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Collaborative research to promote energy efficiency innovation towards significant reduction in buildings energy use in the United States and India

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March 2014

Environmental Energy Tecnologies Division

CBERD

The U.S. –India Joint Centre for Building Energy Research and Development (CBERD) was developed to facilitate joint research and development on clean energy to improve energy access and promote low-carbon growth.

This report summarizes CBERD's joint research and development activities for Year 1 and for the first half of Year 2, covering the time frame from November 2012 to March 2014.

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CBERD is an U.S.-India Joint funded research project involving a partnership of eleven leading R&D institutions and twenty-four industry /cost-share partners in India and the U.S. CBERD. The consortia is jointly led by CEPT University, Ahmedabad, India, and Lawrence Berkeley National Laboratory, Berkeley, California, USA.

US-India Joint Centre for Building Energy Research and Development (CBERD)

Collaborative research to promote energy efficiency innovation towards significant reduction in buildings energy use in the United States and India

November 2012 - March 2014
http://cberd.org

CBERD R&D Partners (India)

1. CEPT University, Ahmedabad (Lead)
2. Auroville Centre for Scientific Research
3. The International Institute of Information Technology Hyderabad
4. Indian Institute of Management Ahmedabad
5. Indian Institute of Technology Bombay
6. Malaviya National Institute of Technology Jaipur

CBERD R&D Partners (U.S.)

1. Lawrence Berkeley National Laboratory (Lead)
2. Carnegie Mellon University
3. University of California Berkeley
4. Oak Ridge National Laboratory
5. Rensselaer Polytechnic Institute

Industry/cost-share partners (India)

1. Asahi India Glass Ltd.
2. Biodiversity Conservation India (Private) Ltd.
3. Infosys Technologies Limited
4. Neosilica Technologies Pvt Ltd.
5. Oorja Energy Engg Services Hyd Pvt. Ltd.
6. Paharpur Business Centre / Green Spaces
7. PLUSS Polymers Pvt. Ltd
8. Philips Electronics India Ltd
9. Saint-Gobain Glass India Ltd
10. Schneider Electric India Pvt. Ltd.
11. SINTEX Industries
12. Skyshade

Industry/cost-share partners (U.S.)

1. Autodesk, Inc.
2. California Energy Commission
3. Delphi
4. enlighted Inc.
5. Honeywell
6. Lighting Science Group
7. Nexant
8. Saint Gobain Corp
9. Synapsense
10. Indian Society of Lighting Engineers (collaborating with U.S. company, Lighting Science)

Organizational Partners (India)

1. Glazing Society of India
2. Indian Green Building Center, Confederation of Indian Industries
3. Indian Society of Heating Refrigeration and Air Conditioning Engineers (ISHRAE)
4. Rajasthan Electronics and Instruments Limited (REIL)

Organizational Partners (U.S.)

1. City of San Jose
2. HOK Architects
3. Natural Resources Defense Council

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Executive Summary

CEPT University (CEPT) in India and Lawrence Berkeley National Laboratory (LBNL) in the United States are jointly leading the U.S.–India Joint Center for Building Energy Research and Development (CBERD) project. It has brought together multidisciplinary expertise from eleven leading research and academic institutes in India and the U.S. to conduct collaborative research in order to promote energy efficiency innovation that leads towards significant reduction in building energy use in the United States and India.

This report summarizes the work jointly conducted by all consortia partners from November 2012 through March 2014. As stated in the original proposal document, the goal of CBERD is to conduct collaborative research that results in measurable and significant reduction in building energy use in both nations. This goal will be achieved through three key strategies, as described below.

First, through a research thrust specifically developed to address the key barriers to low-energy buildings while providing synergies with existing research efforts in both nations.

Second, by developing a tightly coordinated team consisting world-class building energy efficiency experts from both nations.

Third, by setting up organizational, collaboration, and management structures that will ensure accountability and success. CBERD's leadership team has an outstanding record of success, in bringing new technologies to market at scale, to provide game-changing innovation.

In the U.S., the lead institution is Lawrence Berkeley National Lab (LBNL). LBNL's partners include Oak Ridge National Laboratory (ORNL), University of California, Berkeley (UCB), Carnegie Mellon University (CMU), and Rensselaer Polytechnic Institute (RPI). The lead Indian institution is the Center for Environmental Planning and Technology (CEPT). CEPT's partners include the International Institute of Information Technology Hyderabad (IIIT-H), Malaviya National Institute of Technology Jaipur (MNIT-J), Indian Institute of Management Ahmedabad (IIM-A), Indian Institute of Technology Bombay (IIT-B), and Auroville Centre for Scientific Research (CSR).

An unprecedented set of industrial partners and supporting organizations have committed to collaborate with CBERD to develop advanced building tools and technologies to reduce energy consumption. The Industry partners are contributing both "in-kind" and cash cost-share to the project. The U.S. contributing partners include Autodesk Inc., Delphi, Enlighted, HOK Architects, Honeywell, Lighting Research Center, Lighting Science, Nexant, Natural Resources Defense Council, and SynapSense. The Indian contributing partners include Asahi India Glass, Biodiversity Conservation India Ltd. (BCIL), Infosys, Neosilica Technologies, Oorja Energy Engineering Services, PBC Ventures, Philips, PLUSS Polymers, Schneider Electric, Sintex, Skyshade Daylights, and Wipro EcoEnergy. Windows manufacturer Saint-Gobain will contribute in both nations. CBERD has also received support from the following non-profit organizations: City of San Jose, California Energy Commission, Confederation of Indian Industry–Sohrabji Godrej Green Business Centre, Glazing Society of India, Indian Society of Heating Refrigerating and Air-conditioning Engineers, Indian Society of Lighting Engineers, Rajasthan Electronics & Instruments Limited. The deep level of collaboration with industry and not-for-profit collaborators will amplify and accelerate advanced building technologies available to commercial building markets in both nations.

CBERD partners in the U.S. and India are all well positioned to transfer results to key building stakeholders by creating new ties as well as by leveraging existing relationships and ongoing projects. Both LBNL and CEPT and their partners already maintain strong, long-standing connections to U.S. and India building energy efficiency programs through their ongoing research and training activities.

CBERD Project

Background

The collaboration and cooperation between the United States of America (U.S) and India across several fields have brought friendship and understanding between the two largest democracies. Relying on successful historic partnerships and recognizing the need to address climate change and create a clean energy future, the Indian Prime Minister Dr. Manmohan Singh and U.S. President Barack Obama signed a Memorandum of Understanding (MoU) in 2009. The U.S.-India Partnership to Advance Clean Energy (PACE) was formed as a result of this MoU. Through one of the early PACE initiatives, PACE– Research (PACE-R), the U.S. Department of Energy (DOE) and the Government of India signed an agreement to establish a U.S.-India Joint Clean Energy Research and Development Centre (JCERDC). This joint research centre was mandated to foster collaborative research and development in the three areas of solar energy, second-generation biofuels, and building energy efficiency. The centres in the three identified areas are expected to accelerate transition to a low-carbon, high-performance, energy-secure economy. The PACE-R activities are coordinated by India's Department of Biotechnology and Department of Science and Technology. They are administered by the Indo-U.S. Science and Technology Forum (IUSSTF) in India and by the Department of Energy (DOE) in the U.S.

In 2011, under the JCERDC program, both governments sought a proposal to form joint consortia across both countries comprising of research and industry partners while securing matching cost-share commitments. After an extensive merit-review process, the U.S. and Indian awardees were announced in April 2012. The joint consortia named U.S.-India Joint Centre for Building Energy Research and Development (CBERD) was selected to lead the JCERDC Building Energy Efficiency area for five years. CBERD is led by Lawrence Berkeley National Laboratory, Berkeley, California, in the U.S. and by CEPT University, Ahmedabad, in India. It comprises a diverse set of consortia partners in both countries. CBERD brings together under one virtual roof world-class researchers and scientists from academia, industry, and national laboratories, as well as institutional partners from both India and the United States.

Overview

The United States and India are among the highest energy users in the world, with building energy use constituting a majority of that consumption. The development and widespread dissemination of highly efficient building technologies in both countries can significantly mitigate that energy use.

India is now the world's seventh-largest energy consumer, sixth-largest source of greenhouse gas (GHG) emissions, and second in terms of annual GHG emissions growth (UNDP 2011). India's electricity demand is projected to reach 1,900 terawatt-hours (TWh), with a peak electric demand of 298 GW by 2021–2022 (MOP, 2007), and its carbon dioxide (CO_2) emissions from coal combustion are projected increase by 118% between 2010 and 2035 to reach 3.5 GT CO_2 in 2030 (International Energy Agency, 2007). India's building energy use accounts for 33% of the nation's energy use, and this is growing by 8% annually (Climate Works, 2010). The largest floor-space growth is in the commercial (office, hospitality, retail, hospitals) and residential sectors Given the explosive growth in floor space, increased intensity of energy use and service-level requirements in the commercial sector, India must address energy efficiency in this sector (see Figure 1).

The need is also evident in the United States. The buildings sector contributes to 40% of the nation's energy consumption and CO2 emissions—the highest of all sectors— and this sector's energy use is increasing faster than any other's (Coffey, 2009). The DOE forecasts that the U.S. will need to add another 235 gigawatts of electricity generation capacity by 2035, at a cost of $0.5 trillion to $1 trillion (Rs. 22 trillion to 45 trillion (EIA, 2012).

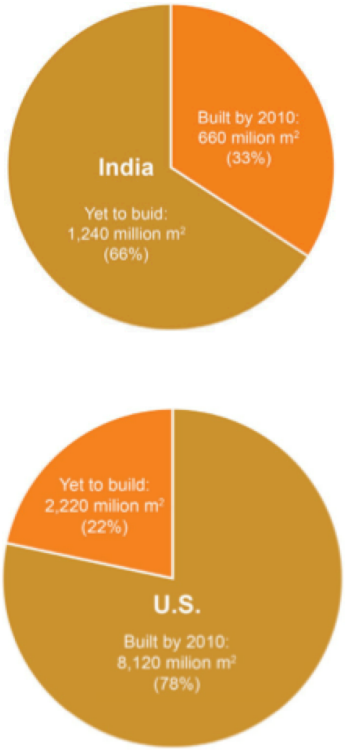

Figure 1: Proportion of floor space constructed by 2010 in India and the United States (Source: ECO III, 2010; EIA, 2012)

Fortunately, by drawing on the research and technological capabilities of the U.S. and India, substantial energy savings can be achieved. The CBERD focus is on building system integration through joint research and public/private-sector partnership. CBERD will help to achieve substantial energy savings in both countries' buildings sectors. Aligning with the Government of India's (GOI) goals of achieving energy-efficient buildings by reducing the need for lighting, heating, ventilation, and air-conditioning, two of LBNL's projects in India already have demonstrated that systems-level integration through innovative technologies can reduce energy consumption by at least 60%, compared to the ASHRAE 90.1-2007 baseline.

Figure 2 shows a technical energy saving potential of 209 TW/year (40% savings) in India. This assumes a 60% reduction in energy use for new construction, and a conservative 10% reduction through retrofits from the average benchmarked value of approximately 273 kilowatt-hours per square meter per year (kWh/m2/year) or 27.3 kWh per square foot (ft2) per year. The average is derived from a wide range of benchmark data for offices, hotels, hospitals, and shopping malls (ECO-III, 2010).

CBERD's vision is to build a foundation of collaborative knowledge, technologies, human capabilities, and relationships that position the U.S. and India for a future of high-performance buildings, with accelerated, measurable, and significant energy use reduction. The focus on the highest-growth sectors, i.e., commercial and high-rise multi-family buildings, targets primarily new construction in India and retrofits and operations in the United States. While this will create the maximum impact, the results will have spillover benefits to other building sectors. CBERD will draw from its collaborative R&D and commercial experience to align with the goals of Government of India and U.S. Department of Energy (U.S. DOE Multi-year Plan, 2011–2015), as well as societal concerns, and industry benefits.

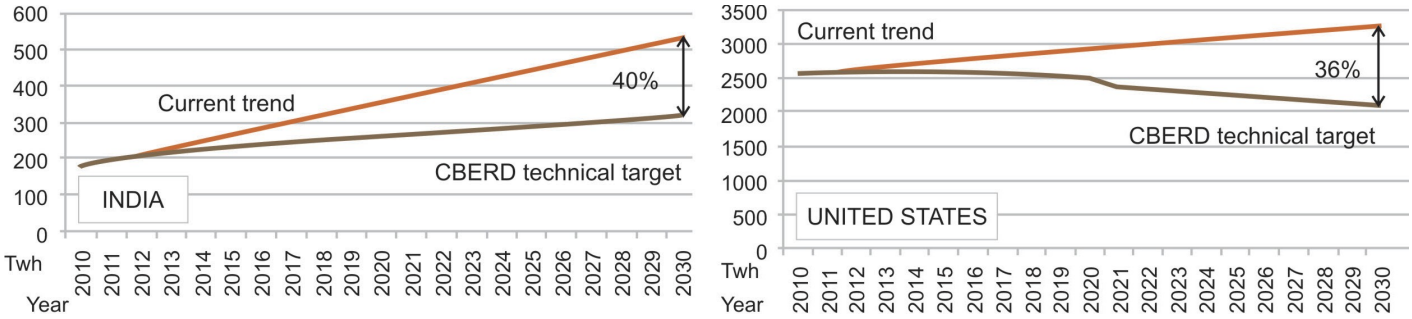

Figure 2: Building energy-saving potential identified by the CBERD

CBERD is a R&D collaboration on buildings energy efficiency spanning both sides of the ocean under one virtual roof.

The CBERD vision is to:

- *Accelerate building energy efficiency benefit through leveraged and novel tools, technologies and guidelines*
- *Maximize opportunities for bilateral learning and exchange by drawing upon the complementarity of R&D experience and knowledge*
- *Create bridges towards commercialization and deployment by mapping to commercial strengths of our industry partners in both nations*

CBERD Project Objectives

Objective 1: Optimize the building systems integration using a whole-building approach across the building lifecycle to facilitate and advance high-performance buildings

CBERD is providing an in-depth analysis of how buildings in India and the U.S. use energy, and is creating a Lifecycle Performance Assurance Framework (LPAF) that supports building system integration throughout the building's design, construction, and operation—a departure from the conventional, single-stage, and hence fragmented approach. This enables a whole-building, integrated view and simultaneously assures high performance, both in terms of energy efficiency and comfort/service levels. In the LPAF framework, the crucial integration occurs between the buildings' physical systems by using innovative building information technology. The LPAF framework creates metrics at the three stages of the building lifecycle: by predicting, commissioning, and measuring building performance. This objective includes development of whole-building and systems simulation tools/models that can estimate the building's energy performance and code compliance; development of controls and sensors for continuous measurement and tracking of real-time performance relative to the original design intent; and benchmarking to provide feedback loops to the next generation of building modeling. The LPAF is organized primarily around two primary research thrusts: (1) building information systems, and (2) building physical systems, and a cross-cutting view on supplemental applications such as Smart Grid responsiveness, renewable energy source integration, and cost optimization (See figures 3 and 4).

The overall research and development (R&D) strategy is structured and prioritized to provide guidance on the selection of key technologies and components for each major building system, to meet the desired performance levels, and on cost-effective solutions. The LPAF for better technology and integrated systems has the benefits of getting CBERD closer to its performance targets and increasing the likelihood that the envisaged results can be achieved in the real world.

Objective 2: Formulate building energy efficiency R&D strategies targeted to the diversity of building types

This effort focuses on increasing the breadth of the building stock that will be affected while increasing the depth of energy savings in each building type. The objective is to create a convergence of high levels of service and comfort with resource- and energy-efficient solutions for a diversity of building types, e.g., offices (one/two/three shift, public/private sector), retail, hospitality, hospitals, and multi-storied housing.

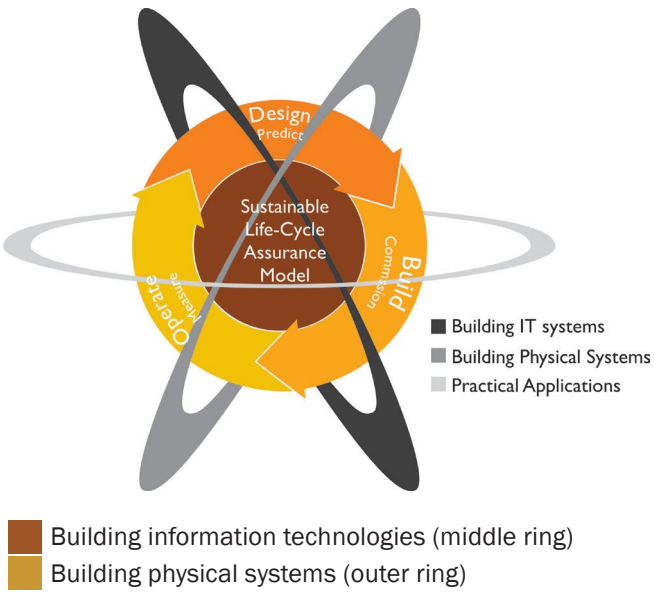

Figure 3: CBERD's program consists of two R&D thrusts and supplemental applications that span the building lifecycle and yield new technology.

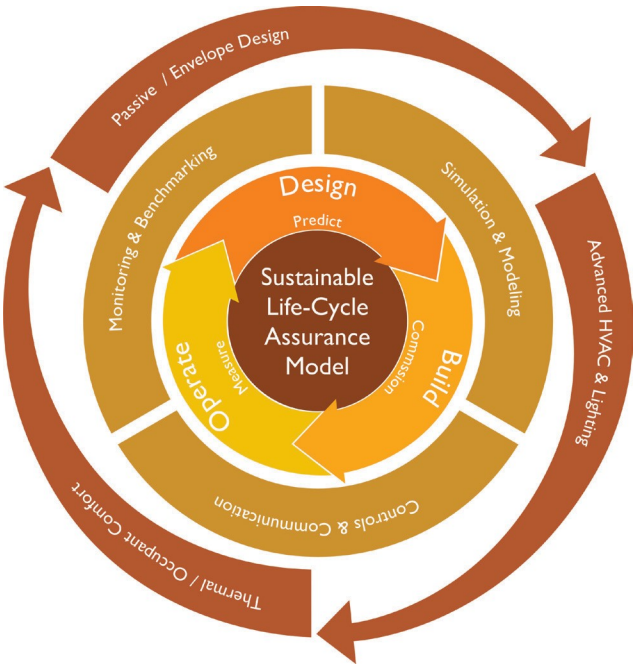

Figure 4: Key Diagram: CBERD's focus on Building Information Technology and Physical Systems integration will simultaneously enable a whole-building view and assure high performance.

Objective 3: Develop a suite of R&D strategies customized for U.S. and Indian applications, enabling rapid development of regional and localized low-energy building practices and technologies

The CBERD focus is on applied R&D, including innovative cooling and daylight technologies, passive and envelope design, and products that suit indigenous needs, regional variations, and climate diversity (see Figure 5). Work on this objective generates solutions geared towards Indian applications and advances appropriate regional and local technologies. This work is coordinated with that of Objective 2 to ensure that the technologies apply to all pertinent building types. The knowledge and lessons learned are documented and applied in both countries. R&D focuses on both technology solutions and regional adaptation that can leapfrog transitional technologies while developing and advancing appropriate regional and local ones.

Objective 4: Enhance compliance and development of building standards and codes

To bridge the gap between standards and their implementation, CBERD is developing design specifications, decision tools, algorithms, and best practices guides. These are supported by benchmarked and ongoing measured data to achieve five-year performance targets for commercial and multi-storied residential buildings. This effort will enable opportunities for significant improvements in building energy performance.

Objective 5: Promote the long-term sustainability of building energy efficiency through collaborative education and training

CBERD focuses on helping overcome knowledge gaps of building research, design, and developer communities through training and education curricula. CBERD documents, demonstrates, educates, and uses consortium-wide use of test-bed facilities to accomplish this. Boosting the two-way knowledge transfer and capability levels of buildings stakeholders facilitates information exchange and speeds technology and product development that can help generate significant efficiencies for the U.S. and India. This work will be conducted through collaboration with deployment channels in both countries.

Objective 6: Accelerate building efficiency R&D and deployment through a solid, functioning consortium with bilateral public-private partnerships

Building on collaborative efforts to establish long-term relationships among researchers, CBERD aims to achieve demanding energy performance targets through a dedicated, long-term cooperative effort on the part of many stakeholders. This effort would help the building stakeholders navigate the path from business-as-usual to high-performance buildings. CBERD leverages team member's R&D, commercial experience, and expertise to create cohesive, significant, dramatic impacts in both nations.

Figure 5: CBERD is developing a suite of R&D strategies customized for regional and localized applications, among a diversity of building types.

CBERD R&D Tasks and Collaboration Activities

1.0: Consortia Management and Coordination

2.0: Building Information Technology

Subtask: 2.1 Simulation and Modeling
Subtask: 2.2 Monitoring and Benchmarking
Subtask: 2.3 Controls and Communications Integration

3.0: Building Physical Systems

Subtask: 3.1 Envelope / Passive Design (including Energy Efficient Building Materials and Advanced Shells, Cool Roofs, Windows and Daylighting, and Passive Design)
Subtask: 3.2 Advanced Technologies (including Advanced HVAC and Advanced Lighting)
Subtask: 3.3 Comfort Studies

4.0: Supplemental Applications

Subtask: 4.1 Grid-Responsive Buildings
Subtask: 4.2 Renewable Integration
Subtask: 4.3 Cost Optimization of Energy Efficiency

5.0: Scientific Collaboration

1.0: Consortia Management and Coordination

The CBERD Consortia Management Office (CMO) provides core management support to all partners to achieve project objectives, consortium effectiveness, and quality at every stage of research and development. The CMO manages periodic reporting, budgeting, finances, and intellectual property management of CBERD.

Background

To coordinate and manage a project of this scale, LBNL and CEPT have formed the CBERD Management Office (CMO), led by the CBERD Principal and Co-Principal Investigators and supported by the Project Directors (PDs) and Operations Manager (OM) (see Figure 6). The CMO also coordinates and drives R&D communications, decision-making, and industry partnerships in both nations. LBNL is the U.S. Consortium's operating agent, conducting administrative, fiscal, contracting, and R&D responsibilities for the U.S. DOE. CEPT is playing a parallel role for the IUSSTF GOI. The CMO is also responsible for effective coordination/communication between team members and other project participants, including technical, business, financial, and other appropriate activities.

The CMO team has assembled a focused set of industry partnerships that support the team's R&D agenda. Each R&D task is implemented by R&D Project Leads with the direction of the PIs.

Progress so far

Key activities of the U.S. and Indian CBERD Management Offices (CMOs) have included coordinating project R&D, continued facilitation of industry engagement in the R&D activities, conducting partner meetings and work sessions, finalizing subcontracts, and finalizing a comprehensive joint technology management plan for intellectual property (IP management plan).

Activities have included the following:

- Strategic R&D planning to meet the joint R&D objectives in partnership with the research institutions and industry team members in both countries, determining the R&D progress and outcomes, and identifying challenges and measures to overcome them.
- U.S.-India coordination through joint calls and web meetings to discuss project management and R&D coordination among institutional and industry partners.
- Project briefings and presentations to the U.S. and Indian governments (DOE, IUSSTF) on management and R&D updates, and identification of issues and areas of mutual support.
- Under the CBERD Consortia management task, the CMO also maintains a collaborative web portal, CBERD website, and CBERD outreach activities.

The results of this joint consortia management by CMOs in both countries has enabled us to:

1. Reach an agreement on a framework for joint R&D activities.
2. Establish five-year project plans and one-year work plans for each of the R&D tasks.
3. Set up a secure web-based project management tool.
4. Conduct U.S.–India CBERD joint quarterly virtual meetings using video conferencing facilities.
5. Design and maintain the CBERD website (www.cberd.org).
6. Facilitate monthly meetings between task leaders.
7. Facilitate exchange of scholars in both countries.

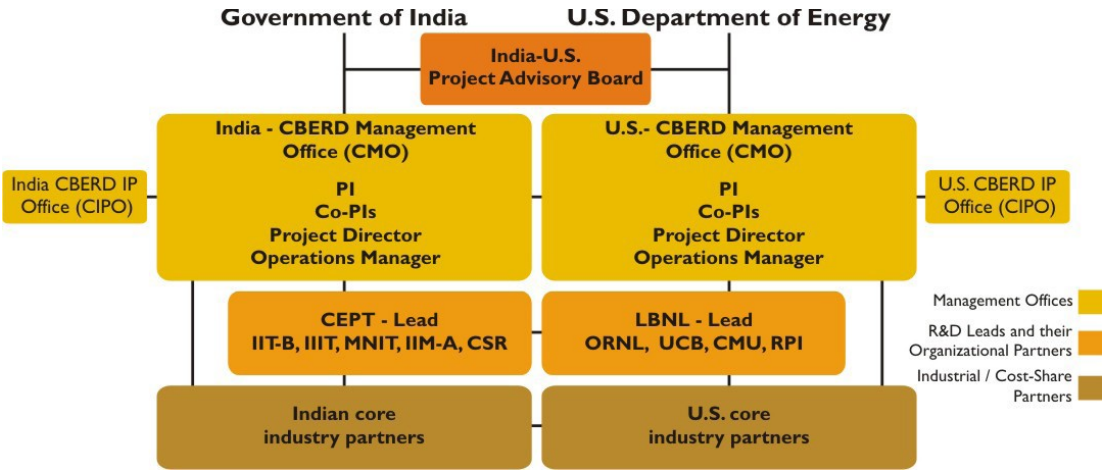

Figure 6: CBERD organizational/governance structure for project coordination and management.

2.0: Building Information Technology

Subtask 2.1: Simulation and Modeling

This task's research focus is to reduce barriers to energy efficiency through the use of information technology computations, integrated simulation tools, and R&D of new methods for reducing energy use of existing and new buildings.

Background

The Simulation and Modeling subtask focuses on building tools to help architects and building developers who design and operate building energy systems. It concentrates especially in technical areas identified by stakeholders in India and in DOE's Building Technologies Program Multi-Year (2011–2015) Work Plan. This subtask is divided into subtasks focusing on (1) graphical user interface of building energy modeling tool rapid optimization tools, and (2) tools for real-time monitoring and performance benchmarking.

Team members

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IIIT-Hyderabad	Vishal Garg, Aviruch Bhatia, Rathish Sathyabama Arumugam, Nitin Dixit, Ravi Kumar Singh, Rahul Tibrewal, Saransh Khanna, Deep Dixit
CEPT	Rajan Rawal, Agam Shah

Progress so far

Activities have focused on adapting the EnergyPlus graphical user interface (GUI) for advanced design, operations, and performance rating and benchmarking activities. For Simergy, the EnergyPlus GUI developed at LBNL, a detailed design specification for the natural ventilation system interface has been developed and partly implemented. Low-energy systems, including radiant-slab cooling and evaporative cooling in air handling units, have already been implemented in Simergy.

An Indian construction material database for energy simulation is being developed, for which identification and characterization of materials has been completed. This material database will be integrated with the simulation tool.

Expanded tools for rapid design, modeling, and optimization are being developed, and an early-stage window design tool for window optimization (WINOPT) has been developed (See Fig 7). This tool will help users optimize and select appropriate combinations of window glass, window-to-wall ratios (WWRs), and overhang depths for different façade orientations and different cities of India.

Theoretical tools to evaluate the possibility of using fast, robust algorithms in model predictive control design were developed using an EnergyPlus model of the Brower Center, a building with radiant-slab cooling located in Berkeley, California, USA. The study helped to verify that for slow response systems, such as radiant-slab systems, using the expected disturbance is sufficient to minimize expected cost. To enable rapid modeling using a desktop tool, EnergyPlus using file synchronization techniques (EPsysnc) and parallel computing over several nodes has been developed.

Tools for real-time building performance monitoring and benchmarking are also being developed. For this, a detailed literature review has been conducted, with a focus on the design and operation of experimental test facilities for the evaluation of automated fault detection and diagnosis methods.

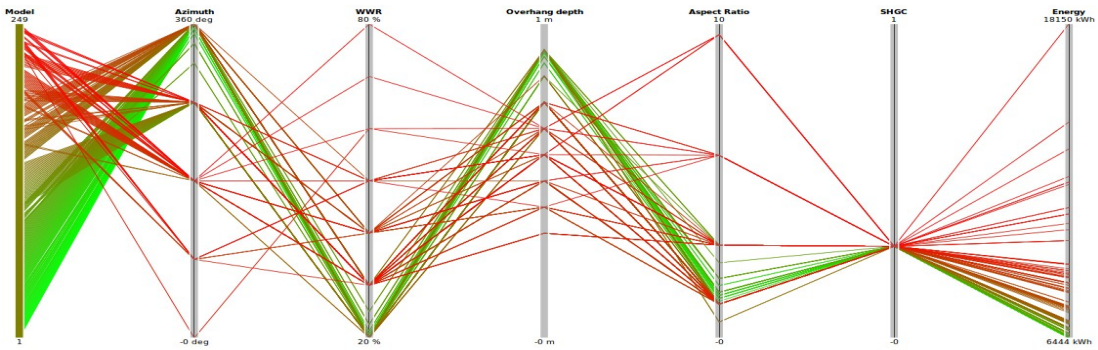

Figure 7: Screen shot of WINOPT tool, momogram

Notable Achievements

Public release of version 1.0 of Simergy, the free, practitioner-oriented user interface for EnergyPlus. Simergy that will be developed further and extended for use in low-energy system design, particularly in early stage design, and for use in performance-based code compliance.

Subtask 2.2: Monitoring and Benchmarking

The two research foci of this task are to provide a foundation for India's cost-effective benchmarking and monitoring program and to develop cost-effective, packaged, scalable energy information system (EIS) solutions for both countries.

Background

This subtask builds on applicable concepts from U.S. benchmarking and energy information systems (EIS) activities. Expected deliverables are: (1) a set of methods and framework for web-based software tools for whole- building and system-level benchmarking adapted to the Indian context, and (2) cost-effective, scalable approaches for continuous measurement and monitoring of commercial buildings, which can be integrated into energy information systems (EIS) and metering products with broad applicability in the U.S. and Indian markets.

Team members

Affiliation	Name
LBNL	Paul Mathew, Jessica Granderson, Reshma Singh
CEPT University	Yash Shukla, Mithi Dave

Progress so far

An action plan for advancing state-of-the-art building energy benchmarking in India has been developed. This plan is based on an extensive literature review of benchmarking efforts in the U.S., India, and Europe; documentation of highlights and lessons learned, and gap analysis relative to Indian benchmarking conducted in collaboration with industry partners Schneider Electric India and Wipro EcoEnergy. The purpose of this action plan is to define a specific set of strategies and actions for advancing the state of the art of benchmarking in India, including new methods that can be used to advance U.S. benchmarking tools and programs. The action plan includes not just an emphasis on traditional whole-building benchmarking, but also granular system-level benchmarking and an additional deconstruction into asset and operational benchmarking. Data collection forms for whole-building and system-level benchmarking have been developed. The data collected from these forms will be used to benchmark algorithm testing. Additionally, architectural asset data and operational energy data is being collected across almost 100 new buildings in Gujarat. The CBERD project has collaborated with the UNDP-GEF project administered by the Bureau of Energy Efficiency, India, to gather energy consumption data from approximately 1,000 buildings across India.

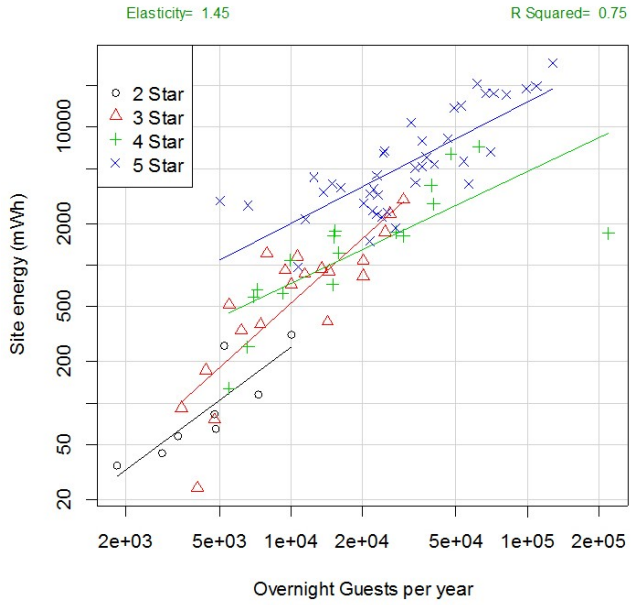

Figure 8: Benchmarking analysis of the Energy performance of hotels

As part of the ongoing activities, data for hotels and hospitals in India from previous USAID ECO-III benchmarking activities have been gathered (see Figure 8) and a benchmarking model for these two sectors has been initiated. The benchmarking model will be completed in Year 2 of CBERD. The building energy efficiency industry, as well as the cost-share partners in both countries, would benefit through early access to, and joint development of the outputs of the monitoring and benchmarking subtask.

A framework for EIS guidelines is under development that includes key performance indicators, hardware, communications, and software requirements. This set of guidelines has an initial data centre target focus, which is now complete. The data center EIS guidelines provide a bounded building typology where energy consumption is a

critical concern (data centres can utilize up to 100 times The comprehensive and vendor-neutral EIS guidelines have direct relevance for both U.S. and Indian data centres. (See Figure 9). This would empower data centre owners, developers, operators, and energy service companies (ESCOs) to select and specify the appropriate EIS for their business purposes to deliver a sound return on investment. The EIS sample specification and selection guidelines for the overall commercial buildings sector will be finalized after inputs from industry partners SynapSense, Schneider Electric India, and Wipro EcoEnergy in Year 2 of this project. The guidance will be expanded to selected high-growth commercial building typologies such as offices, retail, hospitality and quick service restaurants.

Notable Achievements

An Action Plan for Indian Benchmarking and an advanced data collection template for India has been completed, and is being reviewed by the Indian Bureau of Energy Efficiency for deployment. Energy consumption and architectural characteristics data of 95 new buildings in Gujarat, India has been collected. An EIS guide for data centers has been developed that targets a high energy use building type, and will be piloted in the U.S. by industry partner Synapsense.

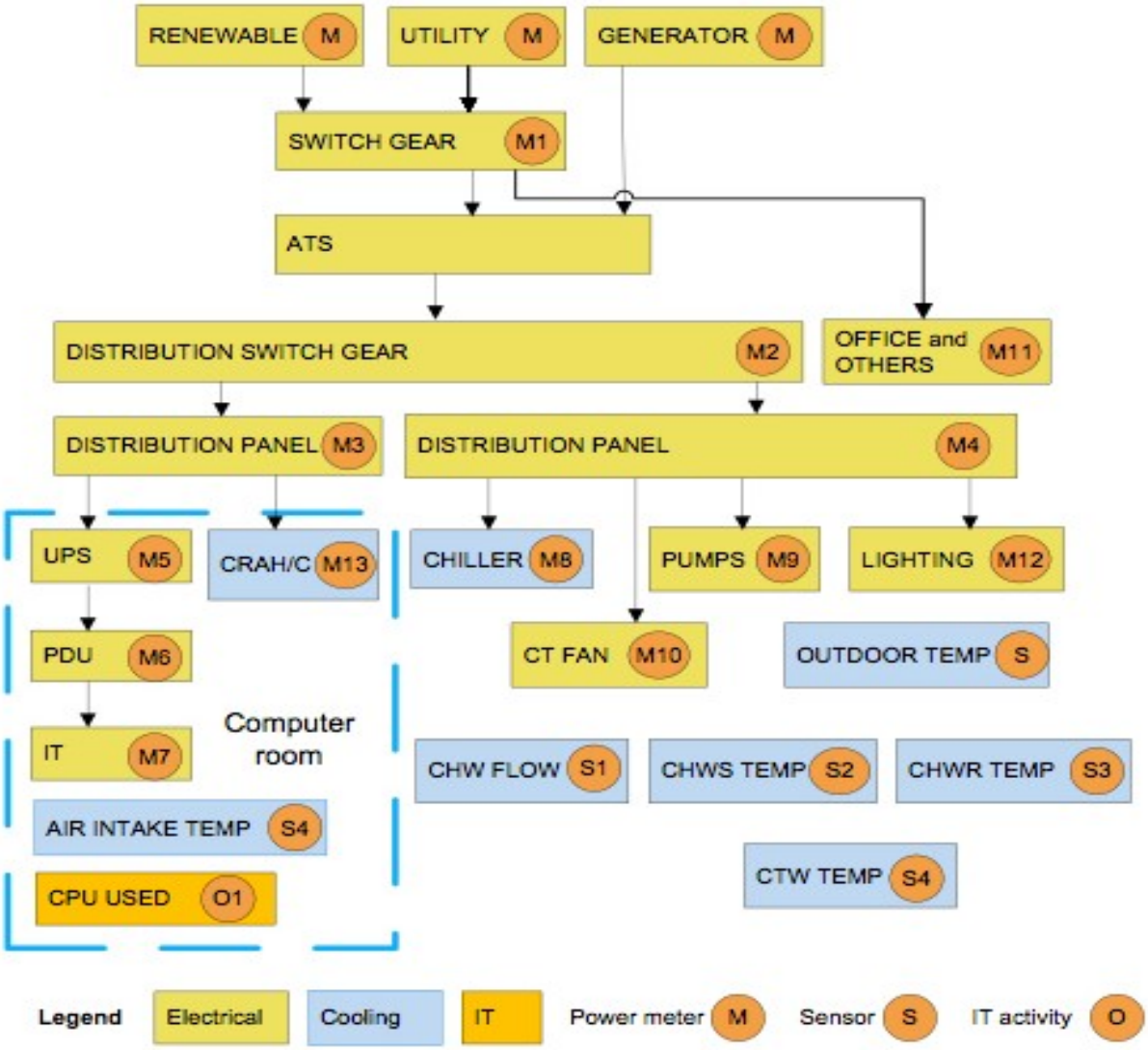

Figure 9: CBERD-recommended metering diagram for Data Centre Energy Information System (EIS)

Subtask 2.3: Integrated Controls and Communication

The research focus of this task is to develop and field test integrated communications and control technologies across building systems such as heating, ventilating, air conditioning, lighting and daylighting, and plug load systems.

Background

The subtask R&D includes development and field-testing of communication and control technologies across building systems. This includes advanced lighting, HVAC, and plug-load controls that: minimize energy use; respond to changes in occupancy and environmental factors; improve their functionality, reliability, and operational insight; integrate sensor data across building systems; and enhance occupant comfort. This work is helping to develop new smart luminaires and plug-load controllers; validate and improve wireless communication technologies for ubiquitous sensing and control of building loads; and develop and identify protocols and data structures to standardize exchange of all building data between systems. Activities are integrated around:

- Advanced lighting
- Plug-load controls
- HVAC, lighting and building systems

Team members

Affiliation	Name
LBNL	Francis Rubinstein, Steven Lanzisera, Richard Brown
IIIT-Hyderabad	Vishal Garg, Janyathi Sivaswami, Shubhajit Roy Chowdhury, K. Niranjan Reddy, Prabhakar Rao, Siddarth Jain, Divanshu Shivraj

Progress so far

Through collaborative work between the Indian and U.S. teams, a foundational understanding of building systems in India has been developed. This work has particularly focused on commonalities with and differences from standard U.S. commercial building systems.

Advanced Lighting and Integration

The design of the Smart Luminaire Controller designed by IIIT-H has been revised, and sample testing is under way at the IIIT Hyderabad facilities. A dynamic window controller is being developed to integrate lighting with the building envelope and to harvest daylight. This dynamic window controller varies the amount of natural light reaching the work desk depending on the solar radiation and lux level set at the table. Working with industry partner Enlighted, LBNL is planning for the first demonstration of advanced light-emitting diode (LED) lighting control systems to be deployed at LBNL facilities.

Plug-load controls and integration

In line with the plug load monitoring performed at LBNL, an energy meter has been designed at IIIT-H for monitoring the plug load and energy usage in various buildings in India. As a first step towards this, one hundred energy test meters are being produced for a monitoring experiment at IIIT-H. Plug loads have high potential for reduction in energy usage. Using an extensive database of device-level plug-load power traces collected in U.S. buildings by LBNL, advanced algorithms that categorize loads into sensitive and standard loads are being developed. to identify if a load is sensitive (e.g., a computer), and only switch off power to non-sensitive loads (e.g., lights, displays) when the space is unoccupied or unutilized.

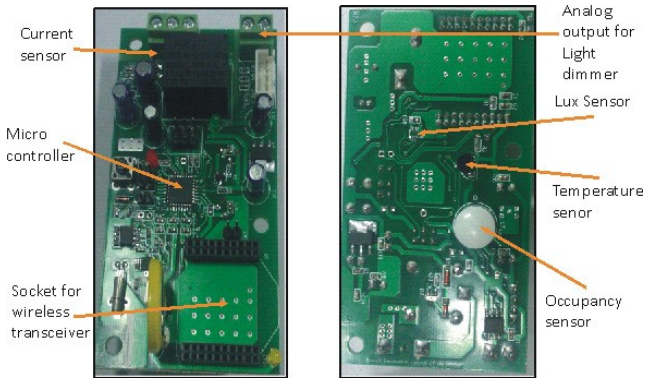

Figure 10: Smart Luminaire controller developed by ***CBERD team***

HVAC, Lighting, and Building System Integration

Starting with the UC Berkeley-developed Simple Measurement and Actuation Profile (sMAP) system, LBNL has developed data exchange system foundation and testing its capabilities. Working with Enlighted and Honeywell, LBNL is investigating systems that are appropriate for interconnection with the data exchange platform. This work on data exchange and new control systems promises significant energy savings across the commercial buildings sector. The buildings equipment and controls industry stands to benefit through early access to and joint development of these technologies.

Notable Achievements

Design and production of power meters for plug monitoring completed; Preliminary algorithms that identify plug loads appropriate for on/ off power control developed

3.0: Building Physical Systems

Subtask 3.1: Envelope / Passive Design

This task focuses on physical building systems, end uses and advanced technologies that are important to the building energy efficiency needs. This task is divided into four subtasks: (1) Energy Efficient Building Materials and Advanced Shells; (2) Cool Roofs; (3) Windows and Daylighting, and (4) Passive Design.

Background

This task is divided into four subtasks: (1) Energy Efficient Building Materials and Advanced Shells; (2) Cool Roofs; (3) Windows and Daylighting, and (4) Passive Design.

Activities under these work streams are focusing on:

1. Evaluating performance of insulation materials for their thermo-physical and hygrothermal properties, and development of a construction materials and assembly database.
2. Development and testing of cool roof technologies and advancing state-of-the-art technologies for both nations.
3. Development, testing, demonstration, and validation of high-performance glazing and daylight harvesting solutions.
4. Development of India-centric numerical tools to help architects and engineers make informed design decisions.
5. Generation of a performance database of products and technologies available in India and enhancement of test facilities to develop and evaluate complex fenestration systems available in India.
6. Scientific evaluation of passive design strategies used in buildings in India, development of prototypes, and communication of test results with the building community.

Team members

Affiliation	Name
Energy Efficient Building Materials and Advanced Shells Team	
CEPT	Rajan Rawal, Sanyogita Manu, Vinod Patel, Srijan Didwania
ORNL	Andre Desjarlais, Kaushik Biswas, Manfred Kehrer
Cool Roof Team	
LBNL	Ronnen Levinson, Jayant Sathaye Pablo Rosado
IIIT-Hyderabad	Vishal Garg, K. Niranjan Reddy, Rathish Sathyabama Arumugam
CEPT	Rajan Rawal, Vinod Patel, Agam Shah
Windows and Day lighting Team	
CEPT	Rajan Rawal, Sanyogita Manu, Yash Shukla, Agam Shah, Pranav Kishor, Vinod Patel
LBNL	Christian Kohler, Charlie Curcija, Robin Mitchell
Passive Design team	
CEPT	Rajan Rawal, Sanyogita Manu, Agam Shah, Mihir Vakharia
MNIT	Jyotirmay Mathur
Auroville CSR	Mona Doctor Pingel, Tency Baetens, Alma Bakhlina, Vijay K.
UCB - CBE	Gail Brager, Anoop Noonekeri

Progress so far

Research Subtask 3.1A: Energy Efficient Building Materials and Advanced Shells

Design of the first phase of physical infrastructure for testing thermo- physical and hygrothermal properties of building materials has been done. This includes the design and construction of a Guarded Hot Box (GHB) (See Figure 14). This is in accordance with ASTM C236, to test wall, fenestration and floor, and complex assemblies up to 1,000 mm x 1,000 mm x 350 mm thickness, thus making it very contextual to India. Another unique capability is the ability to conduct dynamic guarded hotbox tests on heavy thermal mass wall assemblies. GHB climate chamber temperature can be controlled from 50 to 60˚C and air velocity from 0.2 to 1.0 meters per second (m/s). GHB metering chamber temperature can be controlled from 22 to 28 ˚C. The development of the hygrothermal facility (see Figure 11) includes procurement, installation, and calibration of pressure plates, a climate chamber, drying

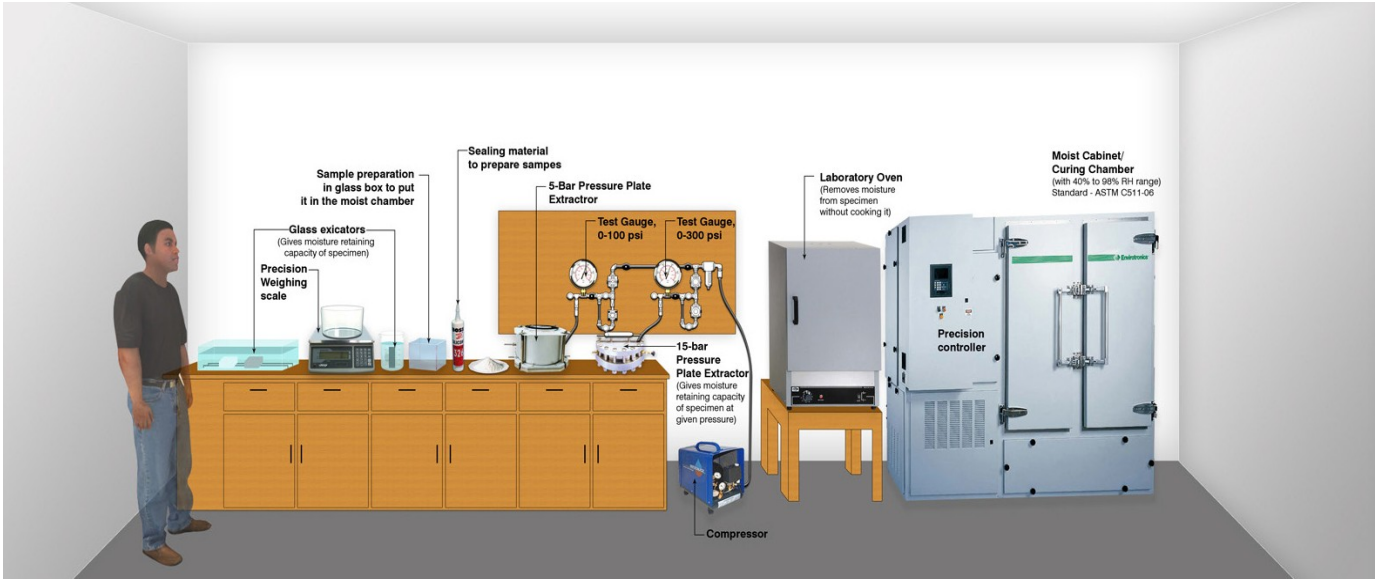

Figure 11: Artist's image of hygrothermal characterization facility for building material

ovens, an inert gas oven, and ancillary equipment. The CBERD project team has identified ASTM standards C1498, C1699, and E96, and ISO standards 15148 and C518 as applicable standards. This facility will have a climate chamber with relative humidity (RH) controllability between 20% and 95%, with precision of 3%. Output pressure can be regulated from 0.7 to 16 bar. For the guarded hot box and hygrothermal task facilities, the CEPT team has received technical guidance by ORNL.

Insulation materials and generic building materials are being tested for development of a database that will feed into a simulation tool to coordinate activities for the passive design task. Building materials and assemblies will be tested for buildings being monitored for energy and environmental performance. To accomplish this, a state-of-the-art, one-of-a-kind facility at CEPT will be used. CEPT and ORNL are working with industry partner BCIL to expand the materials database. BCIL is helping the CEPT team construct wall assemblies, which will be tested at GHB. Another industry partner, PLUSS, is working with CEPT and ORNL to develop phase-change material panels, and the form-stabilized PCM panels that have been developed have been an encouraging step forward.

Research Subtask 3.1B: Cool Roofs

Approximately 120 cool roof materials are being tested at CEPT with the guidance of LBNL, in accordance with ASTM E903 standards. CEPT also has developed a framework for Indian cool roof rating systems, elaborating on testing protocols, testing equipment, and proposed administrative and market mechanisms. An unconditioned building has been identified for a cool roof demonstration in Nagpur (composite climate), and instrumentation and minor modifications of the building are in progress. The IIIT-H team is conducting field experiments. In addition, a protocol to test cool roofs for aging properties is being developed. Manufacturers have been contacted to collect samples available in India. These samples will be naturally exposed to study the weathering and aging of roofing products. This should help the U.S.-India team develop a variant of LBNL's accelerated aging protocol suitable for roofing products in Indian climates.

Research Subtask 3.1C: Windows and Day lighting

Figure 12: Testing of window with daylighting system for Solar Heat Gain Coefficient

The main objective of this subtask is to develop, test, demonstrate, and validate cost-effective, high-performance glazing, shading, and daylight harvesting solutions. Characterization of glass for its optical properties such as visual transmittance, absorptance, and reflectance has been conducted in accordance with ISO 9050 and EN 410, and in a solar range as well as a near-IR range. The CEPT team has tested approximately 200 glazing samples (See Figure 12) available in the Indian

Figure 13: Artificial Clear Sky and Mirror Box

market, which covers approximately 80% of the glass samples available in the Indian market from the organized market. These test results are available in the public domain. The results will be added to the LBNL Commercial Fenestration tool (COMFEN) database and will be available in the International Glass Database maintained by LBNL.

CEPT has developed a design and specifications document for a mirror box to create artificial sky conditions. (See Figure 13). This will be constructed in Year 2 of the CBERD project. A mirror box is used to simulate overcast sky conditions for building models, which helps architects and engineers understand daylighting inside the building and make design improvements necessary to increase building performance and reduce energy consumption from artificial lighting. This box will also help in researching design variations with daylight harvesting technologies. A mirror box consists of highly reflective homogenously lit ceiling and mirrored walls. The light source is a milky white diffusing acrylic sheet illuminated with over 10,000 LEDs working as light source. The mirrors, arranged vertically all around the periphery of the box, produce an image of the lit ceiling by reflection and inter-reflection to infinity. The mirror box would generate light levels between 12,000 to 15,000 lux on the work plane. The building model to be analyzed for daylighting is placed inside the mirror box,

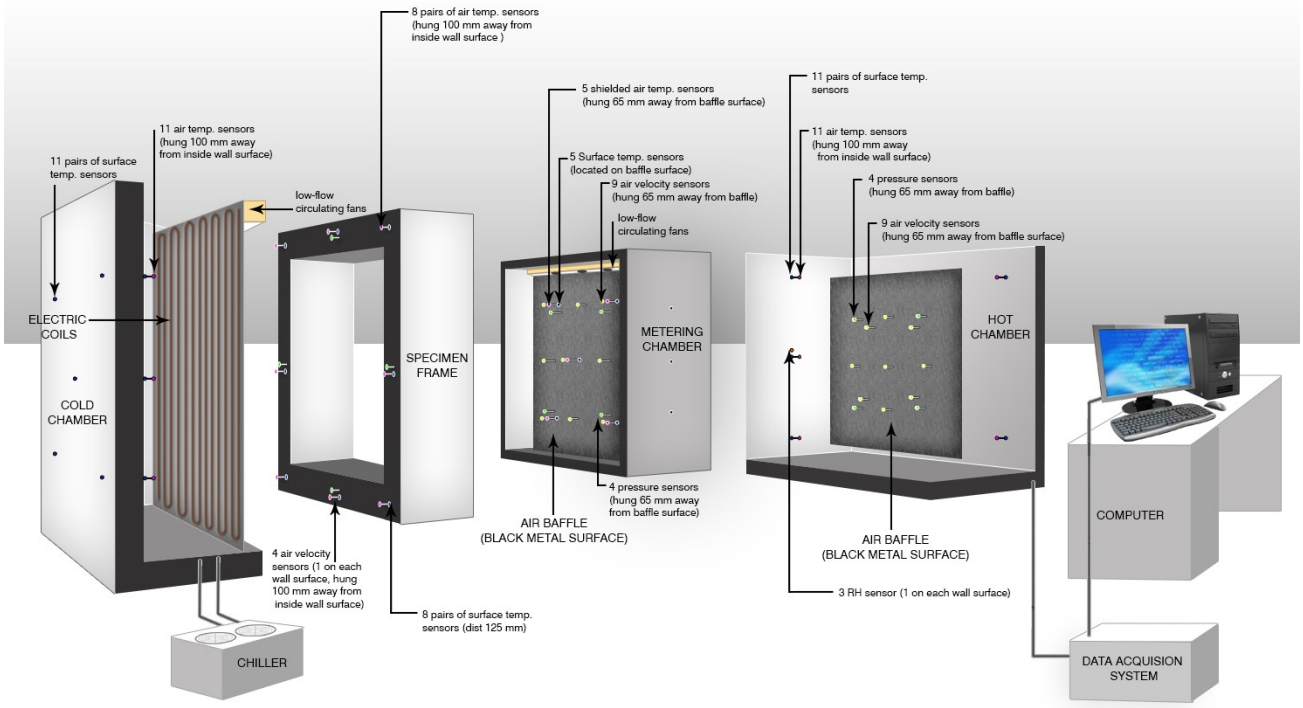

Figure 14: Artist's image of guarded hot box

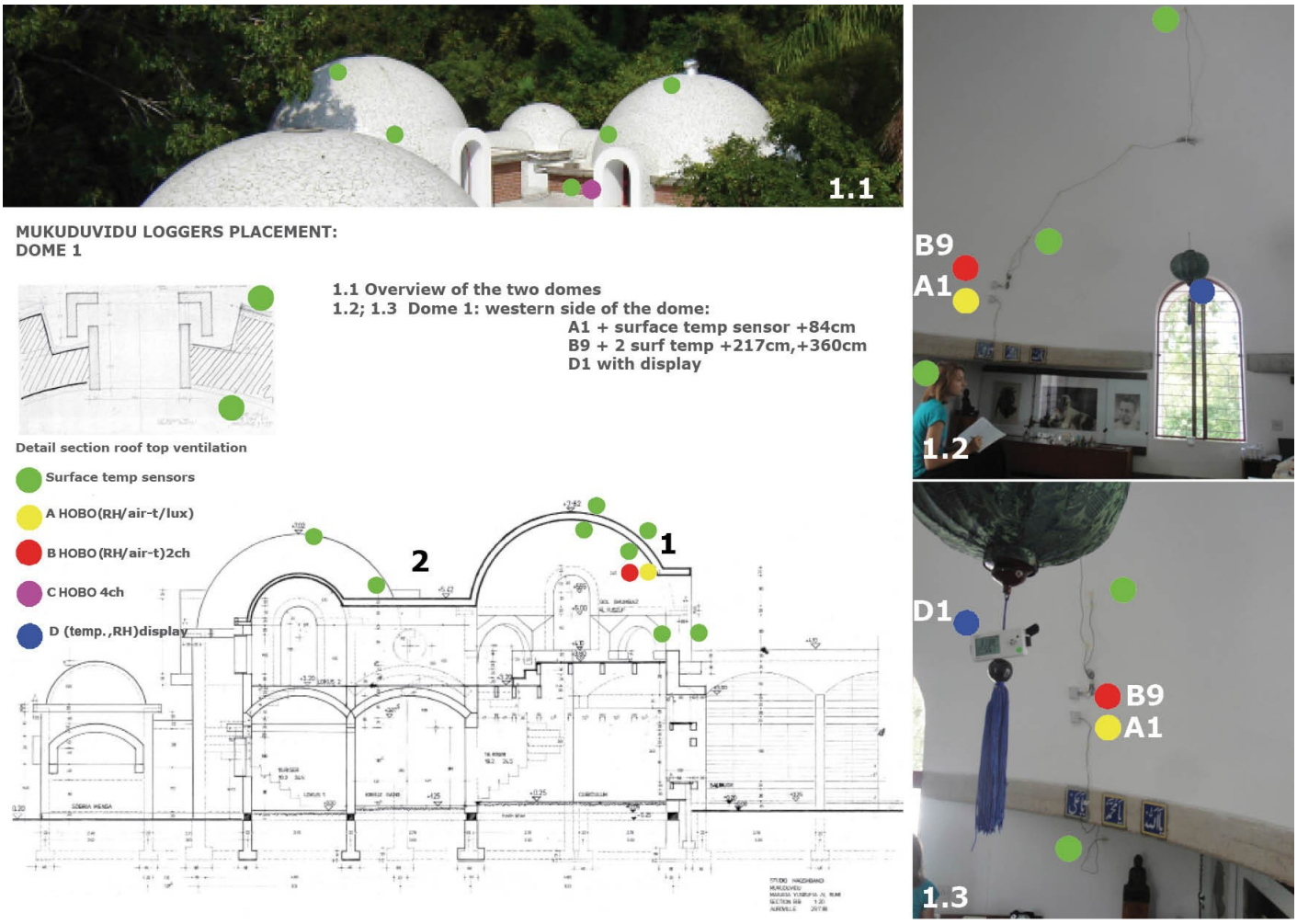

Figure 15: Passive design, field measurements at Auroville

and luminance levels are measured using a lux meter. This will create uniformly distributed sky conditions. Installation of the Sky Simulator, which simulates various sky conditions for building models, is being analyzed for clear sky conditions. The system consists of a turntable, mirror, and Fresnel lamp. The building design to be analyzed for daylighting is fixed on the turntable's platform, and the turntable can rotate the model about two axes. The turntable receives lighting from the Fresnel lamp after reflection from the mirror. The lamp emulates one sky patch out of the total 145 virtual divisions with equal area of the sky dome as per Tregenza's model. The turntable rotates the model such that the lamp is positioned in each of the 145 divisions of the sky dome. For each division, illuminance levels are measured inside the space using lux meters. These measured readings are then computed to give daylighting performance of the space.

COMFEN is a tool designed to support the systematic evaluation of alternative fenestration systems for project-specific commercial building applications. It provides a simplified user interface that focuses attention on key variables in fenestration design. Under the hood is Energy Plus, a sophisticated analysis engine that dynamically simulates the effects of these key fenestration variables on energy consumption, peak energy demand, and thermal and visual comfort. The results from the Energy Plus simulations are presented in graphical and tabular format within the simplified user interface for comparative fenestration design cases, to help users move towards optimal fenestration design choices for their project. The CBERD project team has developed a COMFEN India version (See Figure 16).

Sixty-five weather files for Indian locations have been included in the COMFEN database. Occupancy, lighting, equipment, and HVAC schedules have been customized to reflect the daytime and 24/7 operation of office buildings in India. More than 100 generic Indian building materials, with their physical properties, have been identified to be included in the COMFEN database. Window and wall construction templates have been created to represent business-as-usual cases of India, as well as to represent ECBC (Energy Conservation Building Code)-compliant cases. Work has started on inclusion of CO_2 emissions and material cost-related Indian conditions, and CEPT and LBNL are developing an option for modeling electric heating in addition to current gas heating.

The U.S. team at LBNL has developed and documented an angular tubes accessory for measuring angular properties

scattering of materials (e.g., shade fabrics). The design documentation consists of 2-D drawings (DXF exchange file format) and 3-D drawings (Solid Works), and a report detailing the fabrication process, including number of CAD and actual images of angular tubes. The report also includes the step-by-step process of installing tubes into the spectrometer instrument.

The CEPT and LBNL teams are working with Sky Shade and Infosys to characterize laser cut panels (LCP), which have

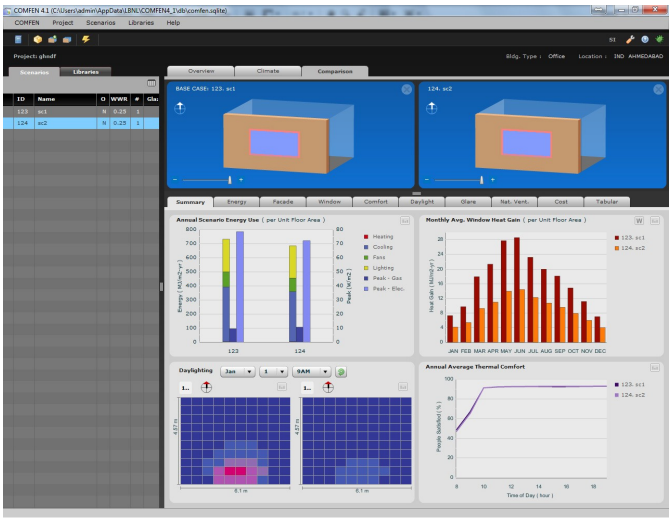

Figure 16: COMFEN India version screenshot

capabilities to transport daylight into the building floor space. These panels will help reduce dependence on electric light during the daytime. With the help of a photo-goniometer, the CBERD team is working on a bidirectional scattering distribution function (BSDF) to characterize LCPs. This will help with simulating LCPs in building energy models such as Radiance.

Research Subtask 3.1D: Passive Design

The criteria for the selection of naturally ventilated buildings to be monitored was defined, and a matrix listing all possible candidates for the study was prepared. Site visits to approximately 25 short-listed buildings in Auroville/ Pondicherry were organized. Of these 25, six buildings were further selected for whole-building monitoring and two selected for monitoring of a specific strategy. These buildings have been monitored since August 2013. (See Figure 15)

A literature study was conducted to understand the simulation criteria for naturally ventilated buildings. The CBERD team has identified critical simulation inputs to successfully simulate naturally ventilated buildings. Using various studies from the past, and available knowledge from industry, the values and extent of these parameters have been framed.

Five buildings with unique features for studying passive design features have been selected for the next phase. These buildings are the Haryana Renewable Energy Development Agency (HAREDA) in Chandigarh; Environmental Sanitation Institute (ESI) in Ahmedabad; Building of Comptroller Auditor General (CAG) in Jaipur; Foundation for Liberal and Management Education (FLAME) in Pune; and Institute of Rural Research and Development (IRRAD) in New Delhi.

Notable Achievements

- *Detailed design and specification of a guarded hot box and hygrothermal test have been prepared, tracing it to ASTM & ISO standards.*
- *The COMFEN India tool has been customized for Indian conditions and is publicly available.*
- *Buildings have been identified for monitoring and permissions to access one-year continuous monitoring along with spot measurements and surveys are in place.*

Subtask 3.2: Advanced Technologies

The objective of this subtask is to re-optimize existing cooling and dehumidification system approaches for India's commercial/multi-family new construction market. The task targets, develops, and tests advancements in HVAC technology which can significantly reduce energy use in both nations. Another objective of this subtask is to characterize and identify high-performance LED systems, identify lighting applications in built environments that can benefit from LED technology, and understand the interaction of lighting systems with building cooling systems.

Background

Subtask 3.2 Advanced Technologies, consists of two tasks: (1) Advanced HVAC and (2) Advanced Lighting.

In the Advanced HVAC task, work is being conducted to identify and optimize existing cooling and dehumidification systems, to improve market acceptability by increasing efficacy and reducing complexity and cost. Through field demonstration, the efficacy of improvements in Dedicated Outdoor Air Systems (DOAS) and Micro Channel Heat Exchangers (MCHX) will be developed, deployed, and validated.

Team members

Affiliation	Name
Advanced HVAC team	
MNIT-J	Jyotirmay Mathur, Lalit . K. Joshi, Kamlesh Jagratwal, Pramod Kumar, Dharmendra
IIT-B	Milind Rane
	Mahabir Bhandari, Isaac Mahderekal, Patrick Hughes
Advanced Lighting team	
RPI	Nadarajah Narendran
CEPT	Rajan Rawal, Agam Shah
IIIT–H	Vishal Garg, Hema Rallapalli

Progress so far

Subtask 3.2A: Advanced HVAC

Subsequent to a detailed review of chilled water systems in India, ten sites have been identified for the performance evaluation of chilled water systems. Data on past performance of chillers is also being collected from industrial partners in CBERD and PACE- R energy consultant's reports. The initial performance assessment has been done for six locations.

The analysis framework for existing chillers and prevailing practices has been completed. A comprehensive methodology for evaluating the performance of chillers has been prepared and circulated to HVAC experts for suggestions and observations. This methodology, besides evaluating the field assessment of chillers, simultaneously evaluates maintenance practices and historical data for the past 12 months.

A visit to the Underwriters Laboratories (UL) test labs at Chennai and Hyderabad was taken to assess the test facilities for chillers and unitary air conditioners. UL has offered the use of their test facilities until one is available at MNIT-J.

The radiant cooling system offers significant saving options in chilled water systems. Presently the installations in India are limited. The simulation-based analysis of radiant systems and validation with measured parameters has been carried out for Tech Mahindra building in Hyderabad (See Figure 17), and similar work is being conducted for Infosys building in Hyderabad. As an extension of innovative ways for optimizing chilled water systems, a radiant table for personalized cooling was developed and performance evaluation was carried out, both through simulation and validation with actual deployment data. (See Figure 18).

In the absence of Indian chiller rating standards, the current dependence is on ASHRAE/AHRI standards, which are not aptly suited to Indian climatic conditions. MNIT-J has actively participated in the finalization of these standards for the Indian context. This will help in appropriate sizing of chillers for India's climatic conditions. MNIT has conducted comfort surveys and carried out extensive statistical analyses for conditioned, hybrid, and unconditioned buildings in the composite climatic zone for assessment of energy-saving potential.

A variety of non-compressor DOAS options are available in the Indian market. Literature review and market research suggests that these systems could reduce overall energy consumption in Indian HVAC systems by 30% to 80%,

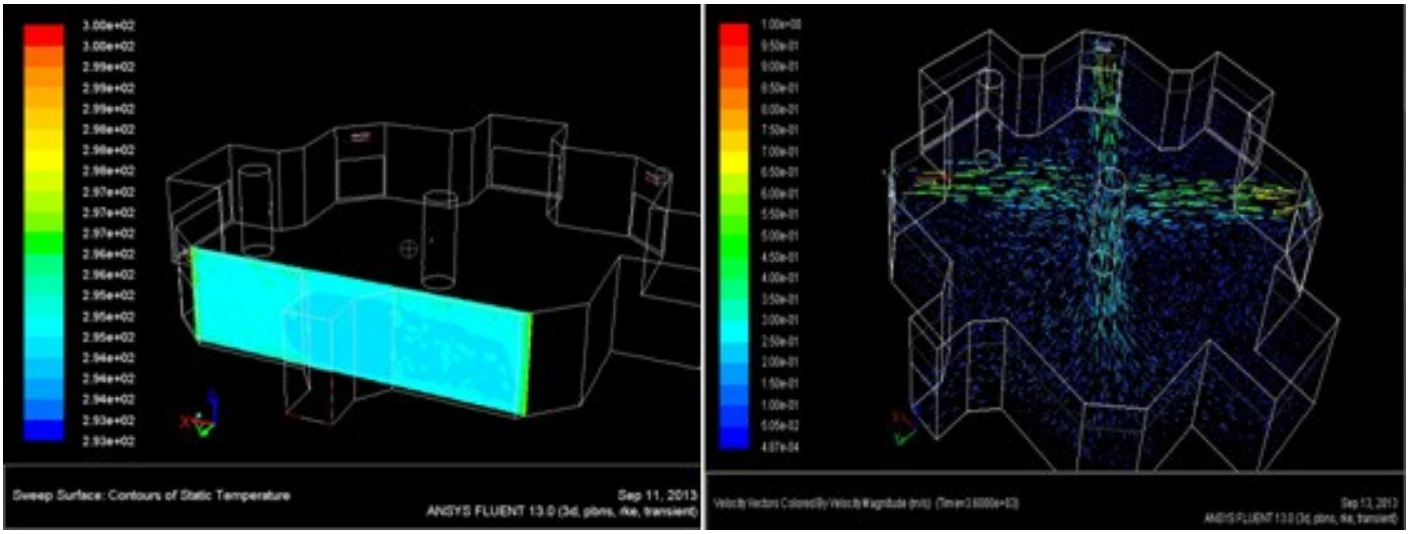

Figure 17: A snapshot of a computational fluid dynamics (CFD) model for a radiant cooling system at Tech Mahindra.

depending on the outdoor and indoor design conditions in effect when deployed to treat ventilation air. It is understood that the savings potential increases with a corresponding increase in outdoor dry-bulb temperature (DBT) and dew point temperature (DPT) or RH. Among the various DOAS systems being considered for further development are an Air-to-Air Heat Exchanger system and Liquid Desiccant System for Fresh Air Dehumidification.

Findings from a brief literature review on the features and challenges of micro channel heat exchangers (MCHX) suggests that whilst the MCHX have the potential to reduce the size, weight, and cost of the evaporator, they have had limited success in the field and market acceptability within India, and manufacturers have been wary of adopting MCHX due to past failures.

Subtask 3.2B: Advanced Lighting

As part of the establishment of the test facility for LED lighting at IIIT-H, the RPI and IIIT-H teams are finalizing the list of equipment and the design of the test setup.

Two 2-day advanced lighting workshops were conducted in Bangalore and Delhi. In September 2013, the Indian Society of Lighting Engineers provided half the funds (cost share), and took care of the logistics of running these two workshops. The workshops were very successful, exceeding the total number of participants anticipated. Between Bangalore and Delhi, more than 75 people participated.

RPI has offered admission and scholarship to a student from India to pursue graduate studies in Lighting. The total value of the package exceeds $70,000 for the academic year 2013/14). This student will work on research projects relevant to the CBERD program.

Notable Achievements

- *A review of the current state of the art on DOAS and MCHX for evaporators in small unitary systems has been completed, together with an initial performance assessment of chilled water systems in six locations.*
- *The team conducted well-received workshops on Advanced Lighting in two Indian cities.*

Figure 18: An experimental radiant cooling table for personalised cooling.

Subtask 3.3: Comfort Studies

Major/Key Research Objectives

The primary objective of this task is to develop methodology, protocols, and techniques for the study of human thermal comfort in a climate chamber and in commercial buildings in India.

Background

This subtask has two key activities: (1) Post-occupancy evaluation of buildings employing a building user survey, and (2) Development of an adaptive thermal comfort tool linked to simulation tools.

Team members

Affiliation	Name
CEPT	Rajan Rawal , Sanyogita Manu, Yash Shukla, Agam Shah
MNIT–J	Jyotirmay Mathur
UCB - CBE	Gail Brager

Progress so far

CEPT and UC Berkeley have conducted a literature review of conventional and advanced office design attributes for five Indian climates. Data on existing methods for assessing insulation of Indian clothing (clo) has been gathered.

For the subjective assessments, an online survey tool developed by the Center for the Built Environment (CBE) at UC Berkeley is being used. This survey has previously been deployed in over 600 buildings, and the data collected will provide a unique benchmark for comparing the performance of U.S. buildings. The survey tool is being contextualized for India, and a pilot survey is being administered. Criteria for selection of buildings to survey have been established.

The CBERD team has conducted a literature study of existing chambers, type of experimentation, and specifications, and has identified the research questions for the chamber experiments. Specifications of systems, hardware, and software required for the chamber have been formulated. Indian researchers have received training in the design and operation of the chamber, experimental protocols, and survey design and administration.

CEPT and the CBE team have prepared a detailed design and specification for a Thermal Comfort Chamber (TCC). TCC is a specially designed chamber measuring 5 m x 4 m x 3 m, representing a typical office space. (See Figure 19). The chamber can precisely simulate a wide range of indoor environmental conditions with temperatures ranging from 15°C to 35°C and

Figure 19: Thermal Comfort Chamber

relative humidity from 20% to 80%, along with changing air distribution patterns as well as air speed . These conditions are maintained and monitored by sophisticated air conditioning systems and control devices. The purpose of the TCC is to conduct experiments to evaluate the impact of various indoor environmental conditions on occupant comfort, productivity, etc. Individuals participating in the study would sit at one of four workstations in TCC and experience thermal conditions set by the research team. At the end of the experiment, they will take a survey and provide quantitative and qualitative feedback about their experience.

Notable Achievements

The Comfort Studies teams at UC Berkeley and CEPT have jointly finalized the survey questionnaire and will begin programming so that it is ready for implementation.

4.0: Supplemental Applications

Activities of this task are to (1) Explore the grid responsiveness and renewable integration for commercial buildings, (2) Coordinate R&D expertise and industry for building integrated photovoltaic (BIPV) technology development and its application in roof, wall, and window-mounted versions. Another objective is to prepare final specifications for public dissemination, preparation of guidelines and renewable energy (RE) products that are ready for deployment. (3) Conduct a triple bottom line cost analysis of building energy efficiency systems and technologies.

Background

This work task is divided into three subtasks: (1) Grid-Responsive Buildings, (2) Renewable Integration, and (3) Cost Optimization of Energy Efficiency. The grid-responsive and connected building application is the key to link energy efficiency and daily operations, such as demand response (DR), to achieve electricity reliability and operational efficiencies through CBERD building technologies.

Team members

Affiliation	Name
LBNL	Girish Ghatikar
IIM-A	Dr. Amit Garg
IIT-B	Dr. Milind Rane
MNIT-J	Dr. Jyotirmay Mathur, Lalit K. Joshi, Kamlesh Jagratwal, Sumit Sharma, Dharmendra Kumar, Sanjay Kumawat
CEPT	Rajan Rawal, Agam Shah, Sanyogita Manu
CMU	Vivian Loftness, Rohini

Progress so far

4.1 Grid-Responsive Buildings

This activity has produced a framework to integrate building technologies to the Smart Grid through collaborative knowledge and industry partnerships, including identification of the key sectors for intervention to bolster grid responsiveness. These activities will help develop integrated building technologies for both energy efficiency and needs of the Smart Grid.The team has conducted an extensive literature review of Smart Grid initiatives/projects in India and internationally, grid-responsive buildings, automated demand response (AutoDR), and various building automation and control technologies systems . A load survey of various institutional buildings, malls, commercial buildings, hospital buildings, hotel buildings, and others has been completed. A grid- responsive building (GRB) implementation draft proposal has been prepared.

4.2 Renewable Integration

BIPV/building-applied PV (BAPV) technology has been short-listed by the U.S. and Indian institutional partners as the main focus area for renewable integration in buildings to increase the energy yield. To leverage the opportunity of using BIPV products in the upcoming new facility of industrial partner REIL at Jaipur (scheduled by 2014), the design of various early-stage BIPV prototypes has been undertaken. Their performance monitoring would be done by MNIT-J. Some of the prototype designs are shown in Figure 20 below.

For concept validation, and to test the performance of BIPV/BAPV systems, an in-house design of a “flexilab” has been developed (Figure 21). The test facility would enable researchers to forecast the energy yield of configurations at different orientations/directions, and the effect on indoor daylighting

Figure 20: A BIPV prototype developed and being monitored

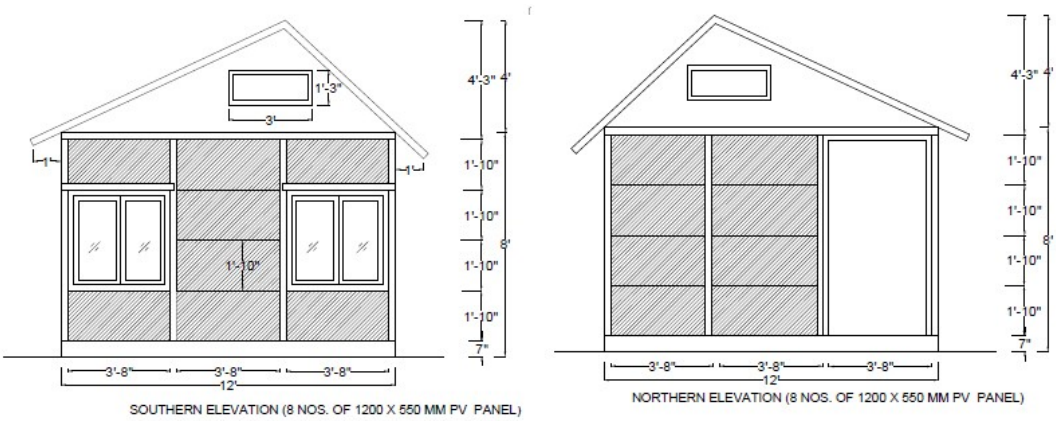

Figure 21: 'Flexilab' in-house facility for testing BIPV/BAPV system

and altered heating/cooling needs due to use of BIPV products. Additionally, the performance evaluation of existing RE systems has been conducted at ten locations.

4.3 Cost Optimization

The United Nation's ICLEI Triple Bottom Line standard, the dominant public-sector full-cost accounting tool, has been identified as the framework of choice to reflect the benefits of investing in energy-efficient technologies in India and the United States. Cost-effectiveness will be measured in simple payback and net present values, in three successive calculations that reflect economic, environmental, and human benefits.

Emissions data for CO_2, SO_2, and NO from coal-fired plants in India have been collected. In Year 2 of this project, collaboration with other projects at LBNL should provide environmental data on particulate emissions and water use from coal power plants.

Conventional and advanced office attributes for five climates in India have been identified, and the building stock has been classified as Historic (Colonial era); Indigenous Climate-Responsive; Rapid Low-Cost, and Modern High-Technology buildings.

The nature of clothing in Indian climates has been assessed in collaboration with Task 3.3. That assessment may change conditioning priorities in offices in different climates of India, including: the temperatures at which cooling might be needed; the viability of natural ventilation and fan cooling; and the ability to eliminate heating.

To create a repository of passive design techniques that can be promoted in the U.S. and India, passive design strategies beneficial to achieving energy efficiency and thermal comfort in Indian buildings have been identified.

Notable Achievements

1. *Designs have been evolved for Innovative BIPV products like overhangs (flexible &fixed types) and double skin.*
2. *Dissemination of knowledge for enhanced RE utilisation in buildings has been done in conferences and seminars in India.*
3. *CBERD-MNITJ have associated with REIL at the building design stage for developing the facility as net zero/near net zero through improved design and enhanced use of innovative BIPV products to showcase RE opportunities in buildings.*

5.0: Scientific Collaboration

The objective for this task is to conduct scientific collaboration for development of R&D education and advancement. CBERD's plans include consideration and analysis of such collaboration, which is currently lacking and is a key barrier to the advancement of building energy efficiency.

Background

Scientific collaboration focuses on advancement of R&D education and creating pathways towards deployment of the R&D coming out of CBERD. Scientific collaboration is understood as a key barrier to the advancement of buildings energy efficiency. educate building energy stakeholders This activity is distinct from workforce development or capacity building that are both deployment specific. CBERD partners understand the skills needed at various levels, and the engagement of our academic partners (e.g., UCB, CMU, CEPT, IIM-A) and deployment partner, Nexant will help us develop training and curricula, including any necessary student and R&D staff exchange, while keeping in mind intellectual property issues and government policies.

Team members

Affiliation	Name
LBNL	Reshma Singh
CEPT	Rajan Rawal
Indian team	Milind Rane (IIT-B), Jyotirmay Mathur (MNIT-J), Vishal Garg (IIIT_H), Amit Garg (IIM-A). Mona Doctor (CSR)
US team	Gail Brager, Francesco Borelli (UCB), Vivian Loftness (CMU), Naren Narendran (RPI)

Progress so far

An internal collaboration tool, the "Project Pier" has been constructed. This will enable participants to share CBERD management and R&D documents, and it will be a repository of ongoing reports, deliverables, and publications.

A total of six research exchanges have occurred. Researchers from the Indian institutions MNIT-J and IIIT-H have visited the U.S. and trained with LBNL and ORNL experts on hygrothermal laboratory equipment, simulation/modeling, and cool-roof equipment testing protocols.

A CEPT researcher visited UCB and LBNL for a period of four weeks to work jointly on the Windows and Daylighting,

Comfort Studies, and Passive Design R&D subtasks. The researcher was trained in the design and operation of a controlled environment chamber, methods of data collection, instrumentation, and data analysis. Another researcher from MNIT visited ORNL in October 2013 to work jointly on the Advanced HVAC subtask.

A calendar of conferences/workshops that can be leveraged has been developed to disseminate research findings of various technical tasks.

White papers, journal papers, and reports have been prepared or submitted for the various technical tasks, such as Simulation and Modeling, Monitoring and Benchmarking, Cool Roofs, and Advanced HVAC.

Notable Achievements

- *Launched Project Pier, a project collaboration tool*
- *Released 13 joint publications and papers*
- *Conducted six productive researcher exchanges*
- *Held two well-received workshops in India on solid-state lighting*

Key Outcomes

The first year-and-a-half of CBERD activity has strongly emphasized the creation of a vibrant consortium of 11 R&D partners, over 30 industry partners, and organizational partners in both countries. CBERD is gaining momentum in joint research and collaboration, and is setting out towards achieving its technical goals. CBERD has also placed a substantial focus on initiating a productive collaborative relationship with its industry partners through work sessions, ongoing communications, and development of an over-arching common technology management plan for intellectual property (an IP management plan). In addition to the major thrust dedicated to managing and coordinating a project of this magnitude, researchers in both countries have collaborated to conduct joint R&D, with first-year contributions towards technical R&D outcomes, research exchanges and workshops, and publications, as detailed below.

Technical R&D Outcomes

The R&D outcomes for each task/subtask are categorized by contributions in energy analysis and tools, methodologies and models, and technology development.

A. Energy Analysis and Tools

The Simulation and Modeling R&D team developed a semi-automated tool for Model Predictive Control based on EnergyPlus for low-energy cooling systems (e.g., radiant and night flush-natural ventilation), which will be field-tested in the cost-share partner facilities. The Envelope / Passive Design R&D team's outcomes included an early stage, web-based, windows and façade optimization tool; WinOpt development; joint development of new COMFEN-India; and a cool roof calculator updated to optimize use of radiant barriers, bulk insulation, and reflective roofing to save energy and money.

B. Methodologies and Models

The Monitoring and Benchmarking R&D team developed a roadmap for advancing state-of-the-art building energy benchmarking in India. This included the development of a building energy benchmarking data collection template that is under review by the Indian Bureau of Energy Efficiency (BEE) for the purposes of deployment. A new benchmarking model for hotels and hospitals in India was developed that would also inform the U.S. benchmarking models. This team also developed a data centre EIS guide, which is a methodology for selecting and installing an appropriate energy information system in data centres. An outcome of the Advanced HVAC systems R&D team included the creation of a new methodology for chiller performance evaluation. The research outcome of the Comfort Studies R&D team included new methods for assessing Indian clothing (clo) values for adaptive thermal comfort.

C. Technology Development:

The Controls and Communication R&D team developed a new, smart, wireless luminaire controller with temperature, illuminance, electrical power, and occupancy sensors, Also developed was a low-cost energy meter that logs energy data for the connected device, producing algorithms to identify load types plugged into an outlet based on device-level metering. There is ongoing technology development in the area of advanced HVAC systems that includes a new micro-channel heat exchanger for use in a unitary HVAC system, which is being developed in coordination with a cost-share partner. The U.S. team provided technical assistance to the Indian team on the development of equipment and instruments for the purpose of building test beds at Indian team institutions. This included:

(1) angular tubes spectrometer accessory prototypes for accurate windows/daylighting measurements, (2) guarded hot-box and hygrothermal facilities, and (3) a fault detection and diagnostics lab.

Research Exchanges and Workshops

In February 2013, LBNL hosted a two-day visit by representatives from five of the six Indian R&D institutions (CEPT, IIT-B, IIIT-H, MNIT-J, and CSR). They reviewed the scope and respective work products and also familiarized themselves with researchers from both countries.

In September 2013, RPI provided two 2-day interactive workshops in India, focused on solid-state lighting, for lighting professionals and stakeholders. The workshops were co sponsored by the Indian Society of Lighting Engineers (ISLE) and CBERD U.S. DOE. The workshops increased attendees' knowledge and awareness of energy-efficient solid-state lighting technologies, application, and design strategies. They also allowed information exchange on the latest LED developments; LED product characteristic and performance needs for successful indoor and outdoor lighting applications in commercial buildings in India; and LED lighting standards and recommended practices in the U.S. and India.

In order to better facilitate PACE-R and PACE-D collaboration, the U.S. and Indian CMOs continue to engage PACE-D partner Nexant, and have conducted meetings and work sessions to identify deployment pathways to disseminate CBERD research through PACE-D infrastructure.

CBERD industry partner Schneider Electric collaborated with the Indian and U.S. research and development team in development and preparation of "Gap Analysis Relative to Current State of the Art in Indian Benchmarking".

U.S. experts from LBNL and ORNL visited India to provide technical guidance to the India team for development of physical infrastructure for thermophysical and hygrothermal testing facilities. They also conducted work sessions on monitoring/benchmarking with CEPT University. An EIS charette was held in New Delhi between the R&D and industry partners to leverage U.S. partner expertise in energy information systems.

Gail Brager of CBE visited CEPT University to advance activities on thermal comfort research, whilst Rohini Srivastava, of CMU, visited CEPT University to advance work on cost-optimisation.

There have also been multiple visits by Indian team members to the U.S. institutions, as described below:

- Indian industry partner Skyshade visited RPI-LRC to get training on hygrothermal laboratory equipment.
- Two IIIT-Hyderabad staff members visited LBNL; one to understand the equipment and testing protocols used by LBNL for cool roofs; and the other, for fault detection and diagnosis in simulation tools.
- A researcher from CEPT was stationed for four weeks at UCB and LBNL to work on Windows/Daylighting, Thermal Comfort, and Passive Design R&D subtasks. The researcher was trained in the design and operation of a controlled environment chamber, as well as in methods of data collection, instrumentation, and data analysis. A researcher from MNIT visited ORNL to work on Advanced HVAC sub- task.
- A researcher from MNIT visited ORNL to work on the Advanced HVAC subtask.

Publications

R&D Work Task 2.0

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3. *Mathew, Paul, Reshma Singh, Saket Sarraf, Shilpi Anand, Yash Shukla, and Satish Kumar. "Building Energy Benchmarking in India: An Plan Action for Advancing the State-of-the-Art." 2014.*
4. *Singh, Reshma, Rod Mahdavi, Paul Mathew, Jessica Granderson, and Yash Shukla. "Guidelines for Data Center Energy Information Systems." 2013.*
5. *Cheung, Iris, Steven Lanzisera, and Vishal Garg. "Evaluation of the Market and Products Enabling Energy Efficiency Lighting, Plug-loads, and HVAC in Buildings." 2014.*
6. *Chuang, F. "Performance Guarantees for Certainty Equivalence Control with Uncertain Linear Dynamical Systems. Application to Low Energy HVAC Systems."*
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9. *Slack, Jonathan, D. Charlie Curcija, and Jacob Johnsson. "Angular Tubes Spectrometer Accessory." 2013.*
10. *Tetali, S. et al. "Effect of Roof Insulation on Energy Consumption in Office Buildings with Cool Roofs in India." 2014.*
11. *"Optimizing Roof Insulation for Roofs with High Albedo"*
12. *"Coating and Radiant Barriers in India"*
13. *Rane, Milind V., Shreyas Chavan. "DOAS with Evaporative Precooling of Exhaust Air Using Rotating Contacting Device." Paper presented at the First International Conference on Energy and Indoor Environment for Hot Climates, Doha, Qatar, February 24-26, 2014.*
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14. *Rane, Milind V., Shreyas Chavan. Multi Utility Evaporative Cooler with Diabatic Contacting Device." Paper presented at the First International Conference on Energy and Indoor Environment for Hot Climates, Doha, Qatar, February 24-26, 2014.*
15. *Mathur, J., Vaibhav Rai Khare, Yasin Khan, Mahabir Bhandari. "Radiant cooling system: A case study of assessment of energy savings in an office building. " Paper presented at the 3rd National Conference on Refrigeration and Air Conditioning., Madras, Chennai, December 12-14, 2103.*

R&D Work Task 4.0

16. *Basu, Chandrayee, Girish Ghatikar, Prateek Bansal. "Enabling Efficient, Responsive, and Resilient Buildings: A Collaboration Between the United States and India." Paper presented at the IEEE Great Lakes Symposium on Smart Grid and the New Energy Economy, Chicago, Illinois,September,23-25,2013*

Key Next Steps

Task 2.0: Building Information Technology

a. Develop T-24 rule sets for the Simergy implementation of the CEC SDK, 90.1. rule sets for CEC SDK and alpha version of the EnergyPlus GUI with code compliance features and support for low energy design using hybrid ventilation

b. Pilot EIS selection and specification guide for data centres and extend to other commercial buildings for use in US and Indian data centers. Develop advanced algorithms for hotel and hospital benchmarking.

c. Deploy a stable version of the building data exchange and controls platform in both India and the US, conduct preliminary integration of EnLighted and Honeywell building systems with this platform and analyze the data from the plug load monitoring experiment to be conducted in IIIT Hyderabad.

Task 3.0: Building Physical Systems

d. Begin natural exposure of Indian roofing products shortly to provide three years of natural exposure within the CBERD time frame. The initial and aged values of solar reflectance and thermal emittance will be used to calibrate a laboratory method of accelerated aging suitable for Indian climates.

e. Continue further characterization of glass products sold in India and submit them for inclusion in the International Glazing Database (IGDB) and extension of COMFEN features that benefit India's team.

f. Provide advice on the refinement of test bed design and guidance on the fabrication of angular tubes.

g. Refine the characterization of a range of mixed-mode building types in India and procure monitoring equipment and weather stations.

h. Finalize review of simulation criteria for naturally ventilated buildings.

i. Develop new layouts and design nomographs for Earth Air Tunnels, which would be applicable to U.S. buildings as well.

j. Revise the online survey form for the Indian context.

k. Select buildings for the deployment of the online survey.

l. Conduct initial deployment of the online comfort survey in pilot buildings, to test new methods.

m. Continue ongoing design and construction of Thermal Comfort Chamber at CEPT.

n. Conduct demonstration and training of the National Environmental Assessment Toolkit (NEAT) physical instrumentation from CMU.

Supplemental Applications

- Minimize roof glare. Work will start as per the schedule provided in M&D: 1 April 2015 through 30 September 2015.
- Determine the effect of cool roof and insulation. Work will resume as per the schedule provided in M&D (2015).
- Characterize 63 samples from Asahi India Glass Limited and 130 samples from Saint-Gobain Glass India for their optical properties.
- Produce an analysis report of the performance assessment of the application of BIPV/BAPV products in buildings.
- Fabricate concept validation BIPV test lab at MNIT-J and conduct a performance assessment of evolved innovative BIPV products.
- Produce a design document of evolved BIPV products for dissemination and adaptation by industry.
- Produce a joint technical report titled "Scoping study to link building technologies to Smart Grid needs and integration of building control systems to supply-side "
- Technical joint report titled "Scoping study to link building technologies to "Smart Grid needs and integration of building control systems to supply-side"
- Technologies and standards to integrate building energy efficiency for grid-responsiveness.
- Illustrate the range of technologies that are or can be available in the Indian context, with value to the U.S industry as well. Gather cost, performance specification, and benefit information from those industries.
- Initiate a cost-benefit analysis, inclusive of technology first costs, known operation and maintenance costs, and simulated or measured energy savings (first bottom line).
- Initiate second-bottom-line calculations with GHG and water costs for the corresponding energy sources in the five regions (second bottom line).
- Initiate research on human benefits that might be gained through these energy conservation measures (future third bottom line). A user satisfaction survey in existing Indian buildings with variations in shade/daylight and electric light responses may provide insights into the human benefits of these technologies.

Task 5.0: Scientific Collaboration

- Develop stronger collaboration with outcomes deployment partner Nexant.
- Continue to expand researcher and graduate student exchanges.
- Continue to write and publish white papers, presentations and joint publications.

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