Industry/University Collaborative Research Center Prospectus
TODAY’S CHALLENGES TO THE BUILDING INDUSTRY

New technologies allow today’s buildings to be more efficient and responsive to occupant needs than ever before. A challenge to the building industry is to understand the opportunities offered by these new technologies and learning how best to apply them. In addition, detailed information on building performance rarely gets back to design and development teams, leading to a situation in which many building industry professionals make economic and design decisions with insufficient feedback from experience, or input from objective research.

In 1997 a group of industry and government leaders teamed up with faculty and researchers at the University of California, Berkeley to address these challenges. This effort led to the creation of the Center for the Built Environment (CBE), a collaborative research organization serving a consortium of firms and organizations committed to improving the performance of commercial buildings. Under the leadership of Director Edward Arens, CBE has grown and matured, and today CBE faculty, researchers and graduate students are actively involved in a wide range of projects of relevance to the building industry.

PRIMARY OBJECTIVES OF CBE

The Center has two broad purposes. First, our research team and industry partners are developing ways to “take the pulse” of occupied buildings - looking at how people use space, asking them what they like and don’t like about their indoor environment, and linking these responses to physical measurements of indoor environmental quality. This feedback is highly valuable those who manage, operate, and design buildings.

Secondly, we are studying technologies that hold promise for making buildings more environmentally friendly, more productive to work in, and more economical to operate. This helps our manufacturing partners to target their product offerings, and facility management and design partners to apply these new technologies effectively.

CBE’S ORGANIZATIONAL STRUCTURE

The Center operates under the National Science Foundation (NSF) Industry/University Cooperative Research Center (I/UCRC) program. The Center is guided by an Industry Advisory Board (IAB) that meets semi-annually to discuss research directions, approve annual budgets, and plan future research. During these meetings partner representatives provide CBE researchers with valuable comments, feedback, and knowledge gained from practical experience. These meetings are facilitated by an independent NSF evaluator to assure that the center is responsive and equitable to its membership.
BENEFITS OF MEMBERSHIP

As leaders in building technology research, CBE consortium members receive many immediate, practical benefits.

PARTNERING WITH DIVERSE INDUSTRY SECTORS
CBE represents industries across the full spectrum of building design, construction, and operation. The open exchange of information improves our partners’ ability to detect trends and opportunities, and generates opportunities for industry partners to develop business connections within the group. Partners may participate in semi-annual Industry Advisory Board meetings (up to 7 individuals per firm) and in related workshops on special topics.

OPPORTUNITY TO INFLUENCE THE DIRECTION OF RESEARCH
The CBE consortium is a rare opportunity for industry partners to direct research in directions that maximize benefits to their business. By identifying needs for information not being addressed elsewhere, partners can help define CBE research projects useful to their needs, while avoiding the costly investment for in-house research infrastructure.

TIMELY ACCESS TO RESEARCH RESULTS
Membership in CBE provides members with a window on current advances in science and technology that are relevant to their industry. Members receive quarterly updates on all active research projects, before this information becomes available publicly. This information broadens the knowledge capital that partners can use to serve their customers and clients.

ACCESS TO TRAINED PERSONNEL AND RESEARCH FACILITIES
CBE industry partners often recruit our specially trained graduate students who have been working on Center research projects. Industry partners also have access to CBE staff for questions about immediate problems, and access to the Center’s facilities. Partners also receive free implementations (4 per year) of CBE’s Occupant IEQ Survey, with access to CBE’s building benchmarking database.

COST-EFFECTIVENESS
By pooling membership fees, a company’s research investments will be increased 10-15 fold by leveraging other companies’ investments and federal and university resources.

CORPORATE RESPONSIBILITY AND COMMUNITY RELATIONS
Membership represents a commitment to improving the quality of buildings, and partners receive recognition in all of CBE’s publicity, publications, and websites. The UC Berkeley and NSF connections give CBE research a high level of credibility in the industry, increasing its acceptance in practice. Industry partners benefit from being associated with this research, and being able to use it to influence clients and regulators important to their business.
OUR INDUSTRY PARTNERS

CBE’s partners are leading organizations across the spectrum of the building industry, including design firms, manufacturers, builders, and governmental organizations.

The Center currently includes the following firms and organizations (as of October 2007):
- Armstrong World Industries
- Arup*
- California Energy Commission
- Charles M. Salter Associates
- Cohos Evamy
- CPP
- EHDD Architecture
- Engineered Interiors Group
- Flack + Kurtz
- Gensler
- Haworth
- HOK
- Johnson Controls*
- KlingStubbins
- Larson Binkley
- Pacific Gas & Electric Company
- Price Industries
- RTKL Associates
- Skidmore Owings and Merrill
- Stantec
- Steelcase
- Syska Hennessy Group
- Tate Access Floors*
- Taylor Team: Taylor Engineering,
  CTG Energetics, Guttmann & Blaevoet, Southland Industries,
  Swinerton Builders
- Trane
- U.S. Department of Energy (DOE)*
- U.S. General Services Administration (GSA)*
- Webcor Builders*
- Zimmer Gunsul Frasca Architects

*founding members

HOW TO JOIN CBE

Special cost sharing arrangements with the National Science Foundation and UC Berkeley allow CBE to reduce overhead and administrative costs to maximize partner investment in our research projects. As a result, standard annual membership fees of $35,000 provide partners with access to a research portfolio with annual funding of close to $1 million.

The Center staff and industry partners agree that the participation of leading architecture, engineering, and construction (A/E/C) firms is important to the Center’s success. Because research investment in these types of companies is generally modest, CBE has created two membership alternatives for them. One membership option allows the formation of teams, with up to five A/E/C firms, that share one $35,000 membership. Representatives of the firms from these membership teams may attend informational events at IAB meetings, but must choose one team member to serve as their voting representative. Alternatively, individual A/E/C firms may join with a $12,000 annual membership.

Partnership is obtained by signing a participation agreement with the University. To find out more about membership in CBE, please contact us at (510) 642-4950, by e-mail at cbe@berkeley.edu.
The core research group for CBE currently includes ten faculty and research staff members, supported by graduate students and research affiliates from Architecture, Building Science, Business, Construction Management, Electrical Engineering and Computer Science, Environmental Engineering, Environmental Psychology, and Lawrence Berkeley National Laboratory (LBNL). Core faculty and staff include:

**Edward Arens, PhD**, is Professor of Architecture at UC Berkeley. He received his PhD in Architectural Science from the University of Edinburgh, UK, and also holds a BA in architectural history and Masters degrees in Forestry and Urban Studies from Yale University. Prof. Arens started UCB’s Building Science Laboratory in 1980 after heading the Architectural Research Section at the National Bureau of Standards. His research interests are in building design and operation for comfort and energy conservation, building aerodynamics, and innovative building mechanical systems and controls. He is one of the lead faculty in CITRIS, UCB’s new Center for Information Technology Research in the Interest of Society, examining how information from physical sensors and from various types of occupant surveys can be combined to operate buildings more effectively. He has served in technical and standards committees of ASCE and ASHRAE, and is also a member of ASES, SBSE, and IFMA.

**Fred S. Bauman, PE**, is a Research Specialist with CBE. He received an MS in Mechanical Engineering from UC Berkeley, and a BS in Mathematics from Harvey Mudd College. His research interests include underfloor air distribution, thermal comfort, building energy, indoor air quality, and natural ventilation. He leads the development of CBE’s renowned research program on underfloor air distribution, and is the author of the Underfloor Air Distribution (UFAD) Design Guide, published by ASHRAE in 2003. He is an active member of ASHRAE, has chaired several technical committees, and has received two ASHRAE Best Symposium Paper Awards and the ASHRAE Distinguished Service Award.

**Gail S. Brager, PhD**, is Professor of Architecture at UC Berkeley. She received her PhD and MS degrees in Mechanical Engineering from UC Berkeley, and a BS in Mechanical and Environmental Engineering from UC Santa Barbara. Her research interests include thermal comfort and adaptive mechanisms, operable windows and ventilation in offices, climate-responsive building design, and curriculum materials development. Prof. Brager is a Fellow of ASHRAE, and a recipient of ASHRAE’s Distinguished Service and Nevins Awards. Gail has chaired several ASHRAE technical committees, has served as President of the SF Bay Area Golden Gate Chapter, and is a member of ASES and SBSE.
JOHN GOINS is a Research Specialist and lead researcher for CBE’s Occupant IEQ Survey. He was previously a developer of affordable housing and life sciences labs, and has researched the intersection of economics and social development. He holds a graduate certificate in Real Estate Development from the University of Southern California and an M.S. in Architecture from the University of California, Berkeley. His awards include the Zak Asefa Award in Architecture, Marshall School of Business Development Proposal Award and the Arcus Foundation Award. John was also a member of the winning 2006 Bank of America Low-Income Housing Challenge team, and is a member of the Urban Land Institute.

CHARLIE HUIZENGA is a Research Specialist and Lecturer in the Department of Architecture at UC Berkeley. He received a MS in Mechanical Engineering from UC Berkeley and a BA in Engineering Sciences from Dartmouth College. His research interests include building energy monitoring, design and operation of building energy systems, numerical modeling (building energy use, thermal comfort, and window optical and thermal properties), and software development. He is a member of ASHRAE, ASES, SBSE, and AEE.

HUI JIN, PHD, is an Associate Researcher with CBE. He received his PhD in Mechanical Engineering from Oklahoma State University in 2002. He also holds BS and MS degrees in Mechanical Engineering from Shanghai Jiaotong University, China. He has published journal papers on building mechanical systems and the development of EnergyPlus. From 1995 to 1998, he worked as an applications engineer at Carrier China and Carrier Malaysia. He is a member of ASHRAE and IBPSA.

DAVID LEHRER, LEED AP, is CBE’s Director of Partner Relations and Communications. He serves as the primary liaison between our industry partners and the research team, and leads CBE’s publicity and publication efforts. David holds an MArch degree from UC Berkeley and a BFA in Graphic Design from the University of Arizona. Prior to joining CBE, David acquired over 10 years experience as a practicing architect with Gensler’s San Francisco office. He is an adjunct faculty member at the California College of the Arts (CCA), and served as co-chair for the AIA San Francisco Chapter Committee on the Environment.
TOM WEBSTER, PE, is a Research Specialist with CBE. He received a BS in Mechanical Engineering from UC Berkeley. He has been engaged in building energy, controls, and communications for over twenty five years, focusing on building energy analysis and simulation, commercial and residential HVAC systems engineering, distributed control systems, and digital control product development. He also participates in the CEC High Performance Building Project, and the Federal Energy Management Program/New Technology Demonstration Program. Mr. Webster is an active member of ASHRAE.

HUI ZHANG, PHD, is a Research Specialist who is focusing on human thermal comfort modeling in building environments. She received a PhD in Building Science from the Department of Architecture at UC Berkeley in December 2003. In 2004 she received the ASHRAE Ralph Nevins Physiology and Human Environment Award. She received her Master of Engineering in the Architecture Department of Tsinghua University, Beijing, in 1986. Before coming to the United States in 1989, she taught at the Architecture Department of Tsinghua University as an assistant professor for three years.
FACILITIES AND PUBLICATIONS

The Building Science Laboratory at UC Berkeley is a unique facility, entirely dedicated to research on building performance, technology, and human-building interaction.

FACILITIES AT THE UNIVERSITY OF CALIFORNIA, BERKELEY

The Building Science Lab is now among the largest of such university laboratories in the world, with first-rate facilities for measuring and predicting the performance of buildings and their occupants’ responses. The major fixed facilities include a controlled environment chamber, a full-scale underfloor air test facility, a boundary-layer wind tunnel, and a sky simulator. Additional experimental facilities include instrumented “thermal mannequins” and two mobile environmental measurement carts. Each of these facilities has extensive instrumentation and data acquisition equipment. The Laboratory also has an extensive set of mobile and wireless measuring equipment for conducting field studies within operating buildings, and for micro-meteorological investigations outdoors.

Affiliated departments possess extensive experimental facilities, including Computer Science, Electrical Engineering, Environmental Engineering, Public Health, and the Lawrence Berkeley National Laboratory (LBNL). These facilities are available to CBE through the participating faculty and researchers from their respective departments.

REPORTS AND PUBLICATIONS

At the completion of a research project CBE produces Summary Reports to summarize the findings for distribution to the public. At least 60 days prior to public release of the reports, confidential drafts are distributed for industry partners’ review.

CBE also distributes to members Internal Reports—technical summaries produced at interim points in a project or in some cases in lieu of a Summary Report. They are confidential and are intended to provide our Partners with adequate detail on relevant research.

In addition, articles and papers that summarize research by CBE and affiliated institutions have appeared in journals, trade magazines, and conference proceedings. For a list of CBE’s publications, see CBE’s website at www.cbe.berkeley.edu/research/publications.htm.
OUR RESEARCH PORTFOLIO

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.

INDOOR ENVIRONMENTAL QUALITY (IEQ)

CBE has developed methods to measure the performance of occupied buildings in terms of occupant comfort, workplace efficiency, and building operations. Project areas include:

• Occupant IEQ survey and building benchmarking database
• Advanced thermal comfort model
• Thermal comfort in non-uniform environments
• The impact of team space on collaboration
• Speech privacy in office environments
• Acoustical field study in a UFAD building
• The impact of ventilation on productivity

BUILDING HVAC SYSTEMS

Advanced HVAC systems provide opportunities for energy savings and benefits to occupants. Relevant research at CBE includes:

• Radiant heating and cooling research
• UFAD simulations and laboratory testing
• ASHRAE design guide on underfloor air distribution (UFAD) systems
• Energy performance modeling of UFAD systems
• Performance of UFAD air supply plenums
• UFAD room air stratification (RAS) model development
• UFAD cost analysis study
• UFAD building case studies, project database,
• UFAD field study of Sacramento Capitol Area East End complex
• UFAD technology transfer program

BUILDING ENVELOPE SYSTEMS

CBE is developing tools and criteria for evaluating facade performance in terms of occupant comfort and energy efficiency:

• Operable windows and thermal comfort
• Case study research of mixed-mode office buildings
• Mixed-mode building control strategies
• Evaluating facade performance in terms of occupant comfort

BUILDING INFORMATION TECHNOLOGY

New information technologies provide ways to optimize the performance of building systems. Building IT research areas include:

• Development of a prototype wireless lighting control systems
• Demand-response technology development
• Using occupant feedback to improve building operations
**research area:**

**OCCUPANT INDOOR ENVIRONMENTAL QUALITY (IEQ) SURVEY AND BUILDING BENCHMARKING**

*Occupant surveys are an invaluable source of information regarding occupant satisfaction and workplace effectiveness.*

**OBJECTIVE**

Develop and implement a Web-based survey instrument that quantifies how a building is performing from the perspective of its occupants. Create a reporting tool to allow decision makers to benchmark individual buildings against groups of similar buildings in order to make informed management decisions, and to assess the effectiveness of building features and design strategies.

**SIGNIFICANCE**

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. Building occupants represent a wealth of information about how well a building works. The challenge is to collect and analyze this input in a systematic and meaningful manner.

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 employee productivity and effectiveness.

**APPROACH**

CBE has 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 current CBE survey focuses on seven areas of indoor environmental performance, including thermal comfort, air quality, acoustics, lighting, cleanliness, spatial layout, and office furnishings. It has been implemented in over 200 buildings to date, with over 25,000 individual occupant responses. 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.

We are implementing the survey for a number of private and institutional clients on an on-going basis to build up our database of building benchmarking data. We have also implemented the survey in LEED buildings in order to study the relative IEQ performance of these buildings in comparison to other buildings in the survey database.
**research area:**

**Occupant Satisfaction with IEQ in Green and LEED-Certified Buildings**

The LEED system is transforming the building industry, but little is known about occupant satisfaction in these buildings.

**Objective**

Study the performance of green and LEED-certified buildings in comparison to conventional buildings, in terms of occupant satisfaction with indoor environmental quality (IEQ).

**Significance**

The United States Green Building Council (USGBC) created a new framework for rating green buildings with its Leadership in Energy and Environmental Design (LEED) system. By early 2003, over 100-million square feet of buildings were undergoing the certification process through USGBC. The document has gone through three iterations and serves as a basis for a number of other rating systems, such as LEED for Existing Buildings (LEED-EB), and Commercial Interiors (LEED-CI). LEED’s environmental marketing appeal has been such that the Governor of California has mandated that all new and renovated state buildings acquire a rating of silver or higher.

With the success of the rating system, there is general agreement that LEED has brought sustainability into the mainstream of building design and construction. What is less clear is the extent to which it has actually reduced the negative effect of buildings on the environment, and/or improved indoor environments for the occupants of these buildings. Comprehensive post occupancy evaluation (POE) studies of LEED-certified buildings is needed to establish the success and shortcomings of the current LEED system, and to guide future editions.

**Approach**

We are studying occupant satisfaction with “self-assesed” green buildings and LEED-certified buildings, using CBE’s occupant IEQ survey tool and building benchmarking database. This database contains survey responses from over 200 buildings and 35,000 individual occupants, making it a useful measure for studying building performance. The survey consists of a set of core questions to assess occupant satisfaction with four main IEQ factors in the workspace—thermal comfort, lighting, air quality, and acoustics. The survey relies directly on occupants to obtain feedback about how they feel about their IEQ conditions in their space, and how it affects their effectiveness.

We compared survey results of these green and LEED-certified buildings with other buildings in CBE database. Building comparisons were done by ranking individual buildings based on their average scores in each of the four IEQ categories.

Based on the survey results, we will investigate the sources and influences contributing to the level of occupant satisfaction with IEQ in these buildings. A final product of this study will be proposed improvements to the IEQ category of future revisions of the LEED-NC rating system.
**research area:**

**ADVANCED HUMAN THERMAL COMFORT MODEL**

*A tool for predicting human comfort resulting from HVAC, building and facade design decisions.*

**OBJECTIVE**

Develop a computer model of the human body that is sensitive to detailed thermal complexities around the body. Include 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.

**SIGNIFICANCE**

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. In addition, new approaches to building conditioning require an advanced understanding of how occupants respond to thermal sensations in indoor environments. By better understanding occupant comfort in buildings, the building industry may increase revenues for building owners and tenants through improved employee health, satisfaction, and productivity.

**APPROACH**

The Advanced Thermal Comfort Model, originally developed by the Building Sciences Group at UCB for the evaluation of human comfort in automobiles, is one of the most sophisticated thermal comfort models in existence. It is capable of analyzing human thermoregulation and comfort responses in non-uniform, transient conditions. The model has been under development at UC Berkeley since the early 90s.

Recent progress includes the completion of a user interface with the ability to create a room with windows and place the occupant anywhere in the room. We have also developed a library of HVAC systems and creating a simple model for describing stratification and other non-uniform properties. This room model can import climate from EnergyPlus and calculate heat transfer between the occupant and the environment by convection, conduction, and radiation. The model is capable of evaluating the effects of solar gain through windows by calculating how much radiation is hitting the body and where. Based on the description of the environment, the model can generate graphic results such as skin temperature distributions, equivalent homogenous temperatures, and overall comfort indices.

This tool has 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. In the longer term, we plan to integrate the model with energy simulation tools so advanced comfort analysis can become a standard part of energy simulation, and develop comfort rating systems for products such as windows and HVAC components.
**research area:**

**THERMAL COMFORT IN NON-UNIFORM ENVIRONMENTS**

*Using the Advanced Thermal Comfort Model to study comfort implications of emerging green building technologies.*

**OBJECTIVE**

Utilize the Advanced Thermal Comfort Model to assess the impacts on thermal comfort resulting from stratified environments common with today’s advanced HVAC systems.

**SIGNIFICANCE**

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. CBE research has shown that UFAD systems can create conditions where the air at head level is as much as 4°C warmer than the air at the foot level. 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.

CBE’s Advanced Thermal Comfort Model is capable of evaluating comfort perception under asymmetric and transient thermal environments. This model provides not only local sensation and local comfort for 19 body segments, but it also integrates the local sensations to obtain the whole-body thermal sensation and overall thermal comfort.

**APPROACH**

Based on measured stratification profiles from UFAD, displacement ventilation, and radiant HVAC systems, we have used the CBE Advanced Thermal Comfort Model to predict thermal comfort over a range of stratified conditions. We created an interface in our model that allows users to conveniently define stratified conditions in a room. We varied the degree of temperature stratification, air velocity profiles, and overall temperature in these simulations. We also compared stratified air temperature to purely radiant cooling from below. Results indicate that occupant acceptance of stratified environments is more complex than current standards prescribe, and the amount of temperature diversity that is acceptable is highly dependant on the overall temperature. Initial findings have been distributed as Internal Reports to industry partners and submitted to technical journals.

Our future goal is to create guidelines and recommendations for maintaining thermal comfort under stratified conditions. Future phases of this project include chamber or controlled field validation studies to test stratification comfort under realistic office workplace conditions.
research area:

THE IMPACT OF TEAM SPACE DESIGN ON COLLABORATION

Assessing individual and group worker effectiveness in today’s new workplace paradigm.

OBJECTIVE

Study the impact of team workplace design on worker satisfaction and group collaboration. Conduct a review of existing team workspace design strategies described in the literature, and a detailed analysis of 12 case studies.

SIGNIFICANCE

Team workspace is a specific example of the alternative office that supports the activities of highly interactive, multi-disciplinary teams. A common design approach is to provide dedicated individual offices for concentrated work, combined with nearby shared open areas that support informal group collaboration. This strategy is typically motivated by new work models which emphasize higher levels of interaction and inter-dependency among self-directed workers who are responsible for complex and varied tasks.

This new way of working has called for a new kind of workplace, one that supports teamwork and de-emphasizes status. The workplace can either support or hinder this work process and affect a company’s ability to maintain a leading edge in their market. As a result, organizations around the world are rethinking their work environments either by redesigning existing offices or constructing new workspaces altogether. However, there have been few systematic efforts to quantify the beneficial (or detrimental) effects of these changes in office environments.

APPROACH

Sun Microsystems has incorporated team spaces in many of their office buildings to encourage more frequent, spontaneous, and informal collaboration among their workers. These buildings provided an excellent test site for CBE to investigate the effect of team space on workers’ interaction and satisfaction. A field study of team workspace configurations was conducted in five of Sun Microsystems’ West Coast office buildings. Using a modified version of CBE’s web-based survey tool, we investigated how the workplace design affected the nature and extent of team interaction, while also investigating other potential aspects of shared space such as visual and acoustic privacy, and the ability of building occupants to concentrate.

With the help of Dr. Judith Heerwagen, an environmental psychologist, we developed an overall conceptual framework for the project that builds on existing research and theory in environmental psychology (specifically spatial syntax, communications processes, and the cognitive and social structure of work and teams). Drawing on research in the fields of spatial syntax and communications processes, we evaluated how design features—including layout, degree of enclosure, acoustics, and visual access to people—inhibits or enhances the frequency and effectiveness of team interactions.
research area:  

**SPEECH PRIVACY IN OFFICE ENVIRONMENTS**

Validation of a method to predict speech privacy in a diversity of office environments.

**OBJECTIVE**  

Conduct a field study of acoustical conditions in office environments to test an industry-wide speech privacy prediction model. Use the findings of this analysis to suggest changes and/or modifications to the model as necessary.

**SIGNIFICANCE**  

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.

A speech privacy prediction model suitable for today’s open-plan workspaces would be valuable to architects, interior designers, and facility professionals, helping them to avoid costly mistakes when designing or furnishing workplaces. Forty years ago, W. J. Cavanaugh and his associates developed a practical model for predicting the acceptability of speech privacy in enclosed office environments. Acoustical engineering firms have used modified versions of this Speech Privacy Prediction model for design purposes, and found it to be a valuable tool. Since Cavanaugh developed this model, offices have been transformed by the introduction of cubicles with varying-height partitions. However, the model had not been formally tested and validated in the context of today’s offices, and this needed to be done before the model could become widely adopted as a design tool.

**APPROACH**  

The Speech Privacy Predictor (SPP) was evaluated in offices with partitions, telephones/speakerphones, common areas, team spaces, and widespread use of computers. Both open-plan and private offices were tested, and their physical characteristics carefully described. We conducted occupant surveys to identify and characterize acoustical problems in each office configuration. The 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. The final report is now available on CBE’s website at: www.cbe.berkeley.edu/research/publications.htm.
research area:

ACOUSTICAL FIELD STUDY IN A UFAD BUILDING

Verifying acoustical performance of as-built partitions and acoustical construction.

OBJECTIVE

Conduct a field study to quantify the sound transfer in an office environment in a building with an underfloor air distribution (UFAD) system, where acoustical performance is an important consideration.

SIGNIFICANCE

Architects, mechanical engineers, and facility planners are interested in 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.

Studies have shown that noise is probably the most prevalent source of annoyance in offices, and noise can lead to increased stress levels for occupants. Speech privacy may be an even more important design consideration than noise. Yet, acoustics, in most cases, does not receive the level of design attention as thermal, ventilation, lighting, and other architectural and engineering considerations.

APPROACH

For this project CBE is collaborating with Charles M. Salter Associates, consultants in acoustics, audio-visual system design, and telecommunications. The research team is utilizing a new office building with known wall types and acoustical detailing. Prior to final occupancy of the building, the researchers conducted 17 acoustical tests between adjoining spaces. The office spaces in the building have differing acoustical requirements, which fall into five broad categories.

The acoustical testing methodology follows the U.S. General Services Administration’s Workplace 20•20 testing protocol for private offices, “Field measurement of sound insulation in buildings.” The measurements were normalized to account for the furnished conditions. The source sound level, received sound level and background noise were tape recorded. The tape recordings were played back in our laboratory to measure the 1/3 octave band required as part of the testing protocol.

This study represents acoustical measurements in one building with an underfloor ventilation system designed to meet the needs of a particular client. Other plenum layout conditions, floor constructions, partition choices, room sizes and design considerations may yield different results. Future phases of this research may include additional field or laboratory studies to answer more generic questions with respect to the acoustical performance of UFAD systems.
OBJECTIVE
The objective of this research is to understand the relationship between indoor air quality and productivity with a controlled field intervention study. This two-part study was conducted in collaboration with the Indoor Environment Department at Lawrence Berkeley National Laboratory (LBNL).

SIGNIFICANCE
Over 90% of the total operating cost of commercial office buildings is attributed to the cost of employee salaries. Consequently even small improvements in productivity may result in significant cost savings. Previous studies demonstrated that simulated work performance declines when sick building syndrome (SBS) symptoms are present, and showed that simulated office work performance was negatively affected by an indoor pollution source. In this study we studied the effect of ventilation, indoor air quality, and other factors on work performance by analyzing existing data, and by conducting a controlled field intervention.

APPROACH
The study was conducted in a call center operated by an HMO where many work tasks have well-defined productivity metrics in place. The tasks included telephone triage performed by registered nurses, appointment scheduling performed by clerks, and data entry tasks performed by both kinds of employees. The productivity metrics are the times required to handle calls and to perform data-entry tasks. Using statistical methods, we investigated whether or not the ventilation rate was correlated with work performance while controlling for other variables such as temperature.

The first part of this study was an observational analysis of work performance metrics and other variables such as ventilation rate, temperature, and occupancy. Statistical correlations between these variables and work performance metrics were used to evaluate the effect of ventilation rate on performance.

The second part was a double-blind, controlled field intervention. We compared the code-minimum ventilation with one or more higher levels based on the findings from the observational analysis. Indoor air quality metrics were derived from laboratory analysis of air samples, and measurable disturbance variables such as temperature was recorded with portable data-loggers. Performance metrics were derived from the automated call distribution system in the call center. Findings from this project were presented in technical papers and in CBE Summary Reports that may be downloaded from CBE’s website at: www.cbe.berkeley.edu/research/publications.htm.
**Research Area:**

**Radiant Cooling Research Scoping Study**

Evaluating current design practices and research needs for a promising and rapidly evolving building technology.

**Objective**

Characterize the opportunities and limitations of radiant cooling strategies for North America, and identify research needs that CBE might help address. This work is planned as a multi-project research area.

**Significance**

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. Radiant cooling refers to any system where surrounding surface temperatures are lowered so that thermal comfort can be maintained at higher air temperatures. Generally speaking, a one degree reduction in surface temperatures can offset a one degree increase in air temperature. Some radiant systems circulate cool water in specialized panels; other systems cool the building structure (slab, walls, ceilings, and/or beams). Because the surface temperatures are often cooled only 2-4°C below the desired air temperature, there are many opportunities for innovative cooling sources such as night fluid cooling or ground-coupled heat pumps.

One disadvantage of radiant systems is that the surface temperature cannot be lowered below the dew point without causing condensation on interior surfaces that can lead to indoor air quality or maintenance issues. High performance buildings with lower cooling loads may offer better opportunities for radiant cooling applications. In addition, the limited cooling capacities of some low-energy cooling strategies such as displacement and natural ventilation can be extended when combined with radiant cooling.

**Approach**

For the first phase of this project we will conduct a literature search on modern radiant cooling systems, focusing on design issues, case studies and open research questions. We will also conduct interviews with industry professionals with expertise with these systems, including CBE partners, experienced designers, building operators, and researchers. We will distill our findings into a technical paper summarizing our assessment of radiant cooling applications in North America. As we review the material, we will look for potential areas in need of research. There are some natural fits between this study and existing CBE projects, including our UFAD and thermal comfort modeling research. The longer-term goal will be to define one or more bounded research projects to be considered for future funding through CBE or other sources.
**research area:**

**ASHRAE Design Guide on UFAD Systems**

*Peer-reviewed technical guidance for design teams and building operators*

**OBJECTIVE**

Develop an ASHRAE 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.

**SIGNIFICANCE**

UFAD technology is currently experiencing rapid growth in North America because of the broad range of benefits that it offers over conventional ceiling-based air distribution. Although in recent years there have been an increased number of publications on this technology, designers of UFAD systems previously had largely developed guidelines of their own. A comprehensive design guide that is accessible to the design and engineering community was needed to support the continued development and growth of this promising technology.

This project developed the first ASHRAE Design Guide on UFAD and TAC technology and made it available to the professional design and engineering community at large.

**APPROACH**

This project involves the evaluation and synthesis of an extensive body of knowledge that has been developed by UC Berkeley and affiliated research organizations over a period of close to 15 years. The development of the Design Guide was reviewed by CBE industry members and overseen by ASHRAE’s technical committee responsible for the project. Extensive comments and suggestions from industry were incorporated into the final version.

The Design Guide’s comprehensive contents includes chapters on air distribution, thermal comfort, underfloor plenums, controls, operation, maintenance, energy use, construction, commissioning, costs, perimeter systems, standards, codes, design methodology, and the LEED Rating System. The Guide also includes information on and Task/Ambient Conditioning (TAC) systems.


An ASHRAE Professional Development Seminar (PDS) on UFAD Design based on the Guide has also been developed and is offered periodically at ASHRAE meetings.
research area:  

**ENERGY PERFORMANCE MODELING OF UNDERFLOOR AIR DISTRIBUTION SYSTEMS**

*Development of the first tool to provide accurate whole-building modeling of the energy performance of underfloor systems.*

**OBJECTIVE**

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.

**SIGNIFICANCE**

Despite the growth of UFAD applications in North America, the technology is still in its infancy. There are few standardized methods and guidelines for designing and optimizing these systems, and whole-building energy calculation software now available does not allow for their accurate modeling. This slows the adoption of UFAD systems, and results in buildings that may not fully optimize the potential benefits of these systems. The availability of a whole-building energy modeling tool will help UFAD technology achieve its full potential by enabling the design of UFAD systems that are energy efficient, and effective in their performance.

**APPROACH**

This project is a three-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 to supercede DOE-2. The new UFAD capability will be suitable for designing and analyzing UFAD system performance.

For this project CBE is collaborating with UC San Diego, Lawrence Berkeley National Laboratory, and York International. This work is being jointly funded by CBE, The California Energy Commission, the U.S. Department of Energy, and York International. This project has been developed in three phases:

1. The development of a sound theoretical understanding of the behavior of UFAD systems by conducting laboratory bench and full-scale experiments. This work will be conducted at three test facilities: CBE’s full scale UFAD plenum test bed at UC Berkeley, the full scale room air stratification test chamber operated by York International, and the small-scale salt tank laboratory at UCSD.

2. Development of a validated mathematical models of the room air stratification (RAS) phenomenon and the thermal performance of UFAD supply plenums.

3. Integration of the RAS and plenum models along with system upgrades into the EnergyPlus whole-building energy simulation program. The final product will be a version called EnergyPlus/UFAD that can be used by design professionals and others to simulate UFAD system performance.

When the software development is complete, the project team will develop a technology transfer program to promote the adoption of the tool by industry.
research area:

PERFORMANCE OF UNDERFLOOR AIR SUPPLY PLENUMS

Providing specialized resources and knowledge required for proper design and operation of underfloor plenums.

OBJECTIVE

Develop design and specification guidelines to determine optimal system configuration and operating strategies for underfloor air distribution (UFAD) plenums. Include findings in UFAD technology transfer through industry publications, in UFAD technology website, and in CBE reports. Conduct full scale experiments to develop a validated version of the energy simulation tool EnergyPlus capable of modeling UFAD systems.

SIGNIFICANCE

CBE has learned from field studies and industry feedback that incorrect design, specification and/or construction of UFAD plenums may be contributing to poorly performing buildings. Such projects do not realize the full benefits possible with UFAD systems, and slow wider adoption of the technology. Industry practitioners require specialized knowledge to avoid potential problems related to thermal decay, leakage, and thermal comfort.

APPROACH

In this research area a number of full-scale field experiments have been conducted to investigate the airflow and thermal performance of underfloor air supply plenums. CBE maintains a full-scale UFAD test facility, consisting of a 22-foot by 74-foot by 1-foot high plenum. The test bed includes complete HVAC and data acquisition systems. CBE also utilizes computational fluid dynamics modeling to study plenum performance, including air flow and thermal transfer.

A combination of empirical full-scale experiments and computer simulations have been used to study: (1) thermal storage in the concrete slab; (2) heat transfer rate to the underfloor air flow; (3) air temperature variations across the plenum; and (4) heat transfer through the access floor. Tests have studied the minimum effective plenum height that allowed acceptable air flow performance in a pressurized underfloor air supply plenum, and the effect on thermal transfer in underfloor plenums in multi-floor buildings with stratified air temperatures. A simplified plenum model was also been developed to predict underfloor plenum thermal performance using the EnergyPlus energy simulation program.

Additional testing in the plenum test facility is investigating leakage issues, plenum inlet conditions, control issues, different diffusers and fan-powered underfloor mixing boxes, and practical construction and fabrication issues.

The research team for the UFAD and plenum projects has published findings from this research extensively in academic and trade journals, and has been involved in numerous conferences, workshops, and symposia.
research area:

UFAD ROOM AIR STRATIFICATION (RAS) MODEL DEVELOPMENT

Energy performance of UFAD systems can be greatly improved by optimizing the stratification of room air temperatures.

OBJECTIVE

Develop a simplified model that calculates the vertical temperature distribution for a underfloor air distribution (UFAD) system during cooling under various load conditions. Conduct full scale experiments to develop a validated version of the energy simulation code EnergyPlus that is capable of modeling UFAD systems.

SIGNIFICANCE

Design of UFAD systems is complicated due to thermal stratification effects, and therefore does not lend itself to a straightforward application of traditional design principles. Improper design can have a significant impact on thermal comfort, first costs, and energy performance.

For UFAD systems the temperature stratification in the space differs from the well-mixed room air conditions of conventional overhead air distribution systems, with implications for determination of air supply volume and air temperatures that affect occupant comfort. Ultimately this research will yield a model to be used as a simple design tool that will provide designers with a reliable method for sizing UFAD systems and contribute to the development of a UFAD module for the EnergyPlus energy simulation program. The effective prediction of room air stratification (RAS) may allow for significant energy savings in UFAD buildings.

APPROACH

In this project a simplified model is being developed to estimate thermal stratification in the occupied space as a function of air supply volume and heat loads (for cooling conditions) for both interior and exterior zones served by a UFAD system. The model is being developed from fluid mechanics principles derived from well developed displacement-ventilation theory, modified appropriately for the differences inherent in the UFAD approach. Detailed full-scale experiments have been conducted to support model development and verification and to better understand the impact of various design and operating conditions such as diffuser arrangements, supply air temperatures, and airflow rates.

CBE conducted detailed testing at the York Air Distribution Research Lab maintained by CBE partner York International in 2001-2003. This testing led to the preparation of several technical articles published in the *ASHRAE Journal* and other publications, and in reports distributed to CBE industry partners. The RAS model has been incorporated into the energy modeling tool EnergyPlus for UFAD.
research area:

**UNDERFLOOR AIR DISTRIBUTION COST ANALYSIS STUDY**

Addressing industry needs for an accurate method for comparing the costs of UFAD and conventional HVAC systems.

**OBJECTIVE**

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.

**SIGNIFICANCE**

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. A rigorous method is needed by the building industry to allow comparisons between standard overhead systems and the numerous UFAD design options now available.

**APPROACH**

CBE first conducted a preliminary UFAD cost study using input from industry partners. This initial study, completed in 2001, focused on first-cost comparisons and the development of an analysis framework. The result was a first-cost breakdown of major elements in the base building and tenant improvement work for three different UFAD office building prototypes. The study compared the UFAD building prototypes against a traditional overhead system, using a cost estimating database and other information supplied by industry partners. This and subsequent work demonstrated that several key factors affect the cost differential, and that the initial cost of UFAD systems could be comparable to, or slightly higher than, that of conventional systems.

The current research scope, funded by the U.S. General Services Administration (GSA), is a multi-year study to be conducted in three phases. In the first phase CBE investigated the cost analysis methods employed by several CBE industry partner firms. Based on the results of this investigation and the previously developed framework, we created an analysis methodology and cost model structure. In the second phase, CBE 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. The model is now able to predict a range of costs for those elements of a building that are affected by an underfloor system, and will allow for a comparison of underfloor to conventional systems.

The final phase of the project is the development of a model for life-cycle cost analysis. For this phase CBE will gather additional information related to the life-cycle costs, including commissioning, operations, energy, and churn. The final life-cycle analysis will be conducted using the UFAD EnergyPlus simulation program to generate energy data for UFAD buildings.
**UFAD BUILDING CASE STUDIES AND PROJECT DATABASE**

The study and documentation of current industry practices, design trends, success stories, and lessons learned.

**OBJECTIVE**

Develop a body of information to document completed buildings having underfloor air distribution (UFAD) systems. Build a comprehensive database of UFAD buildings, a series of descriptive project profiles, and in-depth field studies.

**SIGNIFICANCE**

Underfloor air distribution has proven to be an effective method of delivering conditioned air to localized diffusers in the occupied zone of the building. As more UFAD buildings are completed and occupied, there is a great opportunity to learn from the experiences of these projects in terms of occupant satisfaction, building operations, and whole-building performance.

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. It will 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 will be useful for building owners, developers, designers, contractors, and manufacturers.

**APPROACH**

In this project we have developed three levels of progressively more detailed information about existing UFAD projects: (1) candidate study projects are reviewed and added to our database along with their basic parameters; (2) project profiles are developed via site visits and interviews with project designers, owners, and facility managers; and (3) in-depth field studies are conducted on selected projects. The project profiles document and characterize underfloor system design issues and solutions, describe the operation of the system, evaluate the overall performance, and list noteworthy attributes discovered during the studies. The field studies focus in more detail on design and operation, and evaluate performance from on-site measurements, analysis of occupant satisfaction surveys, and analysis of energy usage.

Progress on this research includes the identification of over 250 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.
research area:

UFAD FIELD STUDY OF SACRAMENTO CAPITOL AREA EAST END COMPLEX

A detailed comparison of UFAD with conventional overhead systems in two high-performance office buildings.

OBJECTIVE

Conduct a field study to compare the positive and negative impacts of under-floor vs. conventional air distribution in two new office buildings in the Capitol Area East End Complex in Sacramento.

SIGNIFICANCE

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 330,000 ft² 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.

APPROACH

We have developed an overall methodology that will include occupant satisfaction surveys of the occupants for both buildings before and after their move into the new buildings. The range of data to be collected in this field study will be derived from: (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. A comparison of pre- and post-occupancy survey results will quantify differences associated with moving from the original buildings into the new State office building for each group. The relative impacts on occupants of UFAD technology in comparison to conventional overhead systems will be assessed by comparing the magnitude of the above described changes as well as post-occupancy data between the two groups.

This is a long-range project, sponsored by the California Department of General Services (DGS), that will be conducted over a four-year period. The UFAD building Block 225 was completed and occupied during June and August of 2002. The first post-occupancy evaluation (POE) involved physical measurements and occupant surveys in January 2003 (winter mode) was followed by a second POE in August 2003 (summer mode). Secondary building recommissioning was completed on Block 225 in the summer and fall of 2005, and CBE will conduct the final POE and energy studies in 2006.
Research Area:

UFAD Technology Transfer Program

Providing resources, training, and support for architects, engineers, and facility managers.

Objective

This project has two major objectives: (1) to develop and maintain the first website devoted to providing an unbiased source of knowledge on under-floor air distribution (UFAD) and related technologies; and (2) to provide technology transfer on UFAD design to CBE members and the building industry.

Significance

The number of UFAD systems being designed and installed is growing at an increasingly rapid rate, creating a growing need for a set of design tools and guidelines supported by fundamental and applied research. Although in recent years there have been a number of publications on UFAD technology, there still are still major gaps in resources and information.

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.

Approach

This project supports the continuous maintenance of CBE’s Underfloor Air Technology website, and efforts by CBE researchers to respond to the large number of requests for information on UFAD from CBE industry partners and the building industry at large.

CBE’s UFAD technology website went live on the Internet in the fall of 2000, with the URL www.cbe.berkeley.edu/underfloorair. The content of the website is organized into five main categories including fundamentals, design guidelines, case studies, and UFAD events. Future activities include the posting of new CBE reports on: (1) indoor air quality, and (2) a cost analysis of UFAD systems. We will continue to post new material to the site on an ongoing basis, including case studies, design guidelines, and new research reports.

CBE’s numerous articles on UFAD systems in the ASHRAE Journal, ASHRAE Transactions, and other publications have drawn many web users to the site. This underfloor website continues to provide a useful source of information for the building industry at large.

CBE staff also respond to regular inquiries from members of the building industry regarding correct design and operation of UFAD systems, UFAD benefits, and barriers to implementation. In addition, CBE staff provide regular UFAD training seminars and lectures at numerous industry events for engineers, architects, and facility management professionals.
**research area:**

**OPERABLE WINDOWS & THERMAL COMFORT**

*Building occupants with control of operable windows are comfortable in a wider range of conditions than prescribed by existing standards.*

**OBJECTIVE**

Determine how the use of operable windows in office buildings affects occupants’ thermal comfort and the acceptance of variable thermal environments. An application of this research will be the development of industry comfort standards that addresses personal control, and thereby encourage energy-efficient building design strategies that respond to individuals’ preferences and adaptability.

**SIGNIFICANCE**

Thermal environments in buildings with operable windows are typically more variable and less predictable than those in fully air-conditioned buildings. However, current comfort standards such as ASHRAE Standard 55 are universally applied across all building types, climates, and populations. This “one-size-fits-all” approach requires energy-intensive environmental control strategies to deliver stable, consistent temperatures, and can lead to excessive use of air-conditioning. Relaxed thermal standards for situations where people can open windows could result in greater energy efficiency.

Research over the last ten years clearly indicates that personal control affects people’s preferences, but we have no information on the extent to which such control affects the acceptability of varying thermal conditions. Research has also demonstrated that occupants of naturally ventilated buildings are comfortable over a wider range of conditions than occupants of air-conditioned buildings. This research explores whether thermal standards for situations where occupants have control of their environment should allow for a wider range of climatic conditions. This has particular relevance for encouraging widespread adoption of “mixed-mode” and natural ventilation strategies.

**APPROACH**

We conducted a field study to quantify the degree to which personal control of operable windows influences local thermal conditions and occupant response. We selected a building with diverse conditions in terms of centrally-controlled HVAC, operable windows, and stable vs. variable thermal conditions. Test methods included physical measurements and on-line occupant questionnaires that addressed personal control of windows, thermal variability, comfort, and window use patterns.

Our findings offer strong empirical confirmation for the role of shifting expectations in the adaptive model of thermal comfort. We found that occupants experienced similar thermal environments, independent of proximity to, and level of control they had over operable windows. Despite the similarity of conditions, their reactions were significantly different. Our findings reinforce the notion that the wider range of temperatures permitted under the new adaptive version of comfort standards will meet with occupant acceptance if those occupants have personal control of environmental conditions.
CASE STUDY RESEARCH OF MIXED-MODE OFFICE BUILDINGS

Studying the effectiveness of strategies which combine natural ventilation with conventional HVAC strategies.

OBJECTIVE

Develop a set of design recommendations for integrating operable windows with HVAC systems based on an initial field study. Later, develop a web-based library of mixed-mode building case studies, covering a range of climates, design approaches, and control strategies.

SIGNIFICANCE

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. Real and perceived barriers to mixed-mode buildings include general unfamiliarity with mixed-mode strategies, increased complexity in building operations and controls, fire and life-safety issues, energy codes, and humidity concerns associated with air-conditioned spaces that are not sealed.

APPROACH

The first phase of this project focused on investigating the issues of occupant satisfaction and control in four mixed-mode office buildings in Northern California. Each of these sites included air-conditioned office space where occupants have access to operable windows. Surveys were administered at each site to evaluate occupant satisfaction, operable window use, and occupant use of HVAC controls such as thermostats and adjustable air diffusers. Following the surveys, building operators and the building designers were interviewed to determine whether occupant response to the building met the operational and design intent.

The analysis of the field study made comparisons between each site, determining which design aspects of the building envelope and HVAC system were most successful in terms of occupant satisfaction and control. This study was published in Engineered Systems, May 2000, as “Mixed-mode Ventilation: HVAC Meets Mother Nature.”

In a subsequent phase of this research, we developed a web-based library of mixed-mode buildings, including a database of approximately 200 buildings and eight case studies. These case studies were created using existing information from publications, drawings and documents gathered from design firms, and from personal interviews. Every case study includes a consistent set of basic information about the building and HVAC design, operation and control characteristics.
research area:

EVALUATING FACADE PERFORMANCE IN TERMS OF OCCUPANT COMFORT

Creating new industry standards for window manufacturers, designers, and specifiers.

OBJECTIVE

Develop tools and criteria for evaluating facade performance with respect to occupant comfort and energy efficiency, and propose an analytical method for evaluating this impact. Create 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.

SIGNIFICANCE

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, as perimeter zones in buildings are subject to numerous thermal influences resulting in greater fluctuation of temperatures. Although available energy software tools may be adequate for predicting the effect of glazing on building energy performance, current tools are not useful for predicting comfort implications of facade designs. Consequently, design teams may not fully understand the full implications of facade design decisions.

METHOD

This project concentrates on the development of a method for building designers to make best use of the Advanced Thermal Comfort Model to assess thermal comfort in perimeter zones which experience thermal asymmetry due to the building envelope. Such a method would provide a standardized approach to quantify daily/monthly/yearly comfort in transient conditions under a variety of activity levels, clothing levels and environmental conditions. We have placed special emphasis on the way performance data is graphically represented to enable the user to understand the trade-offs they may be making in their design choice.

CBE researchers are developing a number of comfort metrics for possible inclusion into the future comfort standard. These metrics include a number of annual and point-in-time indices. Options include average comfort indices, number of hours inside/outside the comfort zone, and percentage of room floor area inside/outside the comfort zone.

As part of the development of this method, we upgraded the Advanced Thermal Comfort Model with enhancements that will improve its capability to model perimeter zone performance. The latest version of the Lawrence Berkeley National Laboratory (LBNL) Window software is capable of analyzing the thermal and optical properties of a wide variety of high performance glass types (including spectrally selective glass) and shading devices (including interior, exterior or between-glass venetian blinds). We will connect the modeling capabilities of Window with the CBE comfort model to accurately model facade interior surface temperatures and solar gain to enable the analysis of their impact on thermal comfort.
**research area:**

**DEVELOPMENT OF A PROTOTYPE WIRELESS LIGHTING CONTROL SYSTEM**

This low-cost system may lead to short payback periods for energy-saving lighting retrofits.

**OBJECTIVE**

Develop and test a wireless lighting control system based on miniature, low-power radio network technology currently being developed at UC Berkeley. Create low-cost a system that is appropriate for both retrofit and new construction, and could result in significant energy and peak demand savings.

**SIGNIFICANCE**

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. For example, many buildings have adequate daylight along the perimeter, but the installed switching is not adequate to turn off the unnecessary lights.

There are wireless lighting controls on the market, but each has its own specific limitations. Residential systems on the market tie a specific switch to a specific relay or relay channel, and do not provide the flexibility needed for commercial building applications. Commercial systems require that specialized ballasts be installed to replace existing ballasts, making them expensive and unlikely to be used in existing buildings. Our system would not require replacing existing fluorescent ballasts or fixtures—the control relay can be installed in a fixture in a few minutes. With the development of low cost components and simple installation, our system would have great potential for low-cost retrofit applications.

**APPROACH**

Our team is engaged in the design of low-power wireless sensor networks and their applications in buildings. We have already 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 July 2005. Occupants were given remote switches to control the lights over their workstations. In addition, we installed switches in a conference area and filing area. Over a period of two months, we recorded the use of lights with the wireless controls and have measured a 65% reduction in lighting energy use compared with the pattern of use prior to the installation. In addition, occupants were enthusiastic about having personal control over their lighting.

In the next phase of this project we will develop software to run the second-generation control network and allow for a number of operating strategies and user preferences. We will also configure a base computer to run software to communicate information to a network, allowing users to control lights from their desktops.
DEMAND RESPONSE ENABLING TECHNOLOGY DEVELOPMENT

Developing technology for tomorrow’s dynamic electricity-pricing systems.

OBJECTIVE

Develop the technology needed to enable “demand responsive” (DR) systems that will allow for real-time pricing of electricity. Develop and test components including real-time electricity meters, thermostats, and control devices for use in typical California homes.

SIGNIFICANCE

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 state of California is currently developing DR technologies that will allow for real-time pricing of electricity. This will enable utilities to charge rates that reflect the real cost of electricity production. Consumers will be able to save money if their electrical usage can respond to this real-time pricing. In addition, if residential buildings become demand responsive, California’s electricity supply and distribution system could become much more efficient and reliable. To develop this demand responsive capability, homes will have to be equipped with a new generation of electric meters, thermostats, and control devices.

APPROACH

This project is a collaboration between 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 DR system as envisioned would build on several of the latest wireless technologies currently in development at UC Berkeley, including miniature “motes” that consist of small sensors combined with wireless transmitters and independent power sources. These motes would be located throughout the house to communicate with heating and air conditioning systems, lights and other building systems. Additional motes could collect and transmit information on temperature, light levels, and other variables.

Our team is creating a system that reads real-time varying price signals, and automatically adjusts the house’s space-conditioning equipment to best manage the trade-offs between cost and comfort. The system will also be capable of advising occupants about when to use appliances (such as washers) or devices (such as shades) that cannot be automatically controlled. The devices have been field tested in a full-scale test house located near the Berkeley campus.
research area:

**USING OCCUPANT FEEDBACK TO IMPROVE BUILDING OPERATIONS**

A system to help facility managers utilize and respond to building occupant complaints.

**OBJECTIVE**

Study how information exchange between building occupants and facility management staff can be used to improve operations. Develop web-based software allowing occupants to provide feedback to the building control system about building operation. Propose strategies to handle feedback from occupants in a cost-effective manner.

**SIGNIFICANCE**

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. 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.

CBE is developing new, cost-effective methods for collecting and aggregating occupant feedback, as well as new strategies for acting on this information in a manner that will allow facility operators to reduce the cost of responding to occupant requests while improving occupant satisfaction. This will allow an automation system to handle common types of feedback with a minimal use of valuable facility management resources.

**APPROACH**

We developed an occupant feedback user interface that can be used in conjunction with the work request feature of Maximo, a commonly used computerized maintenance management system. We implemented a prototype of the user interface at a facility that is already using the Maximo system. Concurrently, we developed a model-based strategy for handling hot and cold complaints because previous research has found that they are the most frequent kind of service request from occupants.

The research team also 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).

In conjunction with the development of TIEMS, we 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.
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