CBE

CENTER FOR THE BUILT ENVIRONMENT

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PREPARED FOR THE CALIFORNIA ENERGY COMMISSION

CIEE PROJECT AWARD NUMBER C-03-20

1.0 INTRODUCTION

This report has been prepared for the California Energy Commission as a the final deliverable (Task 4, item 7) under the CIEE Project, "Center for the Built Environment Cooperative Research Center," Award number C-03-20. The report summarizes results of multiple research areas at the Center for the Built Environment (CBE), over the term of this award, from October 2003 through September 2007.

1.1 BACKGROUND ON CBE RESEARCH

The Center for the Built Environment (CBE) at the University of California, Berkeley, provides timely, unbiased information on promising new building technologies and design techniques. This work serves CBE's industry partners, a consortium of leading building industry firms and organizations committed to improving the performance of non-residential buildings.

Our research has two broad purposes. First, our research team and industry partners are developing ways to "take the pulse" of occupied buildings, asking occupants what they like and don't like about the interior environment, and linking these responses to physical measurements of indoor environmental quality. Secondly, we are studying new building technologies, applications, and design strategies that hold promise for making buildings more environmentally friendly, more productive workplaces, and more economical to operate.

The Center operates under the National Science Foundation (NSF) Industry/University Cooperative Research Center Program. The Center is guided by an Industry Advisory Board (IAB) that meets semi-annually to discuss research findings and directions, review and approve annual budgets, and discuss ideas for future research. This Advisory Board provides valuable feedback which helps CBE focus its research on issues of relevance and importance to the building industry today.

Board meetings have been facilitated by an independent NSF evaluator to assure that the Center is responsive to its membership. Past evaluations have been highly favorable; during a recent Advisory Board meeting, CBE's evaluator reported that the industry evaluations showed "overwhelming support for the direction of CBE's research," and that the Center is "especially good at responding to industry partners' needs and desires."

2.0 RESEARCH OVERVIEW

The Center's portfolio of research projects has been developed based on industry partner needs, and represents relevant and timely topics in building science research. This research falls primarily into four interrelated areas, as outlined below. Projects are identified here as either *active* (those having a funded scope of work currently underway), or *complete* (designated scope of work complete). All projects are described in section 3.0 of this report, Research Goals and Outcomes.

2.1 BUILDING HVAC SYSTEMS

Mixed mode and underfloor air distribution (UFAD) systems provide opportunities for energy savings and benefits to occupants. UFAD technology has experienced rapid adoption due to the number of potential benefits it offers over conventional ceiling-based air distribution. With its broad research portfolio in this area, CBE has become the leader in UFAD research. CBE's HVAC research projects include:

- Radiant cooling scoping study ***COMPLETE***
- Radiant cooling design tools and applications assessment ***COMPLETE***
- UFAD ASHRAE design guide ***COMPLETE***
- UFAD building commissioning cart ***COMPLETE***
- UFAD case studies and project database ***COMPLETE***
- UFAD cooling airflow design tool ***ACTIVE***
- UFAD cost analysis model ***ACTIVE***
- UFAD energy performance case studies ***ACTIVE***
- UFAD field study of Capitol Area East End Complex ***ACTIVE***
- UFAD technology transfer ***ACTIVE***
- UFAD whole building energy modeling ***ACTIVE***

2.2 BUILDING ENVELOPE SYSTEMS

Building occupants in perimeter zones are affected by outdoor influences such as noise, temperature, and solar radiation, and by their ability to control these influences. CBE is developing tools and criteria for evaluating facade performance in terms of occupant comfort and energy efficiency. We have also conducted extensive field studies to determine how operable windows and control of building features affect occupant comfort. Research areas include:

- Case studies of mixed mode buildings ***COMPLETE***
- Control strategies of mixed mode buildings ***PHASE 1 COMPLETE, FUTURE PHASE FUNDED***
- Evaluation methods for facades and perimeter zones ***COMPLETE***
- Operable windows and thermal comfort ***COMPLETE***

2.3 INDOOR ENVIRONMENTAL QUALITY (IEQ)

CBE has developed methods to measure the performance of occupied buildings in terms of occupant comfort and productivity, energy efficiency, and operations. CBE's Web-based Occupant IEQ Survey quantifies how a building is performing from the perspective of its occupants. This provides immediate feedback for building owners and operators, and assists architects, engineers and builders in the development of future buildings. IEQ research project areas include:

- Using task-ambient conditioning systems to improve comfort and energy performance ***COMPLETE***
- Evaluating thermal comfort with radiant systems ***COMPLETE***
- UCB advanced thermal comfort model ***ACTIVE***
- Thermal comfort in stratified and asymmetrical environments ***COMPLETE***
- Occupant IEQ survey and building benchmarking database ***ACTIVE***
- Speech privacy in the workplace ***COMPLETE***

2.4 BUILDING INFORMATION TECHNOLOGY

New information technologies provide ways to optimize the performance of building systems. We are investigating applications for sensing and control of buildings using wireless communications technology, micro-electromechancial systems (MEMS), and Web-enabled software. The cost of installing wiring for controls and sensors in buildings may represent 50%-90% of the installed cost. With wireless and MEMS technologies we can greatly reduce this cost, enable energy savings, and improve the control of the indoor environment. Building IT research areas include:

- Demand-response technology development ***ACTIVE***
- Wireless lighting control prototype ***ACTIVE***
- Wireless sensing and control strategies ***COMPLETE***
- Using tenant interface systems to improve building operations ***COMPLETE***

3.0 INDUSTRY MEMBERS

CBE's partners are leading organizations across the spectrum of the building industry, including architects, engineers, manufacturers, builders, utilities, and governmental organizations. Member involvement frequently goes beyond participation in regular meetings, and many CBE projects directly involve member representatives, buildings, and resources.

As the Center is viewed by influential members of the building industry as a reliable and objective source for information about building technologies and performance, its membership has grown by 28% during the four-year period of this award. The Center currently includes the following firms and organizations:

1. Armstrong World Industries
2. Arup*
3. California Energy Commission
4. Charles M. Salter Associates
5. Cohos Evamy
6. CPP
7. EHDD Architecture
8. Engineered Interiors Group
9. Flack + Kurtz
10. Gensler
11. Haworth
12. HOK
13. Johnson Controls*
14. KlingStubbins
15. Pacific Gas & Electric Company
16. Price Industries
17. RTKL Associates
18. Skidmore, Owings & Merrill
19. Stantec
20. Steelcase
21. Syska Hennessy Group
22. Tate Access Floors*

    Taylor Team:

    23. Taylor Engineering
    24. CTG Energetics
    25. Guttmann & Blaevoet
    26. Southland Industries
    27. Swinerton Builders
28. Trane
29. U.S. Department of Energy*
30. U.S. General Services Administration*
31. Webcor Builders*
32. Zimmer Gunsul Frasca Architects

*founding partners

4.0 RESEARCH GOALS AND OUTCOMES

Here we provide detailed project descriptions with project goals, outcomes, and key reports and publications. (A complete list of reports and publications from the period of this award is included in section 5.0 of this report.) We include projects funded by CBE membership income, as well as from other sources. Many of CBE's projects were initiated with seed funding from CBE membership, and later expanded through additional funding from CBE's industry partners and other research grants and awards.

4.1 *RESEARCH AREA:* BUILDING HVAC SYSTEMS

4.1.1 RADIANT COOLING SCOPING STUDY

GOALS: Radiant cooling has gained recent popularity in Europe and Canada because it offers the potential to reduce cooling energy consumption and to reduce peak cooling loads when coupled with building thermal mass. The objective of this project was to characterize opportunities and limitations for radiant cooling strategies for North America and to identify research needs that CBE might fulfill. We determined the focus of radiant cooling research that will best leverage CBE capabilities to address the shortcomings of industry resources. Beyond this initial phase, the overarching goal of the project has been to facilitate optimization of radiant cooling design in terms of energy efficiency, cost effectiveness, thermal comfort, and integration with building envelope and mechanical systems.

OUTCOMES: We completed a review of relevant literature, case studies, design tools, web resources, and professional experiences with radiant cooling in North America. An overview of this work and generalized conclusions were distributed as an internal report to CBE's industry partners.

SELECTED REPORTS AND PUBLICATIONS: Moore, T., F. Bauman and C. Huizenga, 2006. "Radiant Cooling Research Scoping Study." Internal Report, April.

4.1.2 RADIANT COOLING DESIGN TOOLS AND APPLICATIONS ASSESSMENT

GOALS: This project focused on understand and report on radiant cooling design applications and simulations. This includes both potential system configurations and the simulation capabilities or methods for modeling them. Along with field studies, planned laboratory testing of chilled panels and surfaces, and related CBE work on thermal comfort for radiant cooling, this supports long-term goals of providing design guidance and contributing to the development of improved simulation and design tools.

OUTCOMES: We distributed an internal report which presents the findings of simulations comparing a range of possible radiant cooling system configurations. While not fully conclusive, these results are pointing toward strategies emphasizing radiant systems with natural ventilation or redundant airside capacity in climates with large numbers of airside economizer hours, and toward greater focus on waterside economizers and similar non-chiller or non-compressor sources of cooling supply water in other climates. This project has also led to discussions with CBE industry partner Price Industries for the development of a collaborative laboratory testing project to advance our understanding of radiant cooled ceilings in practice.

SELECTED REPORTS AND PUBLICATIONS: Moore, T., 2007. "Radiant Cooling Strategy and Application: Initial Simulation Results," Internal Report, October.

Moore, T., and F. Bauman, 2007. "Characterization of Simulation Tools for Radiant Cooling," Internal Report, October.

4.1.3 UFAD ASHRAE DESIGN GUIDE

GOALS: The objective of this project was to develop the Design Guide on Underfloor Air Distribution (UFAD) Systems. This research was conducted in collaboration with the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) as defined in the ASHRAE Research Project 1064-RP.

OUTCOMES: This project developed the first ASHRAE Design Guide on UFAD technology and made it available to the professional design and engineering community at large. The Design Guide was published by ASHRAE in December 2003 and is now available from the ASHRAE bookstore at http://resourcecenter.ashrae.org/store/ashrae/.

An ASHRAE Professional Development Seminar (PDS) on UFAD Design based on the Guide has also been developed and is offered frequently at ASHRAE meetings and other events.

SELECTED REPORTS AND PUBLICATIONS: Bauman, F, 2003. *Underfloor Air Distribution (UFAD) Design Guide.* Atlanta: ASHRAE, American Society of Heating, Refrigerating, and Air-Conditioning Engineers. 243 pp.

4.1.4 UFAD BUILDING COMMISSIONING CART

GOALS: The goal of this project was to develop and test an indoor environmental measurement platform with associated sensors and software for real-time evaluation of HVAC system performance. This commissioning (Cx) cart was designed with special capabilities suitable for detailed analysis of buildings with underfloor air distribution (UFAD) or displacement ventilation (DV) systems.

OUTCOMES: The cart was employed in the commissioning of the new 52-story New York Times (NYT) headquarters building in New York City. The system combined real time measurements with analysis based on emerging UFAD commissioning procedures while supporting the NYT's desired work flow. The use of the cart allowed the building commissioning team to identify and address HVAC operational problems. CBE fabricated a second version of the cart provided to the NY Times, which is now being used for new CBE field studies in UFAD buildings if a research effort sponsored by the U.S. General Services Administration.

SELECTED REPORTS AND PUBLICATIONS: Lehrer, D., 2007. "Delivering Buildings that Work: Commissioning at the New York Times", article for *Centerline*, Center for the Built Environment (CBE), University of California, Berkeley, pp 3-6, July.

4.1.5 UFAD CASE STUDIES AND PROJECT DATABASE

GOALS: The objective of this project is to develop a body of information to document completed buildings having underfloor air distribution (UFAD) systems, including a comprehensive database of UFAD buildings, a series of descriptive project profiles, and in-depth field studies. This project serves as a resource for all parties interested in developing a better understanding of successful designs as well as the barriers to implementation of UFAD systems.

OUTCOMES: Progress on this research includes the identification of approximately 500 UFAD projects in the U.S. and Canada, and documentation of their key characteristics. We have also conducted an on-line questionnaire to investigate trends and performance of a number of these buildings. Six project profiles have been completed and posted to CBE's underfloor technology website, two field studies have been completed, and several Summary Reports and Internal Reports have been produced and distributed to CBE industry partners. These resources provide objective information about systems design, operation, and performance as well as how designers have addressed practical issues and overcome limitations in the availability of design tools and product offerings. This information has been utilized by building owners, developers, designers, contractors, and manufacturers.

SELECTED REPORTS AND PUBLICATIONS: Hogan, M., T. Webster, and F. Bauman. 2006. "Understanding Design and Operation of UFAD Buildings." Summary Report, Center for the Built Environment (CBE), University of California, Berkeley, October.

Hogan, M., T. Webster, and F. Bauman. 2005. "Trends in Design and Operation of UFAD Buildings." Internal Report, October.

Fisk, W.J., D. Faulkner, D. Sullivan, C. Chao, M.P. Wan, L. Zagreus, and T. Webster, 2005. "Results of a Field Study of Underfloor Air Distribution." *Proceedings, Indoor Air 2005: 10th International Conference on Indoor Air Quality and Climate*, September, Beijing. Also available as LBNL-57098.

4.1.6 UFAD COOLING AIRFLOW DESIGN TOOL

GOALS: Design engineers often cite methods for airside design sizing as one of the most important unanswered questions regarding UFAD system design. Determining zone cooling airflows for UFAD systems to optimize energy and comfort performance requires consideration of significant differences between well mixed (i.e., overhead systems where the space air is mixed due to the action of the supply diffusers) and stratified UFAD systems. The goal of this project is to develop simplified, practical design procedures and associated software tools to determine cooling airflow requirements for underfloor air distribution (UFAD) systems in interior and perimeter zones.

OUTCOMES: A preliminary version of the design tool for interior zones was completed in early 2007 and was published in the *ASHRAE Journal*. This version has been distributed to CBE industry members for beta testing. This work allowed CBE to obtain additional funding work is ongoing to improve and refine the UFAD cooling airflow design tool. The final design tool will includes spreadsheet-based software with users manual, a perimeter zone model, improved guidance to account for plenum air leakage, and further validation by comparison with experiment and EnergyPlus/UFAD simulations.

SELECTED REPORTS AND PUBLICATIONS: Bauman, F., T. Webster, and C. Benedek, 2007. "Cooling Airflow Design Calculations for UFAD", *ASHRAE Journal*, pp. 36-44, October.

4.1.7 UFAD COST ANALYSIS MODEL

GOALS: Initial and life-cycle costs are major drivers in decisions regarding building mechanical systems. Accurate initial and life-cycle cost information is crucial to providing a sound basis upon which UFAD systems can be compared to alternatives. However this information is not readily available due to the multiple design factors that come into play in the design and integration of UFAD technology. The goal of this project is to develop a detailed underfloor air distribution (UFAD) cost model to allow for comparisons between UFAD and conventional systems, and evaluation of alternative UFAD system designs.

OUTCOMES: CBE created an analysis methodology and cost model structure, and studied alternative building and system designs to validate the model using data collected from completed projects. Detailed elements of each cost component were identified and reviewed with professional cost estimators. A UFAD first-cost model, which CBE distributed to industry members for use, is able to predict a range of costs for those elements of a building that are affected by an underfloor system, and allows for a comparison of underfloor to conventional systems. CBE is now working on the creation of the life-cycle cost (LCC) portion of the model. This model will have the capability of analyzing the four major input elements of the life-cycle model: churn, energy, maintenance and repair, and the tax savings associated with accelerated depreciation.

SELECTED REPORTS AND PUBLICATIONS: Webster, T., C. Benedek, and F. Bauman, 2006. "Underfloor Air Distribution (UFAD) Cost Study: Analysis of First Cost Tradeoffs in UFAD Systems." Report to U.S. General Services Administration, September.

4.1.8 UFAD FIELD STUDY OF CAPITOL AREA EAST END COMPLEX

GOALS: The objective of this project is to conduct a field study to compare the positive and negative impacts of underfloor vs. conventional air distribution in two new office buildings in the Capitol Area East End Complex in Sacramento. These two new office buildings completed by the State of California, designed with state-of-the-art "green building" design strategies, provide a unique opportunity to compare the performance of UFAD and other design strategies with the performance of a similar building with an overhead HVAC system. The new UFAD facility, designated as Block 225, is a 6-story office building, with UFAD on the top 5 stories, and a conventional overhead system on the ground floor. A similar building, designated as Block 172, was built with a conventional overhead system on all floors. The parallel building program for these buildings provides a unique opportunity for comparative analysis.

OUTCOMES: This is a long-range project, sponsored by the California Department of General Services (DGS), that has been conducted over a five-year period. The range of data to collected in this field study includes: (1) CBE's web-based occupant survey, (2) UFAD system design and operation specifications; (3) energy performance data; (4) monitoring of the physical environment using portable data-loggers and hand-held instruments; (5) cost data; and (6) productivity, absenteeism, and complaint log data. The relative impacts on occupants of UFAD technology in comparison to conventional overhead systems are being assessed by comparing the magnitude of the above described changes as well as post-occupancy data between the two groups. CBE produced a series of interim reports for DGS, and also identified a number of operational deficiencies in Block 225. GDS extended this research effort to allow CBE to support the recommissioning of the building. The final field study of the building is underway (September 2007) and will be issued to DGS at the end of 2007.

SELECTED REPORTS AND PUBLICATIONS: Shirai, R.., and F. Bauman. 2004. "Second Post-Occupancy Evaluation (POE) of Block 225: Capitol Area East End Complex." Interim Report to California State Department of General Services (DGS) and California Energy Commission (CEC), Center for the Built Environment (CBE), University of California, Berkeley, August.

Shirai, R., F. Bauman, and S. Abbaszadeh Fard, 2004. “Baseline Field Study of Block 172 -- Department of Health Services: Capitol Area East End Complex.” Interim Report to California State DGS and CEC, Center for the Built Environment (CBE), University of California, Berkeley, March.

Shirai, R., F. Bauman and L. Zagreus, 2003. “First Post-Occupancy Evaluation (POE) of Block 225: Capitol Area East End Complex.” Interim Report to California State DGS and CEC, Center for the Built Environment (CBE), University of California, Berkeley, August.

4.1.9 UFAD TECHNOLOGY TRANSFER

GOALS: CBE has learned from field studies and industry feedback that incorrect design, specification and/or construction of UFAD systems may be contributing to poorly performing buildings. CBE has made significant progress with its UFAD research, however a strong industry demand remains for the dissemination of these findings through multiple channels. This technology transfer program was developed to address these information needs by providing an unbiased description of UFAD technology. This project has two major objectives: (1) to develop and maintain the first website devoted to providing an unbiased source of knowledge on underfloor air distribution (UFAD) and related technologies; and (2) to provide technology transfer on UFAD design to CBE members and the building industry.

OUTCOMES: CBE research staff has produced numerous articles and papers on UFAD system design, and has presented dozens of lectures and intensive workshops at local and national ASHRAE events, and events sponsored by the USGBC, PG&E, BetterBricks, and many building industry firms. A list of CBE’s UFAD events is listed at www.cbe.berkeley.edu/underfloorair/events.htm. Many of CBE’s UFAD related publications are listed at http://www.cbe.berkeley.edu/research/publications.htm#hvac.

SELECTED REPORTS AND PUBLICATIONS: Webster, T., and F. Bauman, 2006. “Design Guidelines for Stratification in Underfloor Air Distribution (UFAD) Systems.” *HPAC Engineering*, June.

Bauman, F., T. Webster, and H. Jin, 2006. "Design Guidelines for Underfloor Air Supply Plenums." *HPAC Engineering*, July.

Bauman, F., 2006. "New Design and Operating Guidelines and Tools for UFAD Systems." HPAC Engineering Webcast Series, "New Ventilation Design Guidance and Tools: Underfloor Air, Outside Air, and Software Tools." March 1.

Webster, T, 2005. "Alternative Air Conditioning Technologies: Underfloor Air Distribution (UFAD)." chapter for *Energy Engineering*, eds. Wayne C. Turner. pp.58-77.

Webster, T., 2004. “Underfloor Air Distribution Systems,” *Proceedings*, *World Energy Engineering Congress*, *High Performance Facilities*, Austin, TX, September.

Bauman, F, 2003. “Designing and Specifying Underfloor Systems: Shedding Light on Common Myths.” *Heating/Piping/Air Conditioning Engineering*, Vol. 75, No. 12, December.

CBE’s UFAD Technology Website, online at: www.cbe.berkeley.edu/underfloorair/

4.1.10 UFAD WHOLE BUILDING ENERGY MODELING

GOALS: Until recently there have been few standardized methods and guidelines for designing and optimizing underfloor air distribution (UFAD) systems. The lack of whole-building energy calculation software for UFAD systems has resulted in buildings that do not optimize the potential benefits of these systems. The goal of this project is to develop underfloor air distribution (UFAD) system simulation software that can be used by design practitioners to model the energy performance of UFAD systems, optimize UFAD systems design, and to make accurate comparisons with conventional systems. This project is a multi-year, multi-institutional effort that will culminate with a validated UFAD modeling capability for EnergyPlus, the next-generation whole-building energy simulation program developed by the U.S. Department of Energy.

OUTCOMES: This project developed EnergyPlus/UFAD, a version the publicly available whole-building energy simulation program EnergyPlus that adds the capability for modeling underfloor air distribution systems. The project also developed a practical design tool for determining the cooling airflow quantity for underfloor air distribution systems. EnergyPlus/UFAD and the cooling airflow design tool are the first validated underfloor air distribution system tools of their kind. As such, they represent a significant advance in the state of the art of the design and energy analysis of such systems. This highly collaborative effort involved experts and facilities from four organizations, including the Center for the Built Environment at University of California, Berkeley; University of California, San Diego; Lawrence Berkeley National Laboratory; and York International.

SELECTED REPORTS AND PUBLICATIONS: Bauman F., T. Webster, P. Linden, and F. Buhl, 2007. “Energy Performance of Underfloor Air Distribution Systems,” Final Project Report for the California Energy Commission PIER Program, February.

Daly, A., 2006. "Underfloor vs. Overhead: A Comparative Analysis of Air Distribution Systems using the EnergyPlus Simulation Software." M.S. Thesis, Dept. of Architecture, University of California, Berkeley, August.

Bauman, F., H. Jin, and T. Webster, 2006. "Heat Transfer Pathways in Underfloor Air Distribution (UFAD) Systems." *ASHRAE Transactions*, Vol. 112, Part 2.

Jin, H., F. Bauman, and T. Webster, 2006. "Testing and Modeling of Underfloor Air Supply Plenums." *ASHRAE Transactions*, Vol. 112, Part 2.

Jin, H., F. Bauman, and T. Webster. 2005. "Testing and Computational Fluid Dynamics (CFD) Modeling of Underfloor Air Supply Plenums." Internal Report, October.

Bauman, F., H. Jin, and T. Webster. 2005. "Understanding Energy Flows in Underfloor Air Distribution (UFAD) Systems." Internal Report, March.

4.2 RESEARCH AREA: BUILDING ENVELOPE SYSTEMS

4.2.1 CASE STUDIES OF MIXED MODE BUILDINGS

GOALS: Mixed-mode refers to combining natural ventilation with air conditioning in the same building (e.g. operable windows in an air-conditioned office space) Mixed-mode strategies have the potential to offer "the best of all worlds," by using natural ventilation to provide occupant control, high ventilation rates, and reduced HVAC energy, while using air-conditioning to maintain comfort when necessary during temperature extremes. Designing effective mixed-mode buildings, however, presents a host of challenges for architects and mechanical engineers. The goal of this project is to develop a set of design recommendations for integrating operable windows with HVAC systems, and to develop a web-based library of mixed-mode building case studies, covering a range of climates, design approaches, and control strategies.

OUTCOMES: CBE launched its web-based library of mixed-mode buildings, including a database of approximately 200 buildings and eight case studies, in June 2006. Every case study includes a consistent set of basic information about the building and HVAC design, operation and control characteristics. This resources provided building designers and operators with successful examples of mixed-mode buildings, and information on real and perceived barriers to mixed-mode buildings.

SELECTED RESOURCES AND PUBLICATIONS: CBE's Mixed-Mode Website, online at: www.cbe.berkeley.edu/mixedmode/index.html

Weeks, K., D. Lehrer and J. Bean, 2007. "A Model Success: The Carnegie Institute for Global Ecology," Center for the Built Environment, University of California, Berkeley, May.

Brager, G., 2006. "Mixed Mode Cooling." *ASHRAE Journal*, pp. 30-37, August.

4.2.2 CONTROL STRATEGIES OF MIXED MODE BUILDINGS

GOALS: There are no standard protocols for the operations and control strategies for mixed-mode (MM) buildings, nor is there consensus about the relative degree of personal vs. automated controls that one should provide. There is also a lack of easily-accessible sources of information about the range of control options and the various building and climate conditions they can be used to address. The objective of this project was to study and document the operational control strategies for mixed-mode buildings, with a focus on: 1) developing a framework for understanding issues that guide the decision-making process, and 2) identifying examples of specific control algorithms used in existing buildings. We looked at buildings that use a combination of manual and automatic control of either the windows, or some component of the mechanical system, where the automatic control is in response to various indicators of both indoor and/or outdoor environmental conditions.

OUTCOMES: This project provided a conceptual model for the mixed-mode design decisions, with case study examples of buildings and control algorithms, and details about how these case studies fit into this model. This information will help designers and engineers to make informed decisions and to tailor building and HVAC systems to meet the needs of individual buildings, clients, climates, and budgets. Based on the results of the project, CBE is now working with LBNL to conduct energy simulations to quantify the energy savings potential of natural ventilation and MM strategies across California's 16 climate zones, examining both new construction and retrofits, giving special attention to the combination of natural ventilation and radiant slab cooling.

SELECTED REPORTS AND PUBLICATIONS: Brager, G., S. Borgeson, and Y. Lee, 2007. "Control Strategies for Mixed-Mode Buildings," Summary Report, Center for the Built Environment, University of California, Berkeley, October.

4.2.4 EVALUATION METHODS FOR FACADES AND PERIMETER ZONES

GOALS: High performance glazing products now available that allow architects to design facades with large areas of relatively transparent glass. As glazing areas expand, providing comfort within the glazed facade often becomes more problematic, since perimeter zones in buildings are subject to numerous thermal influences resulting in greater fluctuation of temperatures. The goals of this multi-phase project are to: (1) identify trends in occupant satisfaction in perimeter zones, (2) develop case studies of good-performing buildings, (3) create new evaluation methods and criteria to asses the effect of building facades on occupants, and (4) implement a new facades survey module in building with innovative facades.

OUTCOMES: In the first phase of this research, CBE proposed a method that may form the basis for a future National Fenestration Rating Council (NFRC) window comfort rating method, useful to both designers, manufacturers, and consumers. In the second phase of research CBE conducted an extensive analysis of occupant satisfaction using the existing CBE Occupant IEQ Survey database. (See below for details on this project.) This analysis revealed areas of interest that are particular to high-performance facades that are not adequately addressed in the CBE's occupant survey, and suggests new lines of inquiry that may be enriched through the incorporation of a facades survey "module." With the combined knowledge obtained from the analysis of the existing database and the case studies, we are developing a new module for the survey that will focus in on aspects of indoor environmental quality and operability that are unique to innovative facades and perimeter zones.

SELECTED REPORTS AND PUBLICATIONS: Huizenga, C., H. Zhang, P. Mattelaer, T. Yu, E. Arens and P. Lyons, 2006. "Window Performance for Human Thermal Comfort. Final Report to the NFRC," Center for the Built Environment (CBE), University of California, Berkeley, 91 pp., February.

Marcial, R., and E. Arens, 2004. "Evaluating Perimeter Zone Environments," Draft Summary Report, Center for the Built Environment, University of California, Berkeley, October.

4.2.5 OPERABLE WINDOWS AND THERMAL COMFORT

GOALS: Thermal environments in buildings with operable windows are typically more variable and less predictable than those in fully air-conditioned buildings. However, previous comfort standards such as ASHRAE Standard 55 are universally applied across all building types, climates, and populations. The goal of this project is to determine how the use of operable windows in office buildings affects occupants' thermal comfort and the acceptance of variable thermal environments.

OUTCOMES: This research has led to ASHRAE's adoption of a new thermal comfort standard (Standard 55-2004) that allows for more latitude in indoor temperatures for building designs which may addresses personal control, and thereby encourage energy-efficient building design strategies that respond to individuals' preferences and adaptability.

SELECTED REPORTS AND PUBLICATIONS: Brager, G.S., G. Paliaga, and R. de Dear, 2004. "Operable Windows, Personal Control and Occupant Comfort." *ASHRAE Transactions*, 110 (2), June.

Olesen, B. W. and G.S. Brager, 2004. "A Better Way to Predict Comfort: The New ASHRAE Standard 55-2004," *ASHRAE Journal*, August.

4.3 *Research Area:* Indoor Environmental Quality (IEQ)

4.3.1 ACOUSTICAL FIELD STUDY IN A UFAD BUILDING

GOALS: Architects, mechanical engineers, and facility planners are interested in underfloor air distribution (UFAD) systems because of energy conservation, flexibility and other potential benefits. These systems include multiple openings in a raised floor, and may include a variety of non-standard wall types. Consequently design professionals, building owners and tenants have expressed concerns about potential sound transfer between adjacent spaces, and the possibility of unacceptable speech privacy. The goal of this project is to quantify the sound transfer in an office environment in a building with a UFAD system, where acoustical performance is an important consideration.

OUTCOMES: The research team conducted a field study in a new office building with known wall types and acoustical detailing. Prior to final occupancy of the building, the researchers conducted acoustical tests between adjoining spaces in the building with differing acoustical requirements, which are described in five broad categories. The report documents that acoustical speech privacy can be provided in UFAD buildings when appropriate construction standards are followed. The project's summary report provides guidance to designers, builders, and property managers for UFAD buildings that require acoustical separation between rooms.

SELECTED REPORTS AND PUBLICATIONS: Salter, C.M., and R.D. Waldeck, 2006. "Designing Acoustically Successful Work Places: A Case Study Assessment of the Speech Privacy and Sound Isolation of Spaces Having Underfloor Air Distribution Systems." Summary Report, Center for the Built Environment, University of California, Berkeley, April.

4.3.2 USING TASK-AMBIENT CONDITIONING SYSTEMS TO IMPROVE COMFORT AND ENERGY PERFORMANCE

GOALS: Since the early days of air-conditioning, thermal comfort studies have focused on defining the temperature ranges that make people feel thermally neutral and that therefore avoid discomfort. However several recent studies suggest a new perspective to thermal comfort, looking at asymmetry and transience as more than just a disturbance of neutrality. The goal of this project is to quantify environmental conditions that are most promising for task-ambient space conditioning. By quantifying the effects of these conditions on comfort, we can propose new HVAC system designs and operating strategies. This fundamental human subject research may have a significant influence on peak electircal demand and energy conservation in buildings, and provide useful guidance to industry for the specification of building control systems.

OUTCOMES: CBE developed a prototype of the task-ambient conditioning system that allows occupants to adjust airflow to the area around their heads, and also heating and cooling around hands and feet. We conducted a series of randomized human subject tests in CBE's thermal chamber, including tests for dexterity and task efficiency, with and without the task-ambient system. CBE has completed an internal report on this research that will be distributed to industry partners in January 2008, and in engineering journals in spring 2008. We intend to target our findings to ASHRAE Standards 55 in order to enable a transformation in the building industry toward task-ambient conditioning systems.

SELECTED REPORTS AND PUBLICATIONS: Arens, E., 2007. "Assessment of Indoor Environments," *Proceedings, Roomvent 2007: 10th International Conference on Air Distribution in Buildings,* Helsinki, 13-15 June.

Zhang, H., E. Arens, S. Abbaszadeh, C. Huizenga, G. Brager, G. Paliaga, and L. Zagreus, 2006. "Air Movement Preferences Observed in Office Buildings." *Proceedings, NCEUB Windsor 2006 Conference,* Windsor, UK, April.

4.3.3 EVALUATING THERMAL COMFORT WITH RADIANT SYSTEMS

GOALS: Radiant cooling refers to any system where surrounding surface temperatures are lowered as means of removing sensible heat gain and thus contributing to thermal comfort. Some radiant systems circulate cool water in specialized panels, other systems cool the building structure (slab, walls, ceilings, and/or beams). These systems are being adopted in North America for their cooling energy efficiency and to reduce peak cooling loads. The primary objective of this research is to quantify the effects of radiant heating and cooling systems on occupants' comfort and acceptability, allowing the costs and benefits of the technology to be more comprehensively and fairly evaluated.

OUTCOMES: CBE's simulation and analysis provides quantitative design guidance for industry practitioners in the design of radiant cooled ceilings. We distributed an internal report to CBE industry partners, and are currently working on a second phase of this project, evaluating thermal comfort with radiant floors. This study will provide a complete analysis for the radiant floor for both heating and cooling, validating the existing data in the literature, and comparing with the standard.

SELECTED REPORTS AND PUBLICATIONS: Zhang, H., C. Huizenga, T. Yu, E. Arens, and T. Moore, 2007. "Evaluating Thermal Comfort with Radiant Systems," Internal Report, Center for the Built Environment, University of California, Berkeley, October.

4.3.4 UCB ADVANCED THERMAL COMFORT MODEL

GOALS: Buildings are currently designed to achieve comfort by creating static, uniform interior environments. In reality we know that neither indoor environments nor building occupants are static, and that the thermal environment experienced by an occupant in a building is often quite complex. The objective of this multi-project research area is to develop, refine and utilize a computer model of the human body that is sensitive to detailed thermal complexities around the body. The model includes the capability to model the indoor environment in detail, allowing for prediction of comfort and thermal perception, for the body overall, and for specific body parts.

OUTCOMES: This tool has been used in numerous applications in building science research. For example, we conducted studies on comfort stratified environments, as typically found in displacement and UFAD systems. We have also studied comfort implications of facades and glazing, and this may lead to the development of a new standard for use by window manufacturers and specifiers. We are beginning to integrate the model with energy simulation tools so advanced comfort analysis can become a standard part of energy simulation. We have also used the model to develop comfort rating systems for products such as windows and HVAC components, and in industry-sponsored thermal comfort testing in vehicles and subway stations.

SELECTED REPORTS AND PUBLICATIONS: Arens, E., H. Zhang, and C.Huizenga, 2006. "Partial- and Whole-body Thermal Sensation and Comfort, Part I: Uniform Environmental Conditions." *Journal of Thermal Biology,* 31, 53 – 59, March.

Arens, E., H. Zhang, and C.Huizenga, 2006. "Partial- and Whole-body Thermal Sensation and Comfort, Part II: Non-uniform Environmental Conditions." *Journal of Thermal Biology,* 31, 60 – 66, March.

Huizenga, C., H. Zhang, E. Arens, and D. Wang, 2004. "Skin and Core Temperature Response to Partial- and Whole-Body Heating and Cooling," *Journal of Thermal Biology* Vol. 29 (2004) pp. 549–558; and *The First Symposium on Physiology and Pharmacology of Temperature Regulation*, Rhodes, Greece, October.

Zhang, H., C. Huizenga, E. Arens, and D. Wang, 2004. "Thermal Sensation and Comfort in Transient Non-Uniform Thermal Environments." *European Journal of Applied Physiology*, Vol. 92, pp. 728–733. Previously presented at the *Fifth International Meeting on Thermal Manikins and Modeling,* Strasbourg, September 2003.

4.3.5 THERMAL COMFORT IN STRATIFIED AND ASYMMETRICAL ENVIRONMENTS

GOALS: Some HVAC systems–including UFAD, displacement ventilation and some radiant systems–achieve energy savings by conditioning the air in the occupied zone and allowing air higher up in the room to be warmer. Traditional methods of evaluating thermal comfort are not capable of considering such stratified thermal environments. Although the ASHRAE thermal comfort standard has prescribed limits to vertical asymmetry, it does not provide any means of comparing comfort between uniform and stratified conditions. The goal of this research is to utilize the CBE Thermal Comfort Model to assess the impacts on thermal comfort resulting from stratified environments common with today's advanced HVAC systems.

OUTCOMES: Our study challenged existing thermal comfort standards for temperature stratifications that were based on limited research. We found that spaces with stratified temperatures may provide comfort outside of the ranges allowed under current standards based on the overall temperature. Through the use of CBE's model, building designers can explore a wider set of solutions for more efficiently maintaining thermal comfort in buildings.

SELECTED REPORTS AND PUBLICATIONS: Zhang, H., C. Huizenga, E. Arens, T. Yu, 2005. "Modeling Thermal Comfort in Stratified Environments," *Proceedings, Indoor Air 2005: 10th International Conference on Indoor Air Quality and Climate*, Beijing, China, September..

4.3.6 OCCUPANT IEQ SURVEY AND BUILDING BENCHMARKING DATABASE

GOALS: While there has been considerable focus on measuring and regulating the resource efficiency of buildings, less attention has been paid to the issue of how well buildings meet their design intent for the occupants. Surveys of occupant satisfaction allow designers, developers, owners, operators and tenants to objectively gauge how well building services and design features are working. This information is especially useful to building owners and tenants interested in optimizing workplaces to improve employee productivity and effectiveness. The goal of this project is to develop and implement a Web-based survey tool that quantifies how a building is performing from the perspective of its occupants.

OUTCOMES: CBE developed a Web-based survey with an integrated, flexible branching structure, and automated, easy to understand reporting. Its branching structure allows for the collection of more detailed data where appropriate, without burdening all survey respondents with overly detailed or inappropriate questions. The survey focuses on seven areas of indoor environmental performance, including thermal comfort, air quality, acoustics, lighting, cleanliness, spatial layout, and office furnishings. Additional survey modules have been created to gather data on additional topics such as security, accessibility, transportation, and green building features.

Survey results are accessed via an advanced reporting tool. This reporting tool allows researchers, building owners and design teams to view and filter data to study specific questions and trends. They may also aggregate data for a collection of buildings to be sorted and viewed by specific attributes such as building type, region, square footage, or other characteristics. It also allows users to mine the survey data to investigate building performance trends.

The survey has been implemented in over 300 buildings to date, with over 40,000 individual occupant responses. Survey results have been used by dozens of architecture and engineering firms, and building owners wishing to assess and improve building operations. CBE is actively mining the database of survey responses to discover important trends in terms of building features which most strongly impact occupants' satisfaction and perceptions of their indoor environment.

SELECTED REPORTS AND PUBLICATIONS: Moezzi, M., and J. Goins, 2007. "Occupant Satisfaction for Ten Design Changes at JCK PBS Office." Summary Report for U.S. General Services Administration, Center for the Built Environment, University of California, Berkeley, October.

Abbaszadeh, S., L. Zagreus, D. Lehrer and C. Huizenga, 2006. "Occupant Satisfaction with Indoor Environmental Quality in Green Buildings." *Proceedings, Healthy Buildings 2006*, Vol. III, 365-370, Lisbon, Portugal, June.

Huizenga, C., S. Abbaszadeh, L. Zagreus and E. Arens, 2006. "Air Quality and Thermal Comfort in Office Buildings. Results of a Large Indoor Environmental Quality Survey." *Proceedings, Healthy Buildings 2006,* Vol. III, 393-397, Lisbon, Portugal, June.

Jensen, K., E. Arens and L. Zagreus, 2005. "Acoustic Analysis of Commercial Office Buildings Using Post Occupancy Evaluation Surveys," *Proceedings, Indoor Air 2005: 10th International Conference on Indoor Air Quality and Climate*, Beijing, China, September.

Zagreus, L., C. Huizenga and E. Arens, 2004. "A Web-based POE Tool for Measuring Indoor Environmental Quality." *Closing the Loop - Post Occupancy Evaluation: The Next Steps,* Windsor, UK, April 29-May 2.

Zagreus, L., C. Huizenga, E. Arens and D. Lehrer, 2004. "Listening to the Occupants: A Web-based Indoor Environmental Quality Survey." *Building Science: Papers from Indoor Air 14* (s8), 65-74.

4.3.7 SPEECH PRIVACY IN THE WORKPLACE

GOALS: Occupant surveys administered by CBE typically find that acoustics is the leading source of workplace dissatisfaction. This acoustic dissatisfaction is frequently related to speech privacy—overhearing unwanted conversations, or feeling that one is overheard. In one study of seven office buildings, as many as 72% of respondents were dissatisfied with speech privacy in their workplace. The objective of this project was to conduct a field study of acoustical conditions in office environments to test an industry-wide speech privacy prediction model known as the Speech Privacy Predictor (SPP).

OUTCOMES: We conducted occupant surveys to identify and characterize acoustical problems in several office figurations. Measured data was used to assess whether the complaints would have been predicted given the architectural design and the acoustical attributes of the office environments. We found that the measured results correlated closely with predicted results, and that actual survey results and anecdotal comments corresponded with what the SPP analytic procedure predicted. This report provides building designers with a validated method for predicting speech privacy levels in office environments, which may help the building industry to reduce the frequency of acoustical problems in the workplace.

SELECTED REPORTS AND PUBLICATIONS: Salter, Charles, K. Powell, D. Begault, and R. Alvarado, 2003. "Speech Privacy Complaints in Offices," Summary Report, Center for the Built Environment, University of California, Berkeley, January.

4.4 *RESEARCH AREA:* BUILDING CONTROLS AND INFORMATION TECHNOLOGY

4.4.1 DEMAND-RESPONSE TECHNOLOGY DEVELOPMENT

GOALS: The real cost of electrical production varies greatly with its constantly changing demand. During times of high demand load, typically during summer afternoons, the cost of production may be as much as ten times higher than when loads are lowest. However, residential energy users currently have little incentive to reduce energy use during high load times, and the high cost of peak energy production must be averaged among consumers. The goal of this project is to develop the technology needed to enable "demand responsive" (DR) systems that will allow for real-time pricing of electricity. We will develop and test components including real-time electricity meters, thermostats, and control devices for use in typical California homes.

OUTCOMES: The project has been a collaboration between faculty and students in the departments of Mechanical Engineering, Electrical Engineering, Computer Science, and Architecture, and four UC Berkeley research groups: the Center for the Built Environment (CBE), Berkeley Wireless Research Center (BWRC), Berkeley Sensor and Actuator Center (BSAC), and the Intel Research Laboratory at Berkeley. The team developed and tested a system capable of automatically adjusting a house's space-conditioning equipment to best manage the trade-offs between cost and comfort, with the capability of responding to dynamic energy pricing signals. The system is capable of advising occupants about when to use appliances (such as washers) or devices (such as shades) that cannot be automatically controlled. Many of the devices have been fabricated and field tested in a full-scale test house located near the Berkeley campus. The complete development of the system has been described in several detailed reports available to the building industry in an effort to push these new technologies and to allow wide adoption once the DR pricing is available to residential customers.

SELECTED REPORTS AND PUBLICATIONS: Do, A., W. Burke, D. Auslander, R. White, and P. Wright, 2007. "Technical Review of Residential Programmable Communication Thermostat Implementation for Title 24-2008," Draft Report Version 0.1, Center for Environmental Design Research, University of California, November.

Arens, E., et. al., 2006. "Demand Response Enabling Technology Development, Phase I Report: June 2003-November 2005, Overview and Reports from the Four Project Groups," Report to CEC Public Interest Energy Research (PIER) Program, Center for the Built Environment, University of California, Berkeley. 108 pp., April.

Federspiel, C.C., E. Arens, T. Peffer, and D. M. Auslander, 2004. "Design Concepts for Residential Demand Response Systems," submitted to *2004 ACEEE Summer Study on Energy Efficiency in Buildings*.

4.4.2 WIRELESS LIGHTING CONTROL PROTOTYPE

GOALS: Lighting energy accounts for nearly 50% of commercial building electricity consumption and represents 11% of California peak electrical demand (>5.4 GW). In many buildings, much of this energy use is a result of lighting that is on unnecessarily because of inadequate controls. Traditional wired switches are expensive to install, inflexible to changing requirements in the workplace, and unable to respond to available daylight or occupancy. Our objective with this effort is to develop and test a wireless lighting control system based on miniature, low-power radio network technology currently being developed at UC Berkeley. The system will be low-cost and appropriate for both retrofit and new construction, intended to produce significant energy and peak demand savings.

OUTCOMES: We built a prototype wireless lighting controller capable of switching commercial light fixtures on and off, and installed our prototype system in a UC Berkeley open plan office space in 2005. Occupants were given remote switches to control the lights over their workstations, and in a conference area and filing area. Over a period of two months, we measured a 65% reduction in lighting energy use compared with the pattern of use prior to the installation. In 2004 Adura Technologies was founded by CBE Research Specialist Charlie Huizenga and two former MBA students from UC Berkeley's Haas School of Business. Adura was one of five new companies to receive seed funding under California Clean Tech Open, a competition developed to spur investment in clean technologies. Adura received more than $100,000 worth of prizes, including $50,000 cash, legal and accounting services, public relations consulting, and office space. Adura has already completed a number of installations of its wireless system in UC Berkeley libraries, and is seeking additional funding to commercialize

PUBLICATIONS ON THIS PROJECT: "Lights Off," by Catriona Stuart, *California Magazine*, published by the California Alumni Association, May/June 2006

"Spotlight on Systems Research," by Ted Smalley Bowen, *Architectural Record*, June 2005

"UCB Center Wins Funding to Develop Wireless Lighting Controls," by Kathleen Maclay, *UC Berkeley News*, September 2004

4.4.3 WIRELESS SENSING AND CONTROL STRATEGIES

GOALS: The cost of running wire for sensors in buildings is 50%-90% of the cost of the sensor. Wireless communications could eliminate that cost. Combining wireless technology with MEMS technology could reduce the cost further, allow sensors to be embedded in products such as ceiling tiles and furniture, and enable improved control of the indoor environment. The objective of this project is to investigate the potential for applying micro-electromechancial systems (MEMS) sensor technology and wireless communication technology to the control of buildings.

OUTCOMES: This project is a collaboration with the Berkeley Sensor and Actuator Center (BSAC) and the Berkeley Wireless Research Center (BWRC), and is comprised of multiple related projects. The first phase of CBE activities included a demonstration of the sensing system installed in a building on the UC Berkeley campus, Cory Hall. This first phase of research included a network of 100 sensing "motes" in the building, and the design a PC-based control system that can control temperatures and lighting levels in one area of the building. Additional research development was sponsored through the NSF program, "XYZ On A Chip: Integrated Wireless Sensor Networks for the Control of the Indoor Environment In Buildings." For this collaborative research project we developed control algorithms to optimize occupant comfort and energy performance by using multiple sensing points for the control of both conventional and UFAD buildings. We also developed wireless air speed measurement technology (a wireless anemometer) with the ability to chart airflow throughout a building in order to optimize building performance

SELECTED REPORTS AND PUBLICATIONS: Arens, E., C.C. Federspiel, D. Wang and C. Huizenga, 2005. "How Ambient Intelligence Will Improve Habitability and Energy Efficiency in Buildings." chapter for *Ambient Intelligence,* eds. W. Weber, J.M Rabaey and E. Aarts, Springer. pp.63-80.

Tang, S., C. C. Federspiel, and D. M. Auslander, 2003. "Pulsed-Type Ultrasonic Anemometer Based on a Double FFT Procedure," *Proceedings, IEEE Sensors 2003*, October.

Federspiel, C. C. and J. Chen, 2003. "Air-Powered Sensor," *Proceedings, IEEE Sensors 2003*, October.

Wang, D. E. Arens, C.C. Federspiel, 2003 "Opportunities to Save Energy and Improve Comfort by Using Wireless Sensor Networks in Buildings," *Proceedings of the International Conference for Enhanced Building Operations*, Oct. 13-15, Berkeley, CA.

Tang, Shan, C. Federspiel and D. Auslander, 2003. "Pulsed Type Ultrasonic Anemometer Based on a Double FFT Procedure." *Proceedings for 2003 IEEE Sensors*, Toronto, Canada, October.

4.4.4 USING TENANT INTERFACE SYSTEMS TO IMPROVE BUILDING OPERATIONS

GOALS: Building occupants are a valuable source of information about how a building is performing. By examining trends in feedback from occupants, building operations can be improved by identifying and correcting improperly functioning systems. The objective of this study is to learn how information exchange between building occupants and facility management staff can be used to improve operations. We developed a web-based software allowing occupants to provide feedback to the building control system about building operation, and proposed strategies to handle feedback from occupants in a cost-effective manner. We estimate that by providing facility operations personnel with better information and by automating many of the functions that are currently performed manually, US commercial building operators could save more than $2 billion annually in complaint handling costs.

OUTCOMES: The research team developed and tested a web-based occupant feedback information system that interfaces with building control and maintenance systems. We used the GSA Energy and Maintenance Network (GEMNet) for testing. We call this application the Tenant Interface for Energy and Maintenance Systems (TIEMS). We also completed the design of a Maintenance and Operations

Recommender (MORE). MORE uses information from energy management control systems (EMCS) and computerized maintenance management systems (CMMS) to recommend what maintenance personnel should do in response to a service request from an occupant. CBE has published a number of articles and technical papers on complaint prediction, TIEMS, and the MORE system.

SELECTED REPORTS AND PUBLICATIONS: Villafana, L. and C.C. Federspiel, 2003. "Information Technology for Energy and Maintenance Management." *Proceedings of the International Conference For Enhanced Building Operations,* October 13-15, Berkeley, CA. 12 pp.

Federspiel, C.C. and L. Villafana, 2003. "Design of an EMCS/CMMS User Interface for Building Occupants." *ASHRAE Transactions*, 109(2).

Federspiel, C.C. and L. Villafana, 2003. "Design of a Maintenance and Operations Recommender." *ASHRAE Transactions*, 109(2).

Federspiel, C.C. and L. Villafana, 2003. "A Tenant Interface for Energy and Maintenance Systems." *CHI 2003 Conference on Human Factors in Computing Systems,* Fort Lauderdale, FL, April.

5.0 Reports and Publications, 2003-2007

5.1 CBE SUMMARY REPORTS

These reports are produced at the completion of a project. Draft Summary Reports are confidential and intended for Partners' review. Final Summary Report are provided to summarize the main points of the research for distribution to the public.

Do, A., W. Burke, D. Auslander, R. White, and P. Wright, 2007. "Technical Review of Residential Programmable Communication Thermostat Implementation for Title 24-2008," Draft Report Version 0.1, Center for Environmental Design Research, University of California, November.

Arens, E., et. al., 2006. "Demand Response Enabling Technology Development, Phase I Report: June 2003-November 2005, Overview and Reports from the Four Project Groups," Report to CEC Public Interest Energy Research (PIER) Program, Center for the Built Environment, University of California, Berkeley. 108 pp., April.

Brager, G., S. Borgeson, and Y. Lee, 2007. "Control Strategies for Mixed-Mode Buildings," Summary Report, October.

Salter, C.M., and R.D. Waldeck, 2006. "Designing Acoustically Successful Work Places: A Case Study Assessment of the Speech Privacy and Sound Isolation of Spaces Having Underfloor Air Distribution Systems." Summary Report, April.

Hogan, M., T. Webster, and F. Bauman. 2006. "Understanding Design and Operation of UFAD Buildings." Summary Report, October.

Heerwagen, J. and L. Zagreus, 2005. "The Human Factors of Sustainability: A Post Occupancy Evaluation of the Philip Merrill Environmental Center." Summary Report for U.S. Department of Energy, April.

Federspiel, Clifford, R. Martin and H. Yan, 2003. "Thermal Comfort Models and Complaint Frequencies,"
Summary Report, April.

Salter, Charles, K. Powell, D. Begault, and R. Alvarado, 2003. "Speech Privacy Complaints in Offices," Summary Report, January.

5.2 CBE INTERNAL REPORTS

These reports are technical summaries produced at interim points in a project for internal distribution, and reports for funding. They are confidential and are intended to provide our Partners with more detail than our Progress Reports.

Moore, T., and F. Bauman, 2007. “Radiant Cooling Strategy and Application: Initial Simulation Results,” Internal Report, October.

Moore, T., and F. Bauman, 2007. “Characterization of Simulation Tools for Radiant Cooling,.” Internal Report, October.

Zhang, H., C. Huizenga, T. Yu, E. Arens, and T. Moore, 2007. “Evaluating Thermal Comfort with Radiant Systems,” Internal Report, October.

Zhang, H., D. Kim, E. Buchberger, E. Arens, F. Bauman, and C. Huizenga, 2007. “Using Task-Ambient Conditioning (TAC) Systems to Improve Comfort and Energy Performance,” Internal Report, October.

Hui Moezzi, M., and J. Goins, 2007. “Collaboration and Its Discontents: Analysis of JCK Post-Renovation Survey Results.” Summary Report for U.S. General Services Administration, October 2007.

Moezzi, M., and J. Goins, 2007. “Occupant Satisfaction for Ten Design Changes at JCK PBS Office.” Summary Report for U.S. General Services Administration, October.

Brager, G., and Y. Lee, 2007. “Control Strategies For Mixed-Mode Buildings,” Internal Report, April.

Goins, J., and J. Thomas, 2007 Overview of Performance for Selected GSA Workplace 20.20 Buildings: Interim Report,” March.

Bauman F., T. Webster, P. Linden, and F. Buhl, 2007, “Energy Performance of Underfloor Air Distribution Systems,” Final Project Report for the California Energy Commission PIER Program, February.

Huizenga, C., J. Thomas, T. Drew, N. Walter, and L. Edwards, 2007. “CBE/GSA Facility Management Assessment 2006 Delegated Buildings,” Report to US General Services Administration, December.

Webster, T., C. Benedek, and F. Bauman, 2006. “Underfloor Air Distribution (UFAD) Cost Study: Analysis of First Cost Tradeoffs in UFAD Systems.” Report to U.S. General Services Administration, September.

Moore, T., F. Bauman and C. Huizenga, 2006. “Radiant Cooling Research Scoping Study.” Internal Report, April

Zagreus, L., and J. Goins, 2006. "Using the CBE Occupant Survey To Assess Facility Management Performance in GSA Facilities, June-August 2005 Delegated Buildings." Report to U.S. General Services Administration, January.

Zagreus, L., C. Brown and E. Arens, 2006. "Occupant Thermal Comfort and Perceived Productivity in Three Office Buildings Participating in Auto-CPP Pilot Study." Summary report to the Demand Response Research Center, April.

Hogan, M., T. Webster, and F. Bauman. 2005. "Trends in Design and Operation of UFAD Buildings." Internal Report, October.

Huizenga, C., H. Zhang, P. Mattelaer, T. Yu, E. Arens and P. Lyons, 2006. “Window Performance for Human Thermal Comfort.” Final Report to the National Fenestration Rating Council (NFRC), 91 pp. February.

Jin, H., F. Bauman, and T. Webster. 2005. "Testing and Computational Fluid Dynamics (CFD) Modeling of Underfloor Air Supply Plenums." Internal Report, October.

Bauman, F., H. Jin, and T. Webster. 2005. "Understanding Energy Flows in Underfloor Air Distribution (UFAD) Systems." Internal Report, March.

Zagreus, L. and C. Huizenga, 2004. "WorkPlace 20•20 Pilot, Occupant IEQ Survey Results Summary: Discovery Process Surveys at 11 Sites." Draft Interim Report to U.S. General Services Administration, December.

Webster, T., F. Bauman, W. Lukaschek, D. Dickerhoff, 2004. "UFAD Perimeter Zone Preliminary Test Results." Internal Report, November.

Marcial, R., and E. Arens, 2004. "Evaluating Perimeter Zone Environments," Draft Summary Report, October.

Abbaszadeh Fard, S., L. Zagreus and C. Huizenga, 2004. "Using the CBE Occupant Survey To Assess Facility Management Performance in GSA Facilities, May-July 2004 Delegated Buildings." Report to U.S. General Services Administration, October.

Shirai, R.., and F. Bauman. 2004. "Second Post-Occupancy Evaluation (POE) of Block 225: Capitol Area East End Complex." Interim Report to California State Department of General Services and California Energy Commission, August.

Shirai, R., F. Bauman, and S. Abbaszadeh Fard, 2004. "Baseline Field Study of Block 172 -- Department of Health Services: Capitol Area East End Complex." Interim Report to California State Department of General Services and California Energy Commission, March.

Zagreus, L., and C. Huizenga, 2003. "Using the CBE Occupant Survey To Assess Facility Management Performance in GSA Facilities, May 2003 Pilot Test." Report to U.S. General Services Administration, August.

Shirai, R., F. Bauman and L. Zagreus, 2003. "First Post-Occupancy Evaluation (POE) of Block 225: Capitol Area East End Complex." Interim Report to California State Department of General Services and California Energy Commission, August.

5.3 CBE WEB RESOURCES

The following web sites contain material generated by CBE in order to provide industry partners and the industry at large about CBE research topics and findings.

CENTER FOR THE BUILT ENVIRONMENT HOME PAGE: www.cbe.berkeley.edu
The public portion of this site describes CBE and provides brief profiles of its ongoing research projects. The password-protected portion of this site is accessible to CBE's partners and research team, and contains internal reports, presentation materials from previous Advisory Board meetings, and brief summaries of articles of interest published in the popular media and research community.

UNDERFLOOR AIR TECHNOLOGY WEBSITE: www.cbe.berkeley.edu/underfloorair
This site provides an unbiased source of information on underfloor air distribution (UFAD) and related technologies. The site contains several write-ups and knowledge papers addressing the following issues: technology overview, thermal comfort and personal control, technology integration, UFAD design guidelines, and project profiles from select UFAD installations.

CBE INDOOR ENVIRONMENTAL QUALITY ASSESSMENT SURVEY : www.cbesurvey.org
This site describes the IEQ Web Survey, provides an on-line demo and a sample web report.

CBE MIXED MODE BUILDING WEBSITE: www.cbe.berkeley.edu/mixedmode
The purpose of this site is to provide detailed precedents that designers and building owners can learn from and use as examples, to help the building industry better understand of how naturally ventilated and mixed-mode buildings work in practice, and to learn how design teams have overcome barriers to implementation.

5.4 PUBLICATIONS

Papers that summarize research by CBE and affiliated institutions have appeared in the following journals, trade magazines, and conference proceedings.Many of these publications are also available from the eScholarship Repository, on-line at http://repositories.cdlib.org/cedr/cbe/

Arens, E., 2007. “Assessment of Indoor Environments,” *Proceedings, Roomvent 2007--10th International Conference on Air Distribution in Buildings,* Helsinki, June.

Weeks, K., D. Lehrer and J. Bean, 2007. "A Model Success: The Carnegie Institute for Global Ecology," Center for the Built Environment, University of California, Berkeley, May.

Zhang, H., E. Arens, S. Abbaszadeh, C. Huizenga, G. Brager, G. Paliaga, and L. Zagreus, 2007. “Air Movement Preferences Observed in Office Buildings.” Int J Biometeorol 51, pp. 349–360, January. Earlier version published in *Proceedings, NCEUB Windsor 2006 Conference*, Windsor, UK, April 2006.

Arens, E., and H. Zhang, 2006. “The Skin’s Role in Human Thermophysiology and Comfort.” *Thermal and Moisture Transport in Fibrous Materials,* Eds.N. Pan and P. Gibson, Woodhouse Publishing, London, 49 pp.

Brager, G., 2007. “Learning from Experience,” *Frameworks*, College of Environmental Design, University of California, Berkeley, Spring.

Zhang, H., and E. Arens, S. Abbaszadeh Fard, C. Huizenga, G. Paliaga, G.Brager, and L. Zagreus, 2006. "Air Movement Preferences Observed in Office Buildings". *International Journal of Biometeorology*, 79. Also in *Proceedings, The 3rd Comfort and Energy Using in Buildings: Getting Them Right*, Windsor UK, April 27-30.

Brager, G., and C. Benedek, 2007. “Examining Rating Systems: A Look at Green Globes,” *AIA Cote Notes, Newsletter of the Committee on the Environment*,(Internet) March-April, http://www.aia.org/nwsltr_cote.cfm?pagename=cote_a_0703_GG.

Arens, E., and H. Zhang, 2006. "The Skin's Role in Human Thermophysiology and Comfort". *Thermal and Moisture Transport in Fibrous Materials*, Eds. N. Pan and P. Gibson, Woodhouse Publishing, London, pp. 560-602, October.

Brager, G., 2006. "Mixed Mode Cooling," *ASHRAE Journal*, pp. 30-37, August.

Daly, A., 2006. "Underfloor vs. Overhead: A Comparative Analysis of Air Distribution Systems using the EnergyPlus Simulation Software." M.S. Thesis, Dept. of Architecture, University of California, Berkeley, August.

Bauman, F., H. Jin, and T. Webster, 2006. "Heat Transfer Pathways in Underfloor Air Distribution (UFAD) Systems." *ASHRAE Transactions,* Vol. 112, Part 2.

Jin, H., F. Bauman, and T. Webster, 2006. "Testing and Modeling of Underfloor Air Supply Plenums." *ASHRAE Transactions,* Vol. 112, Part 2.

Bauman, F., T. Webster, and H. Jin, 2006. "Design Guidelines for Underfloor Air Supply Plenums." *HPAC Engineering,* July.

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