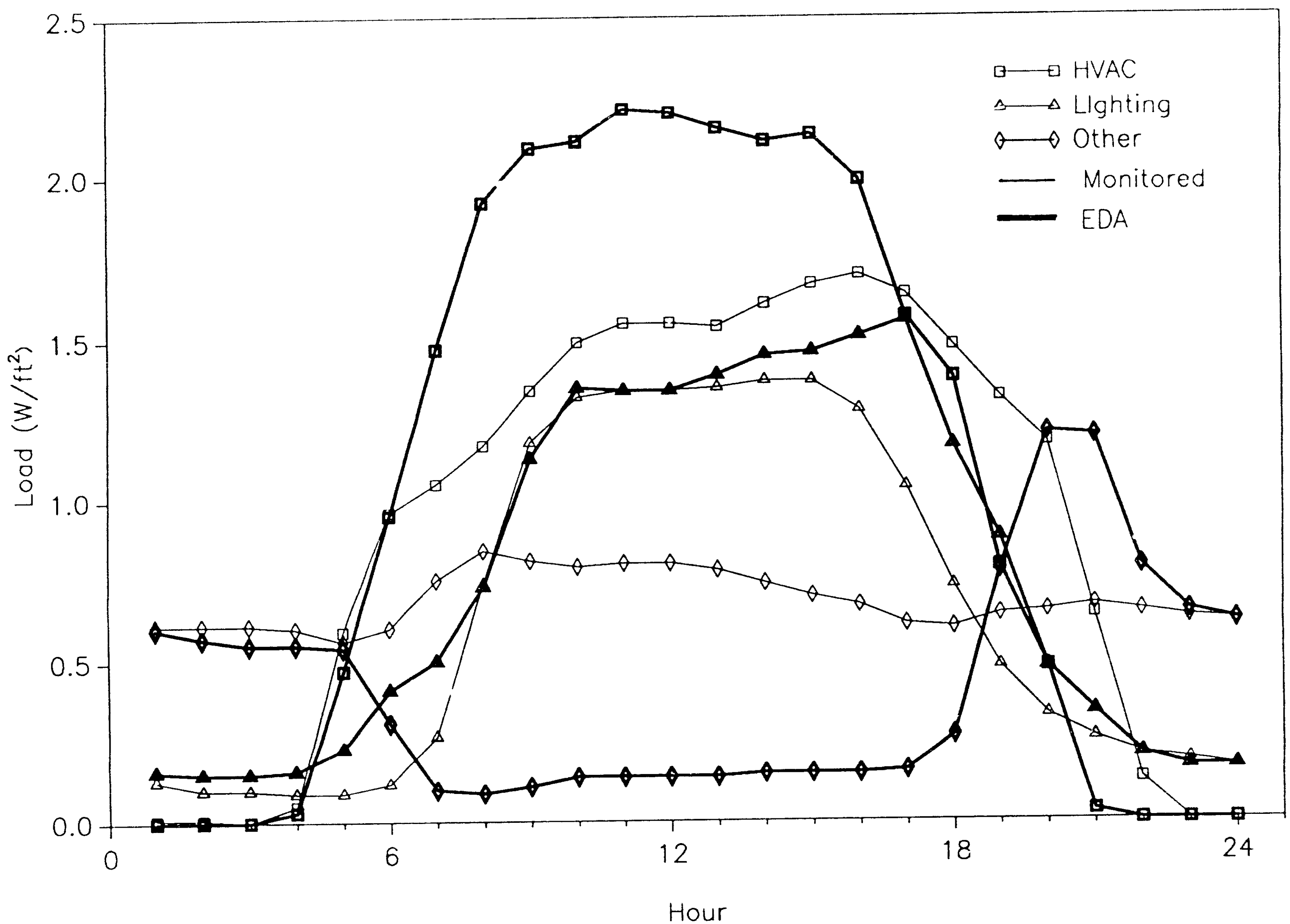
Figure 1: Comparison of Monitored and EDA Estimated End Uses



LIGHTING AUDIT TOOL: A PRECURSOR TO AN EXPERT SYSTEM FOR SPECIFYING ENERGY-EFFICIENT LIGHTING

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ABSTRACT

INTRODUCTION

Increased concern for reducing operating costs in buildings has led to the emergence of many new efficient fluorescent lighting products during the past 15 years. This surfeit of choices is a mixed blessing for the specifier who must now understand the performance characteristics of many lighting components. This task is further confounded by the fact that the particular choice of components used to create a lighting system affects overall performance. This performance variability seriously compromises the designer's ability to specify lighting systems that provide the correct light levels. Difficulty in calculating actual lumen output is often particularly troublesome in retrofit applications where the task of collecting and correctly interpreting manufacturers' component performance data, determining integrated system performance, and deciding the appropriateness and cost effectiveness of retrofits is often delegated to facility managers who have little expertise in lighting.

In this exploratory research project, we produced a microcomputer spreadsheet program that is intended to assist retrofit lighting specifiers in their task. The program uses accepted illuminating engineering principles to precisely determine system efficacy and the power input and light output of common 4 ft fluorescent lighting systems under realistic operating conditions. The spreadsheet is targeted at facilities managers, building energy managers, designers, energy analysts, and utility specialists.

METHODS

An important part of this project was to develop algorithms that describe system performance based on key lighting parameters. These key parameters are the ballast factor, the lamp lumen rating, the lamp/ballast system input power, the thermal factors (for light output and power input), and the luminaire lumen maintenance properties.

Once the appropriate algorithms for determining these parameters are identified, the calculations required to estimate system efficacy, energy usage, and cost-effectiveness are straightforward but tedious to execute. Consequently, a microcomputer program is an ideal method for implementing these calculations. For this project, we encoded the analysis program as a spreadsheet template. Implementing the analysis as a spreadsheet expedites delivery of a working prototype and also allows the equations used in the calculation to be readily inspected and modified as necessary. The spreadsheet, code-named LEAR (Lighting Energy Analysis for Retrofits), is being developed as a template for a popular spreadsheet program (Microsoft Excel) that runs on PCs (under Windows) and on Macintoshes.

For this exploratory project effort, we limited the scope of the program to retrofits of 4 ft fluorescent luminaires that do not significantly alter the relative distribution of light (candlepower) from the fixture. This category covers delamping, relamping, reballasting, combinations of relamping and reballasting, and altered maintenance practices.

In performing its calculations, the spreadsheet accesses several internal databases that contain technical data on lighting components. Since some of these databases contain product-specific technical-performance data, the user does not need to collect any additional data concerning the performance of a specific product of interest. This greatly simplifies the user's task. It is generally not possible to use "generic" performance data without severely compromising the utility of the program. For example, ballast factors for electronic ballasts vary widely between manufacturers and even within a given manufacturer's product line. Thus, differences in product performance are accurately reflected in LEAR's databases.

Program Inputs and Outputs

Table 1 shows the inputs required by the program and lists some of the lighting values that the program computes. Generally, the user need only supply information that is readily obtainable through a simple lighting audit. For example, to describe their existing installation, the user need simply read the nameplate label on the ballast and lamp. To the greatest extent possible, the program was written so that the user need not learn any new terminology or perform any calculations that he/she is not familiar with.

Table 1.
Inputs and Outputs from LEAR Spreadsheet

Required Inputs

- Number of lamps per ballast
- Operating voltage (120 or 277)
- Number of ballasts per fixture
- Fixture category (Lensed, Parabolic, Strip, Open)
- Fixture mounting type (Recessed, Surface, Pendant)
- IES maintenance category (I,II,III,IV,V, VI)
- Fixture efficiency
- Lamp ambient temperature (°C)
- Group relamp interval
- Annual operating hours
- Atmospheric conditions (VD,D,M,C,VC)
- Cleaning interval (in years)
- Month of analysis (month)
- Cost of electricity ($/kWh)
- Component costs

Outputs (not inclusive)

- Initial and maintained luminaire lumen output (with uncertainty)
- Luminaire power input (with uncertainty)
- Energy use and operating cost per fixture per year
- Discounted payback
- Present value
- Savings investment ratio
- System efficacy (with uncertainty)

- Ballast factor
- Thermal factor (light)
- Thermal factor (power)
- Optical efficiency

The most useful outputs from LEAR are the initial and maintained luminaire lumen output values, the luminaire input power values and the energy use per fixture per year values. The luminaire lumen output is especially useful in identifying whether a potential retrofit will be able to provide the same light level as the existing lighting system. It should be emphasized that these values are corrected for the ballast factor, existing maintenance practices, and the thermal environment of the fixture. Since the user will only know the lamp ambient temperature to some limited accuracy, the program lists the uncertainties in the output values explicitly.

Technology Transfer

Although LEAR was only intended to be a prototype of a lighting energy analysis program for lighting retrofits, the algorithms used in the spreadsheet are exportable to other computer programs. One technology transfer path for this project is already being pursued. Under contract to SERI, LBL is translating the core algorithms in LEAR into subroutines written in the C programming language. These subroutines are being incorporated into the FLEX computer program that is currently under development at SERI to assist Federal facilities managers in specifying energy-efficient lighting retrofits in Federal buildings.

SUMMARY

A spreadsheet program for determining the system efficacy, power input, and light output of common 4 ft fluorescent lighting systems under realistic operating conditions is developed and described. The program uses accepted Illuminating Engineering Society (IES) engineering principles to precisely account for ballast factor, existing thermal conditions, and maintenance practices. The spreadsheet, which includes a database of lamp and ballast performance data, can be used to calculate the cost-effectiveness of many common lighting retrofits.

The LEAR program has the potential to be a useful tool for analyzing retrofits for some common lighting systems. We believe it has the appropriate degree of rigor with respect to characterization of the most important lighting parameters. It minimizes the technical information required from the user while requiring sufficient input data to estimate system performance to a degree of precision appropriate for analyzing lighting retrofits. To the most reasonable extent, we have used existing IES and American National Standards Institute (ANSI) procedures for characterizing and analyzing fluorescent lighting systems, and have resisted the temptation to invent new analytical methods.

FORMATION OF NITROGEN OXIDES IN INDUSTRIAL GAS BURNERS

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ABSTRACT

INTRODUCTION

In recent years, air-quality emission regulations have resulted in a substantial reduction in the emission of nitrogen oxides from industrial natural-gas-fired burners. In particular, burner manufacturers and combustion modification specialists have successfully used empirical methods to develop a large and varied population of "low-NO_x burners."

The recent demands to further improve urban air quality have led to a broadened population of industrial sources required to utilize low-NO_x burners, and a requirement to develop "ultra-low-NO_x burners."

The present research project is directed to the development of high-efficiency, ultra-low-NO_x industrial natural-gas-fired burners. To achieve this goal, empirically-derived guidance will be complemented with a detailed understanding of the formation and emission of nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O) in natural gas burners.

The project is based on the premise that the keys to achieving an ultra-low emission of NO_x and high efficiency from natural-gas-fired burners are 1) an understanding of the relationship of nitrogen oxides' formation to the mixing of the fuel and air, and 2) the application of in-situ laser diagnostics and comprehensive modeling to attain the necessary understanding. It is further postulated that the demonstration and implementation of ultra-low NO_x technologies alone, while necessary, are not sufficient. Required, in addition, is a technique to assure that high-efficiency ultra-low-NO_x performance is in fact attained in the field, and maintained during the life of the burner. Active control is being explored for this purpose.

APPROACH

A team approach has been adopted. Participating with the UCI Combustion Laboratory (UCICL) are investigators at the Lawrence Livermore National Laboratory (LLNL), the Sandia National Laboratories, Livermore (SNLL), and the Energy and Environmental Research Corporation (EERC).

The technical approach includes the following activities:

1. Design, fabricate, install, and operate a 100,000 Btu/hr industrial gas burner with full optical access for visualization and laser diagnostics.

2. Incorporate into a comprehensive code a mixing model and methane, thermal NO, prompt NO, NO_2 and N_2O kinetics.

3. Apply the code for guidance in the design of the experiment.

4. Develop and apply a laser diagnostic for the in-situ measurement of NO and NO_2.

5. Acquire 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.

6. Utilize the code in conjunction with the experimental results to develop the needed insight.

7. Identify the boundary and operating conditions that minimize nitrogen oxides formation.

8. Develop and apply active control methodologies for the attainment and maintenance of ultra-low NO_x in practical systems.

STATUS

The current project was initiated on June 1, 1991, and has immediately engaged in the implementation of the approach outlined above. The comprehensive modeling, the design of the 100,000 Btu/hr burner and experimental facility, the foundation of the active control methodology, and the adaptation of Degenerate Four-Wave Mixing (DFWM) for the in-situ measurement of NO and NO_2 are proceeding in earnest. Gas suppliers, burner manufacturers, and low-NO_x combustion specialists are actively participating in the development of the designs and experimental protocols to assure the relevance and effective transfer of the technology.

INTERACTIVE GRAPHIC INPUT FOR SUPERLITE

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ABSTRACT

INTRODUCTION

Buildings consume a significant portion of California's energy production, much of it during peak demand periods. This paper presents an interactive graphic input for a program which calculates natural light levels within buildings. The input is based on the Computer-Aided Architectural Design (CAAD) program and develops and demonstrates several concepts which are necessary for the *simulation* of energy loads in buildings. Such a program allows building designers to *draw* information and to *interactively* perform energy studies.

BACKGROUND

The computer simulation of thermal, light, and energy processes in buildings has long promised to improve the design process and enable researchers to ask complex and interrelated questions. This promise has been only partially fulfilled because of two major problems. One problem has been a mismatch between the way in which humans and computers process information. Conventions inherent in profession and culture must be defined explicitly in the input stream and data structure in order to take on meaning for the machine. The other problem is the way in which data has been structured in previous CAAD programs. CAAD models typically refer to points, lines, and at best polygons, but disregard the connections, enclosures, and real material properties of surfaces. This has prevented CAAD data from being used directly in energy simulations.

THE PROJECT

The team has written an interactive CAAD input module that will work for many different inputs and simulations, and a translator module (SUPERIN) for creating a SUPERLITE file. SUPERLITE is the benchmark daylighting program for the profession. The beta test version has been sent out and is being debugged.

The menu is organized in the now familiar Window or Macintosh pull-down button format. Instructions are continously provided, and are geared to the user's level of expertise ("novice" or "professional").

The floor plan is input by using the mouse to draw the walls which make up the enclosure. The wall height and material properties are shown in the sidebar. There is always a default material, but it may be changed, or materials may be created from scratch. Whenever an element is being drawn, the distances from the last point are displayed at the top of the sidebar.

When the enclosure is complete, the walls are automatically extruded vertically and the object is closed and stored as a connective series of planes. Windows may be created by selecting a surface and drawing on it. Shading devices are attached to the building as overhangs, fins, sills, and light shelves. Interior partitions and external, detached surfaces (garden walls, etc.) may be added.

CONCLUSION

Our aim has been to resolve some of the input and data problems of current CAAD systems in order to facilitate the effective simulation of building environments and energy flows. Combining a CAAD method of defining a building model (which retains physical properties similar to those of a physical model), with a data structure which is also analogous to a physical model —providing elements and properties— allows the simulation of building behavior at early stages and vastly improves the ease of simulation at any stage. This method can now be applied to more complex energy simulations.

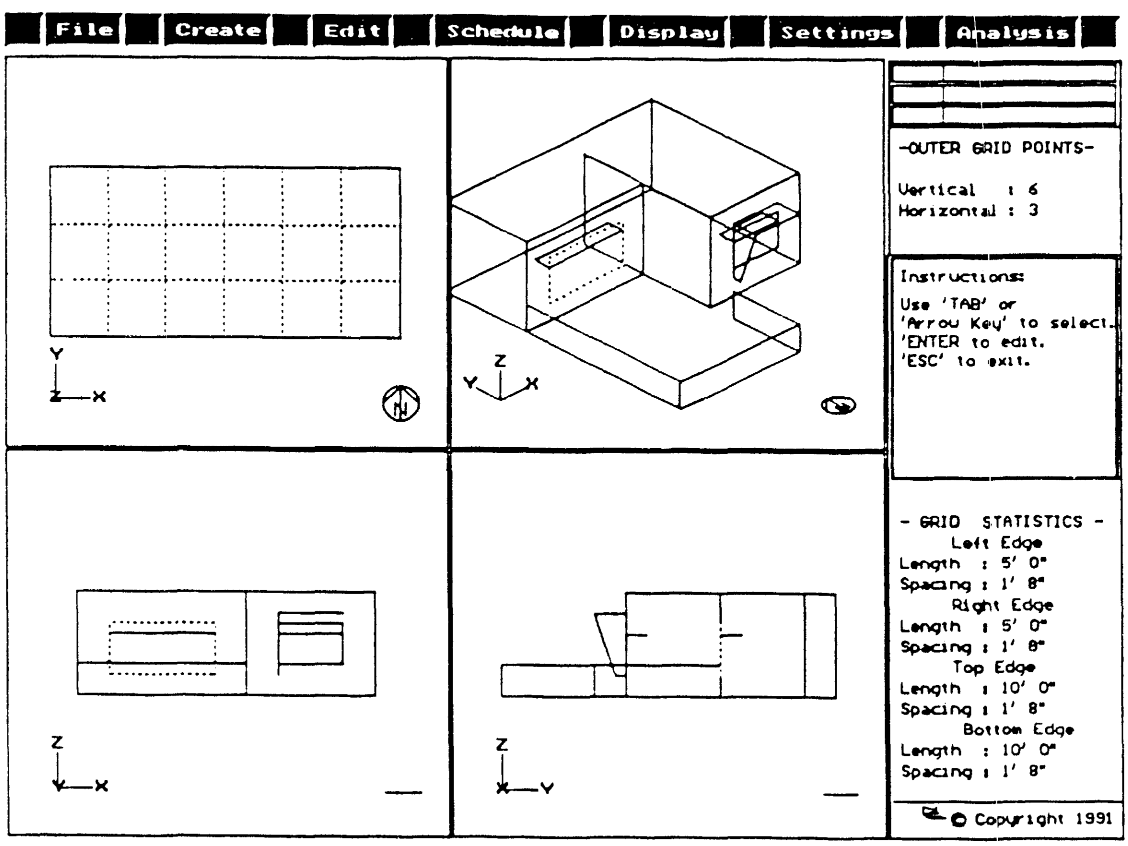

Figure 1. Three active drawing planes and one three-dimensional view as shown on the SUPERIN computer screen.

INTEGRATED ENVELOPE AND LIGHTING TECHNOLOGY TO REDUCE ELECTRIC DEMAND

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ABSTRACT

BACKGROUND

The largest components of peak demand in most California buildings can be traced to the fenestration and illumination systems, which typically impose large electrical loads for cooling and lighting. Reducing or eliminating these loads can be a cost-effective demand-side management option. While the performance of lighting and envelope systems has improved in recent years, new technologies are typically applied in a piecemeal fashion that yields less than optimal results. Additionally, these technologies are presented to the building community in a manner that does not recognize the various constraints and priorities influencing design decisions. The full potential of existing and emerging technologies will be realized only when they are commercially available in a form that facilitates widespread application. Technologies that are packaged as integrated systems and supported by appropriate tools to assist in design, specification, and assurance of performance will have a far greater impact in the building community than is currently seen.

The Building Technologies Program has a long history of developing and analyzing discrete technologies for optimization of building performance. It is a natural extension of this work to combine individual technologies into integrated systems and to examine these systems in the full context of design and industrial markets.

GOALS

Our goal is to develop integrated envelope/lighting systems that enhance comfort and productivity while reducing energy use and peak demand. The project seeks to extend the impact of the work by stimulating industry to adopt and commercialize these technologies, and to stimulate architects and engineers to specify them. We also intend to develop several demonstration sites to assist this process.

Integrated systems will be designed, developed, and demonstrated to minimize envelope cooling loads by controlling solar gain while admitting daylight, minimize electric lighting needs and associated cooling impacts, minimize perimeter heating loads, and coordinate with HVAC control systems. All this will be accomplished within the accepted requirements for thermal and visual comfort.

With respect to implementation, we will provide utility planners with projections of probable impacts of these integrated systems and examine the economic viability of leasing strategies for the new technology options. We will provide performance data and tools to building designers, engineers, and owners to assist them in specifying these technologies, and use demonstration projects to provide hands-on experience and confidence in these solutions.

PROJECT TASK AREAS AND ACCOMPLISHMENTS TO DATE

Seven task areas constitute the first phase of the project, providing a) preparatory background and context definition, b) system design and analysis, and c) technology demonstrations. Background tasks in the project serve the purpose of establishing context and direction for the more intensive design and analysis stages. To date we have:

1. Developed an initial utility impact assessment for new and emerging technologies. An analysis of energy performance potential resulted in preliminary "targets" which were compared to a selection of measured and simulated building performance data and to California energy code requirements as a benchmark (Figure 1).

2. Reviewed existing, emerging, and future technology options in several envelope and lighting categories of systems and hardware. Similarly, reviewed design tools and utility design assistance programs.

3. Examined obstacles, opportunities, priorities, and potentials with respect to market, industry, and design concerns.

System design and analysis is the core of the project and will continue into Phase II. We have:

1. Developed building prototypes for use in this stage, based on common architectural practice and fitting a matrix of envelope typologies.

2. Created algorithms for computer analysis of integrated control systems for shading and lighting systems, as well as for other new systems never previously analyzed or modeled.

3. Developed initial designs for the integrated systems and performed initial analyses for each of the building prototypes. Concurrently conducted a design workshop with an experienced team of architects and engineers to test the feasibility of our own designs and predictions within real-world constraints.

The demonstration phase of the project is an opportunity to field test and monitor our integrated systems, and to demonstrate their potential and feasibility to others. In Phase I we have begun planning for this primarily second-phase activity.

FUTURE TASK AREAS AND DIRECTIONS

We have limited our focus in Phase I to exploring only current technologies for application in new office building construction. In Phase II we will expand that focus to include emerging technologies, other building types, and retrofit applications. We will also explore other mechanisms to assist utilities in making use of our results. Options may include providing technology and case-study databases, developing design tools, and helping improve design assistance programs.

PROJECT TEAM

The work is led by the Building Technologies Program at LBL, with a large team of researchers bringing experience in building technologies, simulation, data analysis, and architectural design to the project. The Building Technologies Program additionally has strong relationships with industry, utilities, professional societies, and design community media, all of which help form the necessary avenues of technology transfer and research implementation. The Graduate School of Architecture and Urban Planning at the University of California at Los Angeles (UCLA) is a participating institution, contributing two decades of research experience in characterizing innovation in architectural design, plus an understanding of the forces that influence the design and industrial communities. In addition, the Graduate School of Architecture and Urban Planning has a well-established and influential role in private sector architectural practice.

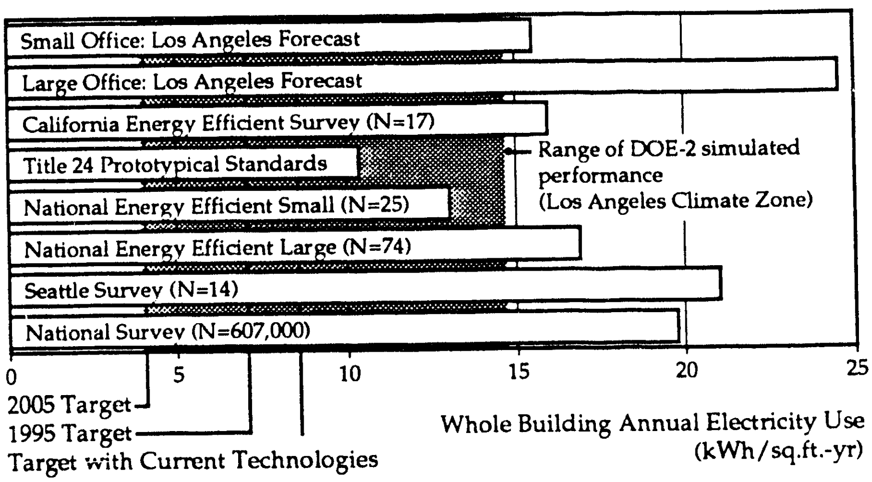

Figure 1: Preliminary "targets" with existing data (studies by others) and code benchmarks.

ANALYSIS OF ENERGY USE IN BUILDING SERVICES OF THE INDUSTRIAL SECTOR IN CALIFORNIA

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ABSTRACT

Energy use patterns in many of California's fastest-growing industries are not typical of those in the mix of industries elsewhere in the U.S. Many California firms operate small- and medium-sized facilities, often in buildings used simultaneously or interchangeably for commercial (office, retail, warehouse) and industrial activities. In these industrial subsectors, the energy required for "building services" to provide occupant comfort and necessities (lighting, HVAC, office equipment, computers, etc.) may be at least as important as the more familiar process energy requirements — especially for electricity and on-peak demand.

This project has two components: analyzing existing data and conducting case studies of industrial facilities. We have compiled and analyzed published or unpublished information on energy use for building services in the industrial sector (Akbari et al 1991). Seven different sources of information and data relevant to California have been identified. Most of these are studies and/or projects were sponsored by DOE, the CEC, and local utilities. The objectives of these studies were diverse; most focused on industrial energy use in general, and in one case, the objective was to analyze energy use in commercial buildings. Only one of these studies focused directly on nonprocess energy use in industrial buildings.

Comparison of the findings of these studies and/or databases is difficult because of the varying objectives of the studies, the reported data format, the way data are aggregated in each study, the varying coverage of industries in each study, and the problem of comparing data from different time periods. The most relevant information for California comes from two studies using data from the U.S. Census Bureau Census of Manufacturers and on-site audit information collected in Northern and Central California during 1981-1984. Although all studies addressed different objectives, focusing on different areas, time periods, and industries, they all pointed to the importance of nonprocess energy use in industry as an area for potential conservation. The situation is even more promising for California where industries like instrumentation and computer manufacturing are concentrated; these industries consume most energy for air conditioning and lighting.

One study approximated building nonprocess energy use to be 15% of total industrial energy use for the U.S.: 84% was used for space heating, 8% for air conditioning, and 8% for lighting. Another study estimated a similar overall percentage (15.3%) for industrial nonprocess energy use, but 17% of that went for lighting, 31% for air conditioning, and 52% for space heating. Also, a national study for the manufacturing sector estimated that 17% of purchased energy used in 1972 in that sector went for space conditioning and lighting.

Our analysis of Northern California data for five selected industries, namely, electronics, instruments, motor vehicles, meat packing, and frozen fruits, shows that the contribution of total electricity consumption for lighting ranges from 9.5% in frozen fruits to 29.1% in instruments: for air conditioning, it ranges from nonexistent in frozen fruits to 35% in instrument manufacturing (Figure 1). None of the five industries selected had significant electrical space

heating. Gas space heating ranges from 5% in motor vehicles facilities to more than 58% in the instrument manufacturing industry.

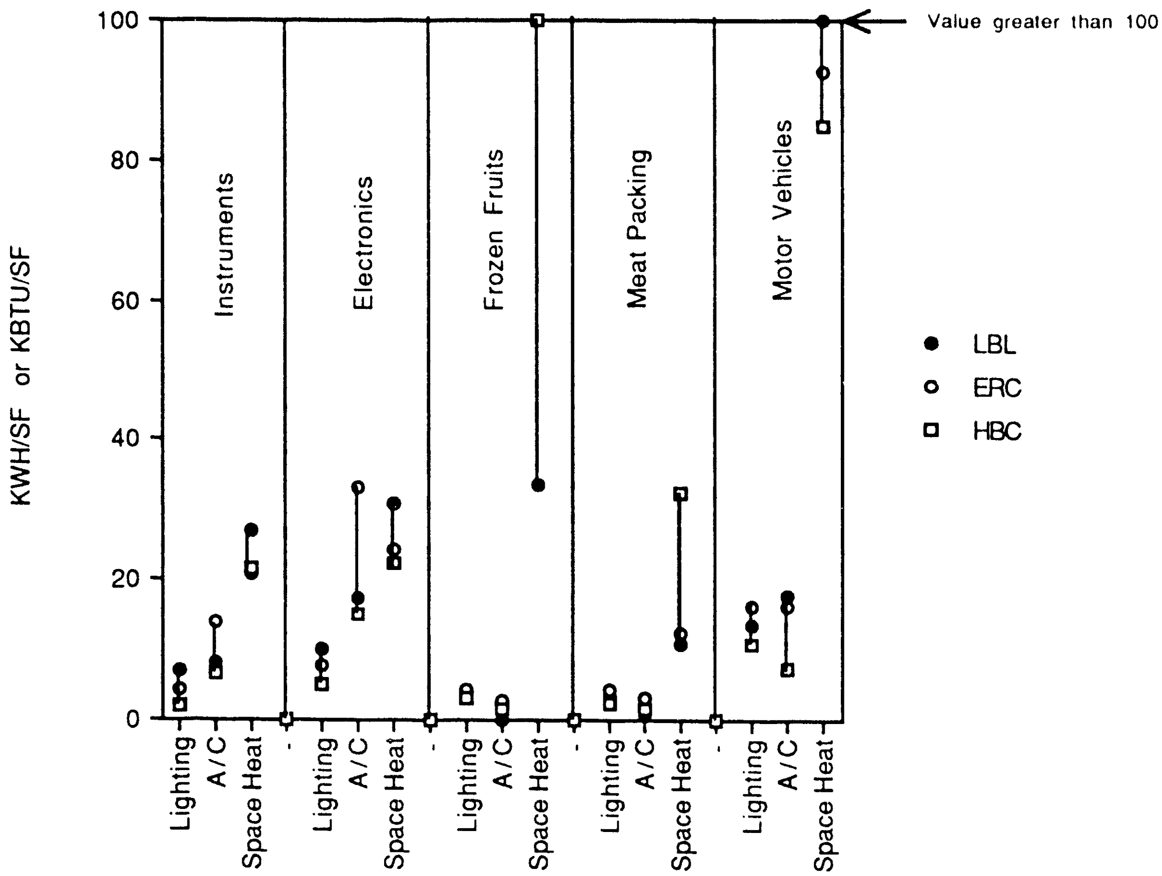

Figure 1. Electricity and Gas Use Intensities for Five Selected Industries in California. "LBL" indicates our analysis of the PG&E industrial database, "ERC" —Energy Resources Consultants, Inc.— indicates the analysis of California data prepared for the CEC, "HBC"—Hagler, Bailly & Co.— indicates the analysis of national data prepared for DOE. Source: LBL Report LBL-29749 (1991).

In order to better characterize the energy use for building services, two industrial facilities were selected for in-depth case studies. The case studies involved interviewing the building owners and the officials of the manufacturing facilities, conducting energy audits of the facilities, and performing simulations and parametric studies to identify the energy conservation potential in these facilities. The results of the two case studies confirm our earlier findings that energy use in the building services constitute a significant portion of the total energy consumption of these facilities.

References

Akbari, H.; Borgers, T.; Gadgil, A.; Sezgen, O. (1991). "Analysis of energy use in building services of the industrial sector in California: A literature review and a preliminary characterization," Lawrence Berkeley Laboratory Report LBL-29749.

MARKET POTENTIAL OF ALTERNATIVE TRANSPORTATION FUELS

Subproject of the Assessment of Natural Gas and Electric Vehicles Project

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ABSTRACT

BACKGROUND

Motor vehicles account for about half the hydrocarbon and nitrogen oxide emissions, about 30% of the greenhouse gases, over 80% of the carbon monoxide, and over half the petroleum consumed in California. The goal of the overarching multiyear research project is to identify and evaluate transportation end-use technologies and strategies that contribute to the cost-effective reduction of air pollution and greenhouse gas emissions in California's urban and rural areas. We focus on vehicles powered by natural gas and electricity, but also include methanol in the study.

SUBPROJECT

This subproject researches the potential demand for electric and natural gas vehicles in the passenger vehicle market in California. Several studies have been conducted on this topic in the U.S. and elsewhere, but they are either out-of-date, methodologically-suspect, or not relevant to California. The problem is that consumers have not had experiences with vehicles that have shorter driving ranges and different refueling characteristics than gasoline vehicles.

Essentially, three methodological approaches may be used to address this problem of estimating demand for a product for which consumers have no experience: 1) stated preference surveys whereby consumers are asked under what conditions they would purchase the new fuel or vehicle, 2) revealed preference surveys of consumers in analogous or experimental situations, and 3) market niche studies in which the attributes of the new products are matched with the attributes and patterns of consumers. We are employing all three methods in this study.

As summarized below, we have completed a market niche study that identifies what proportion of the population has work-trip lengths that can be met by electric vehicles and what proportion lives in residences that are suited to home recharging of electric vehicles. We have also completed the first part of a study that uses stated preferences, but in a more creative and insightful fashion than has been done before. Before posing hypothetical questions about vehicle purchase, we gave individuals the opportunity to test drive the vehicles (on the Rose Bowl grounds) and then provided them with information about the vehicles and fuels. Only then did we convene focus groups. Later, we will follow up with random sample surveys and create "permanent" panel groups that follow individuals over time to understand decision processes better in a dynamic sense.

ACTIVITIES COMPLETED (WITH PUBLICATIONS) AND IN PROGRESS

1. Development of a theoretical framework for studying consumer demand for alternative fuels — in terms of the decision-making process of individuals, as well as the specification of market segments including free riders, short-distance commuters, etc. (publications 1 and 2 below).

2. Test clinic at the Rose Bowl in which 300 randomly-selected individuals test drove a selection of 16 electric, natural gas, and methanol vehicles, followed up by ten focus group interviews and subsequent household interviews (publication 3).

3. Empirical evaluation using national survey data of house infrastructure and trip length constraints to electric vehicle market penetration (publication 4).

4. Telephone survey of current electric vehicle owners in California and owners of natural gas vehicles and home refueling units in Canada, to study their time-of-day recharging patterns, differing travel patterns, and valuation of home refueling.

REPORTS AND PAPERS TO DATE

1. T. Turrentine and D. Sperling, "Theories of New Technology Purchase Decisions: The Case of Alternative Fuel Vehicles," Procs., Intl Conference on Travel Behavior, Quebec, May 1991.

2. D. Sperling, "From Free Riders to Moral Buyers: The Market for 'Green' Fuels and Vehicles," Procs. OECD/IEA Conference on Tomorrow's Clean and Fuel-Efficient Vehicle," Berlin, March 1991.

3. T. Turrentine and D. Sperling, "The Rose Bowl Test Clinic and Focus Group Study of Electric, Natural Gas, and Methanol Vehicles," Institute of Transportation Studies, University of California, Davis, Draft-September 1991.

4. K. Nesbitt, M. DeLuchi, and D. Sperling, "A Constraints Analysis of the Market for Electric Vehicles," Institute of Transportation Studies, University of California, Davis, Draft-September 1991.

IN-KIND AND OTHER CONTRIBUTIONS

1. UERG, $22,000 to fund telephone surveys noted in activity #4.

2. Electric, natural gas, and methanol vehicles loaned for one week for Rose Bowl test clinic by Southern California Gas, San Diego Gas & Electric, Los Angeles Department of Water and Power, Southern California Edison, City of Long Beach Gas and Power, Solectrica, and California Air Resources Board.

3. About ten volunteers per day for one week at Rose Bowl from League of Conservation Voters, Coalition for Clean Air, and Automotive Service Council (worth $11,200).

4. Rose Bowl facilities provided free (worth $15,000).

5. Free extensive consultation with San Jose Focus, market research company (worth $400).

6. Payment by CARB for transport of two electric cars from the East Coast and payment of salary and travel for accompanying technician for use in Rose Bowl study (worth $15,000).

HIGH-ALBEDO MATERIALS FOR REDUCING BUILDING COOLING ENERGY USE

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ABSTRACT

As part of our research on urban climates and city-wide energy use, we have been studying the microclimate and energy use impacts of small- and large-scale albedo modifications. The impact of albedo has been analyzed through computer simulation and shown to be a powerful factor in near-surface microclimates. Our boundary layer simulations and DOE-2 analysis show that for every 0.01% increase in a residential building's albedo,† its cooling energy use drops by 0.3%, whereas for every 0.01% increase in the albedo of a building and its surroundings, the cooling energy drops by 3%. High-albedo urban areas can save 50% in cooling energy and 30% in cooling peak. In addition to saving energy, city-wide implementation of high-albedo materials can indirectly reduce emissions and man-made heat from power plants and building operation as well as minimize other adverse effects of the heat island phenomenon.

Until recently, however, we have not performed actual measurements of albedo to calibrate and validate these simulations. There is a need to field-measure the albedo of a variety of surfaces and to monitor the microclimatic effects associated with changes in this parameter. The objectives for this exploratory project are:

1. To develop a methodology for reliably measuring albedo in the field.

2. To correlate measured albedo changes with surface temperature reductions for a variety of surfaces.

3. To quantify the potential of high-albedo materials for reducing surface temperature and saving cooling energy and peak.

There are several types of high-albedo materials that can be used to reduce cooling energy requirements. At the building scale, roofs and walls can be treated with light-colored versions of paints, elastomeric coatings, single plies, concrete or asphalt shingles, gravel, and aggregates. At the urban scale, additional important surfaces include streets, highways, parking lots, schoolyards, and sidewalks. These can be treated with light-colored aggregates, whitetopping, light-colored slurry and chip seals, and artificial lighteners in cement and concrete pavements. In this exploratory study, we concentrate on modifying the albedo of roofs.

Following the objectives stated earlier, our measurements fit into three categories. The first involves generating an extensive library of albedo values for different surfaces and materials commonly found in the urban environment. We will thus obtain albedo values that we can readily and reliably use; published data, although extensive, are poorly documented and difficult to associate with environmental conditions. The second category involves correlating the changes in albedo to temperature reductions for selected surfaces and is essential in

† The albedo we refer to in this study is the wavelength-integrated reflectivity to solar radiation, which is predominantly in the 0.3-3.0 μm range.

developing guidelines for using albedo as an energy conservation strategy. The third category involves measuring the albedo and surface temperature of white roof paints and coatings to quantify their potential for saving cooling energy.

Our albedo measurements are performed with an Eppley Precision Spectral Pyranometer (PSP) that has a sensitivity of 0.28-2.8 μm. The PSP is mounted on a special stand that we designed based on tests of height-dependence in reflected radiation as measured by the pyranometer in the inverted position. The stand was also designed to cast a minimum shadow on the test area seen by the pyranometer and to occupy only a small portion of the inverted pyranometer's field of view. Surface temperature, on the other hand, is monitored with a non-contact, infrared radiometer (Raynger PM4) and averaged over a test area of about 43 ft^2 (4 m^2) centered at the pyranometer's location. Other variables, such as air temperature and wind speed are also noted, although they are not of central importance in this exploratory project. All measurements are taken under absolutely clear sky and low wind conditions. In the future, albedo measurements will be performed in variable weather and the correlations will be extended to include overcast skies and various meteorological conditions. For that purpose, accurate measurements of wind speed, air temperature, and cloud cover and type will also be made.

So far, we have tested two roofs for hourly albedo variations and the preliminary data indicate negligible variation with solar altitude. The albedo of a gravel roof narrowly fluctuated around a value of 0.09 whereas that of a white-painted roof fluctuated around 0.70. We are currently experimenting with other surfaces to determine the dependence of their albedos on solar angle.

With respect to the compilation of albedo values, we continue to generate a large amount of data for various surfaces. We have categorized these as: 1) parking lots, 2) residential streets, 3) vegetation (short), 4) sidewalks, 5) roof tops, 6) building walls, and 7) miscellaneous. To give examples, the field data we have collected so far in nearby locations indicate that parking lots have an average albedo of 0.10, residential streets of 0.12, short grass of 0.20, and light-colored sidewalks of 0.27.

In terms of correlations with surface temperature, the initial results we have are significant. For example, on a sunny spring day in Berkeley, when the noontime solar radiation at the surface reached 287 $Btu/hr.ft^2$ (905 W/m^2) and the surface albedo was 0.09 (for a built-up roof with gravel top), the surface temperature was 110°F (316 K). On another similar day, a white-painted roof with an albedo of 0.70 had a noontime temperature of about 76°F (297 K) whereas an adjacent bituminous roof with an albedo of ~0.06 was at 122°F (323 K). The air temperature at that time was 75°F (299 K).

In terms of monitoring high-albedo roof materials, we concentrate on white elastomeric coatings and rubber membranes (EPDM) because they are easy to apply on almost any roof type and are effective in increasing surface albedo. Samples of elastomeric coatings and EPDMs were obtained from different manufacturers and are being installed on an actual large and unobstructed roof for monitoring. The samples, each with an area of about 86 ft^2 (8 m^2) are tested side by side on the same roof, for similarity of environmental and substrate conditions. According to manufacturers' specifications, which we will verify in the field, these high-albedo coatings have initial reflectivities between 90% and 95% and weathered reflectivities between 78% and 90%.

We also are compiling information on material and application costs for white coatings and EPDMs and their potential for implementation. Our data so far indicate that contractor costs for white coatings range between $0.2 and $0.7 per ft^2 at an application rate of

1 to 2 gal/100 ft^2. The associated application costs are in the range of \$0.25 to \$0.50 per ft^2. For white EPDMs, the material cost is in the neighborhood of \$0.60 per ft^2 whereas the installed cost is about \$3 per ft^2. The average expected life for most white elastomeric coatings and EPDMs is 15 years.

There seems to be a great potential for application of white coatings and membranes on roofs, either as part of regular maintenance or on new construction. In 1990, the California roofing market (all types) was worth \$0.96 billion in commercial buildings (37.5% new construction and 62.5% reroofing) and \$0.15 billion in residential buildings (26.6% new construction and 73.4% reroofing). Virtually all types can be reroofed with high-albedo materials, but the easiest retrofits involve applying a coating or attaching a membrane. In our paper, we provide a breakdown of the roofing market by types and discuss the feasibility of applying white coatings and EPDMs.

CUSTOMER PARTICIPATION AND END-USE LOAD RESPONSE TO VOLUNTARY DSM PROGRAM

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ABSTRACT

THE ISSUE

Time-of-use (TOU) prices are usually offered to customers as an option in addition to standard (non-time-differentiated) rates. The impact of optional TOU rates on utility profits, revenue requirements, and social welfare depends on which customers choose TOU rates and the response of these customers to the rates.

ANALYSIS

We estimate models of the TOU consumption of customers as a function of the prices in each time period. These models extend and improve upon previous work in two interrelated ways:

1. The models explicitly incorporate the fact that customers choose between TOU and standard rates. Most previous studies have examined mandatory TOU rates, even though optional TOU rates are far more prevalent. The demand response of customers who choose TOU rates can be expected to be quite different from the response of all customers under mandatory TOU rates. The estimation procedure explicitly accounts for this fact by including terms in the demand equations that reflect the customers' choice of rates. The resulting model provides estimates of the demand elasticities of customers who choose TOU rates, customers who choose standard rates, and all customers combined.

2. The model explicitly incorporates the fact that different customers have different levels of demand and different price responses. Furthermore, these differences in demand parameters are what motivate some customers to choose TOU rates and others to choose standard rates when all customers face the same rate options. The model estimates the distribution of these parameters, extending previous work which estimated only the average parameters. This extension is important because the distribution of parameters, not simply the average, determines the impact of optional TOU rates.

APPLICATION

The model is used to calculate, for various TOU rate options, the percent of customers who will choose the TOU rates, the change in TOU consumption in response to these rates, and the change in revenues to the utility. Combining this information with marginal cost figures, TOU rate options are designed that increase utility profit and/or decrease rates, raise social welfare, and even appear to dominate the offering of standard rates alone (i.e., benefit some or all parties without hurting anyone.)

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