The U.S.-India Joint Clean Energy Research and Development Centre
Building Energy Efficiency

US-India Joint Centre for Building Energy Research and Development

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

The U.S. –India Joint Center for Building Energy Research and Development (CBERD)
A summary of the CBERD and Joint R&D activities for Year 1 and first-half of Year 2: November 2012 to March 2014

Published by Consortia Management Office, CEPT University and Lawrence Berkeley National Laboratory, April 2014

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CBERD is an US-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. Consortia is jointly led by CEPT University, Ahmedabad, India and Lawrence Berkeley National Laboratory, Berkeley, USA

Award letter number and date/ IUSSTF/JCERDC-EEB/2012 dated 29 November 2012
The Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, of the U.S. DOE under Contract No. DE-AC02-05CH11231

R&D Partners - India

CEPT University

Auroville Centre for Scientific Research

The International Institute of Information Technology Hyderabad

Indian Institute of Management Ahmedabad

Indian Institute of Technology Bombay

Malaviya National Institute of Technology Jaipur

R&D Partners - USA

Lawrence Berkeley National Laboratory

Carnegie Mellon University

University of California Berkeley

Oak Ridge National Laboratory

Rensselaer Polytechnic Institute

Industry/Cost-Share Partners

India

Asahi India Glass Ltd.

Biodiversity Conservation India (Private) Ltd.

Infosys Technologies Limited

Neosilica Technologies Pvt Ltd.

Oorja Energy Engg Services Hyd Pvt. Ltd.,

Paharpur Business Centre / Green Spaces

PLUSS Polymers Pvt. Ltd.,

Philips Electronics India Ltd.,

Saint-Gobain Glass India Ltd.,

Schneider Electric India Pvt. Ltd.,

SINTEX Industries Limited,

Skyshade Daylights

Wipro EcoEnergy,

U.S.

Autodesk, Inc.

California Energy Commission

Delphi

enLighted Inc.

Honeywell

Lighting Science Group Corp

Nexant

Saint Gobain Corp

Synapsense

Indian Society of Lighting Engineers (collaborating with U.S. company, Lighting Science)

Organizational Partners

India

Glazing Society of India

Indian Green Building Center, Confederation of Indian Industries

Indian Society of Heating Refrigeration and Air Conditioning Engineers (ISHRAE)

Rajasthan Electronics and Instruments Limited (REIL)

U.S.

City of San Jose

HOK Architects

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 US–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 to promote energy efficiency innovation towards significant reduction in buildings energy use in the United States and India.

This report summarizes the work jointly conducted by all consortia partners during the time period November 2012 to 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 buildings energy use in both nations. This goal will be achieved through three key strategies, as described below.

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

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

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, with deep experience in collaborative research, and is accomplished in bringing new technologies to market at scale, to provide game-changing innovation. In the US, 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 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 has committed to collaborate with CBERD to develop advanced building technologies to reduce energy consumption.

The Industry partners are contributing both "In-kind" and "cash"cost-share to the project. There are also selected not–for-profit organizations supporting CBERD's activities. 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 includes Asahi India Glass, Bio diversity Conservation India, Infosys, Neosilica Technologies, Oorja Energy Engineering Services, PBC Ventures, Philips ,Pluss Polymers, Schneider, Sintex, Skyshade Daylights, and Wipro Eco Energy. Saint Gobain will collaborate 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 Center, Glazing Society of India, Indian Society of Heating Refrigerating and Air-conditioning Engineers, Indian Society of Lighting Engineers, Rajasthan Electronics and Instruments Limited. This deep level of collaboration with industry and not for profit collaborators will amplify and accelerate advanced building technologies available to the 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 in the U.S. and India by creating new ties as well as leveraging existing relationships and ongoing projects. Both LBNL and CEPT, and their partners maintain strong, long-standing connections to U.S. and India building energy- efficiency programs through ongoing research and training activities.

CBERD Project

Background

The paths to collaboration and co-operation in many diverse fields have brought friendship and understanding between the two largest democracies, United States of America (U.S) and India. Relying on successful historic partnerships and recognizing the need to address climate change and create a clean energy regime, the Indian Prime Minister Dr. Manmohan Singh and the US President Barack Obama signed a Memorandum of Understanding (MoU) in 2009 to enhance the cooperation. The U.S.-India Partnership to Advance Clean Energy (PACE) was formed as a result of this MoU. Through, one of the early initiatives of 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 areas of Solar Energy, Second Generation Bio fuels and Buildings Energy Efficiency. The Centres in the three identified areas are expected to accelerate transition to low carbon, high performance and energy secure economy. The PACE-R activities are coordinated by the Department of Bio Technology and Department of Science and Technology and administered by Indo-US Science and Technology Forum (IUSSTF) in India and by the Department of Energy (DOE) in the U.S.

Under the JCERDC program, both governments sought a joint proposal seeking aspirants to form joint consortia in both countries that would comprise of research and industry partners and secure commitment in terms of matching cost-share. After an extensive merit-review process, the U.S. and Indian awardees were announced in April 2012. The joint consortia named, the 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. U.S. and CEPT University, Ahmedabad, India and comprises of 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, institutional partners from both India and the U.S.

Overview

The United States and India are amongst 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 buildings technologies in both countries can significantly mitigate that energy use in buildings.

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 (Bureau of Energy Efficiency, 2011). India's electricity demand is projected to reach 1,900 terawatt-hours (TWh) by 2021–2022 (MOP, 2007), and its carbon dioxide (CO_2) emissions from coal combustion are projected to reach 1.3 billion metric tons 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 (IPC, 2011). 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.

The need is also evident in the U.S. The buildings sector contributes to 40% of the nation's energy consumption and CO_2 emissions, the highest of all sectors, and this sector's energy use is increasing faster than any other's (Coffey, 2009; Majumdar, 2009). The forecast is that the US will need another 200 GW of electricity generation capacity by 2030, at a cost of $0.5 trillion to $1 trillion (22 trillion to 45 trillion) (U.S. DOE, 2007)

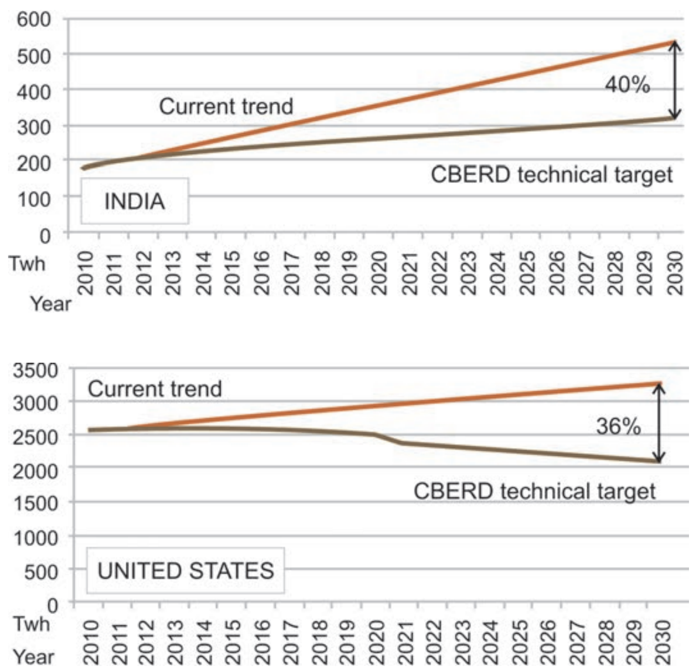


Figure 1: Building energy saving potential identified by the CBERD Project

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 1 shows the technical energy saving potential of 209 TW/year (40% savings) in India, assuming a 60% reduction in energy use for new construction, and a conservative 10% reduction through retrofits from the average benchmarked value approximately of 273 kWh/sq m/year (27.3 kWh/sqft/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, it targets primarily new construction in India and retrofits and operations in the U.S. 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 meet the goals. Aligning its vision with DOE (U.S. DOE Multi-year Plan, 2011–2015) and GOI's (IPC, 2011) societal concerns and industry.

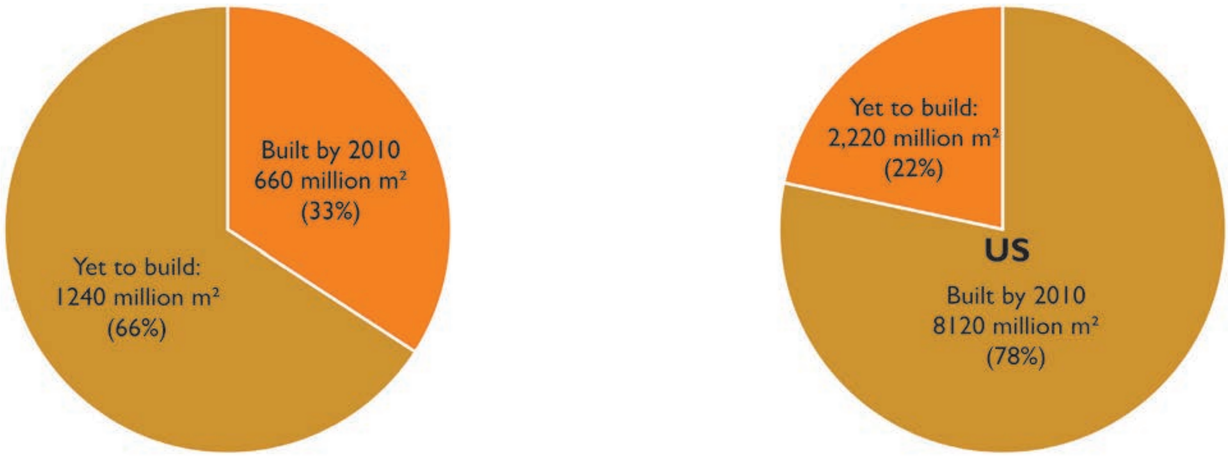


Figure 2: Proportion of floor space constructed by 2010 in India and US (USAID ECO III project)

CBERD is a R&D collaboration spanning both sides of the ocean under one virtual roof with the vision of-

- *Drawing upon the complementarity of R&D partners' experience and knowledge with well defined roles and responsibilities to maximum benefit in the field of building energy efficiency.*
- *Mapping to commercial strengths of industry partners in both nations to create bridges to commercialization/ deployment*
- *Creating opportunities for bilateral learning and exchange*

CBERD Project Objectives

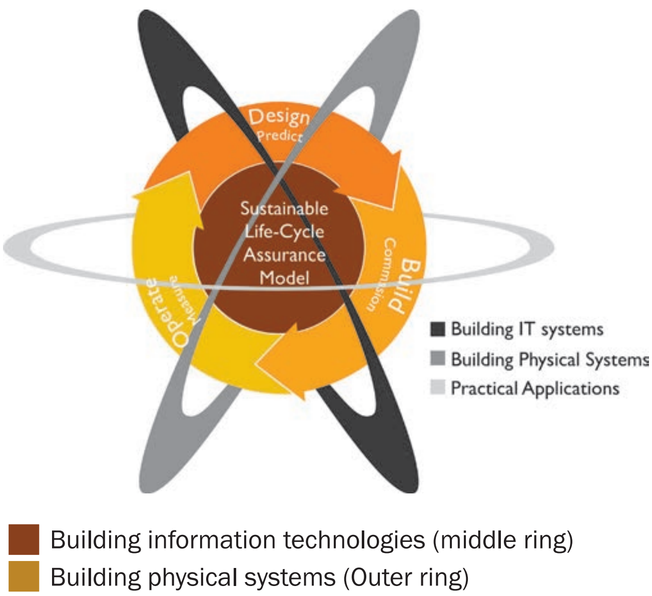
Objective-1: Optimize the building systems integration using the whole building approach across the building lifecycle to facilitate and advance high-performance buildings

CBERD will gain an in-depth analysis of how buildings in India and the U.S. use energy, and create a Lifecycle Performance Assurance Framework (LPAF) that supports building system integration throughout the building's design, construction, and operation, a departure from the conventional, fragmented approach. This will enable a whole-building, integrated view and simultaneously assure 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 utilization of innovative building information technology. This creates metrics at the three stages of the building lifecycle, in order to predict, commission, and measure the building performance. This includes developing whole-building and systems simulation tools/models that can estimate the building's energy performance and code compliance; controls and sensors for continuous measurement and tracking 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 focus on their supplemental application such as responsiveness to smart grid, renewable energy source integration, and cost optimization. (See Figures 3 and 4)

The overall 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 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 will focus on increasing the breadth of the building stock that will be impacted 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.



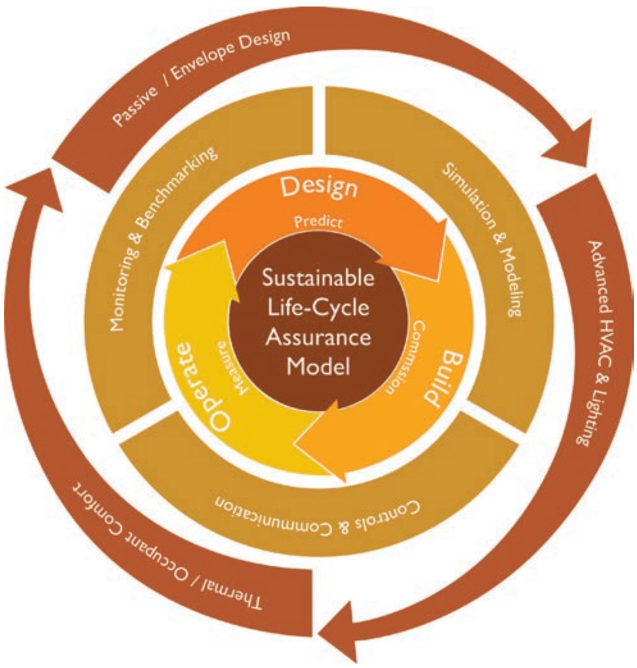


Figure 3 (left): CBERD's program consists of two R&D thrusts and supplemental applications will span the building lifecycle and yield significant new technology; Figure 4 (right): Key Diagram: CBERD's focus on Building Information Technology and Physical Systems integration will simultaneously enable a whole-building view and assure high performance.

Objective-3: Develope 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

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. Work on this objective will generate solutions geared toward Indian applications and advance appropriate regional and local technologies. This work will be coordinated with that of Objective 2 to ensure that the technologies will apply to all pertinent building types. The knowledge and lessons learned will be documented and will be applied in both countries. R&D will focus 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

In order to bridge the gap between standards and their implementation, CBERD will aim to develop design specifications, decision tools, algorithms and best practices guides. These will be supported by benchmarked and ongoing measured data in order to achieve the five-year performance targets for commercial and multi-storied residential buildings. this will enable the opportunity for significant improvements in energy performance of buildings.

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

CBERD will focus on overcoming knowledge gaps of the buildings research, design, and developer communities through training and education curricula. CBERD will aim to document, demonstrate, educate, and also use consortium-wide use of the test-bed facilities to accomplish this. Boosting the two-way knowledge transfer and capability levels of buildings stakeholders will facilitate information exchange, speed technology and product development that can help generate significant efficiencies to the U.S. and India.

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

Building on these 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 will help navigate the path from business-as-usual to high- performance buildings. CBERD will leverage team member's R&D and commercial experience and expertise to cohesively create significant and dramatic impact in both nations.

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

CBERD R&D Tasks and Collaboration Activities

1.0: Consortia Management and Coordination

2.0: Building Information Technology

Sub-task: Simulation and Modeling
Sub-task: Monitoring and Benchmarking
Sub-task: Controls and Communications Integration

3.0: Building Physical Systems

Sub-task: Envelope/Passive Design, Advanced Shells, Cool Roofs, Windows and Daylighting
Sub-task: Advanced Technologies, HVAC Systems, Advanced Lighting
Sub-task: Comfort Studies

4.0:Supplemental Applications

Sub-task: Grid Responsive Buildings
Sub-task: Renewable Integration
Sub-task: 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

In order 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. 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 (CMO) have included project R&D coordination, continued facilitation of industry engagement in the R&D activities, conducting partner meetings and work sessions, finalizing sub-contracts, and finalization of a comprehensive joint technology management plan for intellectual property (IP management plan).

Details are provided below:

- Strategic R&D planning to meet the joint R&D objectives in partnership with the research institutions and industry team members in both countries, and ascertain the R&D progress, outcomes, and identify any 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 identify 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.

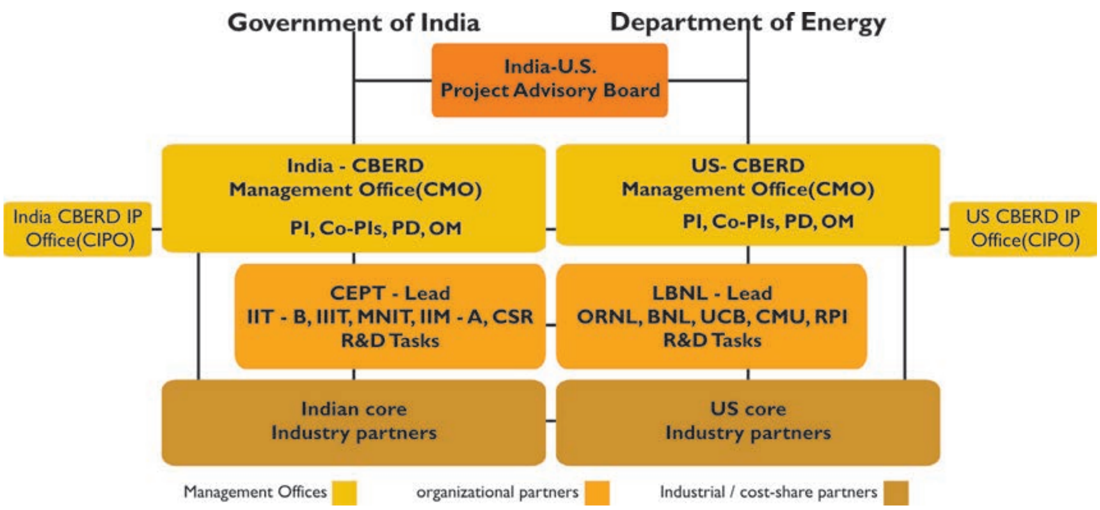


Figure 6: CBERD organizational/governance structure for project coordination and management.

2.0: Building Information Technology

Sub-task 2.1: Simulation and Modeling

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

Background

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

Team members

Affiliation	Name
LBNL	Philip Haves, Samuel Lawrence Brunswick
UCB	Francesco Borrelli
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 EnergyPlus Graphical User Interface (GUI) for advanced design, operations and performance rating and benchmarking activities. For the EnergyPlus GUI under development at LBNL (Simergy), 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. such as, an early stage window design tool for window optimization (WINOPT) has been developed. This tool will help the user in optimizing and selecting appropriate combination of window glass, Window to Wall Ratio (WWR), and overhang depth in different orientations of façade and in 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 (EPsysnc) using file synchronization techniques 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 carried out with a focus on the design and operation of experimental test facilities for the evaluation of Automated Fault Detection and Diagnosis methods.

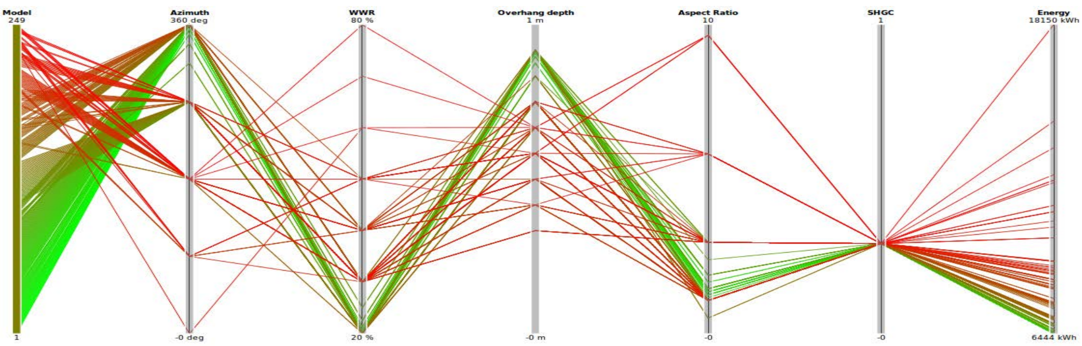


Figure 7: Screen shot of WINOPT tool, momogram

Notable Achievements

Public release of version 1.0 of Simergy, the free, practitioner-oriented user interface for EnergyPlus., Simergy 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.

Sub-task 2.2: Monitoring & 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 Systems (EIS) solutions for both countries.

Background

This sub-task will build on applicable concepts from U.S. benchmarking and energy information systems (EIS) activities. Expected deliverable of this sub-task 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 US and Indian markets.

Team members

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

Progress so far

A framework for EIS Guidelines is under development, including key performance indicators, hardware, communications and software requirements. This set of guidelines has an initial data centre target focus, which is now complete. This provides a bounded building typology where energy consumption is a critical concern (data centers can utilize upto 100 times more energy per unit areas than a standard office building). The comprehensive and vendor-neutral EIS guidelines have direct relevance for both US and Indian data centers and would empower data center owners, developers, operators and ESCOs to select and specify the appropriate EIS for their business purposes to deliver 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 Year2 of this project. The guidance will be expanded to other commercial building typologies such as offices, retail, hospitality, etc.

An action plan for advancing state-of-the-art building energy benchmarking in India has been developed. This is based on an extensive literature review of benchmarking efforts in US, India and Europe, documentation of highlights and lessons learnt, and gap analysis relative to Indian benchmarking-conducted in collaboration with industry partner 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 US benchmarking tools and programs. This includes not just the 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 using these forms will be used for benchmarking algorithm testing. Additionally, architectural asset data and operational energy data is being collected across almost 100 new buildings in Gujarat. CBERD project has collaborated with UNDP-GEF project administered by Bureau of Energy Efficiency, India to gather energy consumption data from approximately 1000 buildings across India.

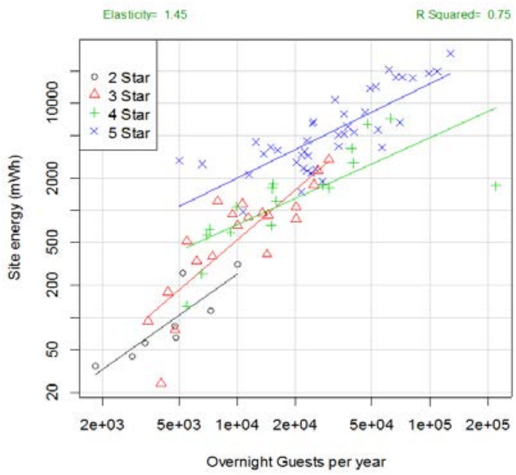


Figure 8: Energy performance of hotels

As part of the on going activities, data for hotels and hospitals in India from previous USAID ECO- III benchmarking activities have been gathered and a benchmarking model for these two sectors has been initiated. The benchmarking model will be completed in Year2 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 sub-task.

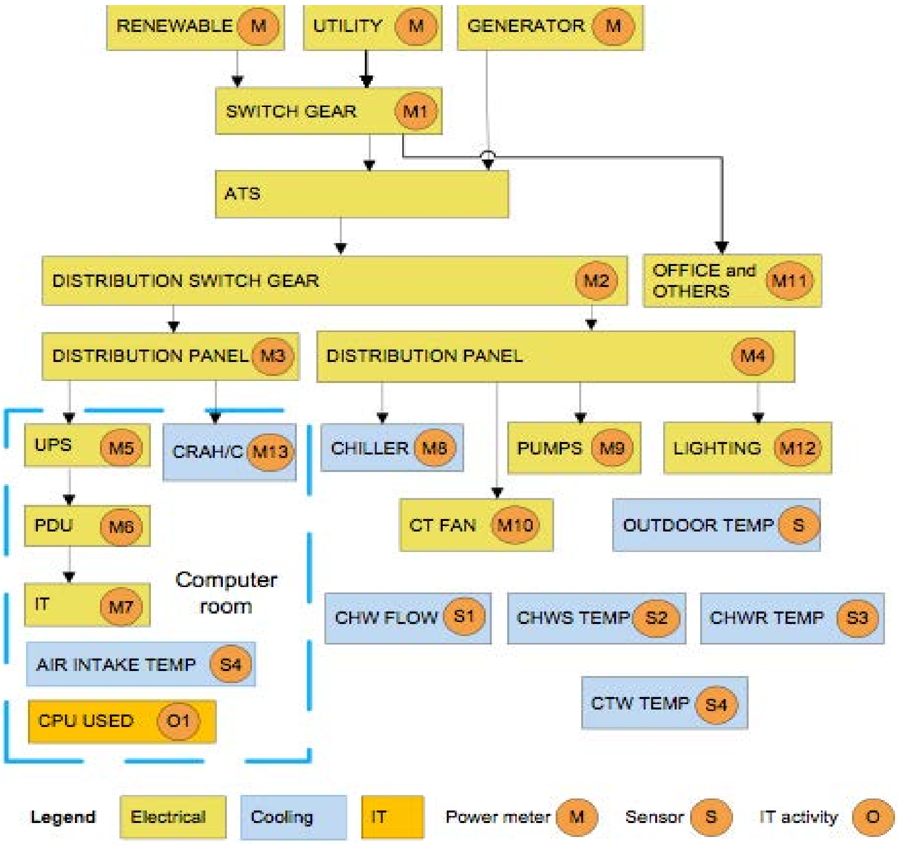


Figure 9: Datacenter EIS framework

Notable Achievements

Action Plan for Indian Bench marking and data collection template relative to India has been completed, being reviewed by the Indian Bureau of Energy Efficiency. 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 and being piloted in the US.

Sub-task 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, plug load.

Background

The sub-task 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 will also develop new smart luminaries 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 in this sub-task are grouped around:

- Advanced Lighting and Integration
- Plug-load controls and integration
- HVAC, Lighting, and Building System Integration

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 US teams, a foundational understanding of building systems in India, with a particular focus on commonalities and differences with standard US commercial building systems has been developed.

Advanced Lighting and Integration

The design of Smart Luminaire Controller designed by IIIT-H has been revised and testing of the samples are underway at IIIT Hyderabad facilities.

A dynamic window controller is being developed in order to integrate lighting with the 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 LED lighting control systems to be deployed at LBNL facilities.

Plug-load controls and integration

In line with the plug load monitoring performed in LBNL, an energy meter has been designed in 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 in the process of production for a monitoring experiment in IIIT-H. Recent studies by IIIT-H and CEPT suggests that plug load amount to very high energy consumption. At the same time, the potential for reduction in energy usage is also significant.

Using an extensive database of device-level plug load power traces collected in US buildings by LBNL, advanced algorithms that categorize loads into sensitive and standard loads are being developed. These algorithms use basic power meter data to identify if a load is sensitive (e.g., a computer), and only switch off power to non-sensitive loads (e.g., lights, displays, etc.) when the space is unoccupied or unutilized.

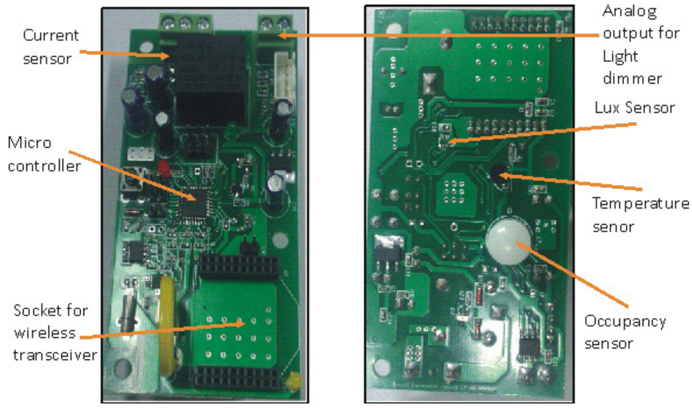


Figure 10: Lighting controls

HVAC, Lighting, and Building System Integration:

Starting with the U.C. Berkeley developed Simple Measurement and Actuation Profile (sMAP) system, LBNL has developed the foundation of a data exchange system running in their buildings to test its functionality and capabilities. Working with EnLighted and Honeywell, LBNL is investigating systems that are appropriate for interconnection with the data exchange platform. The work on data exchange and new control systems promises significant energy savings across the commercial buildings sector. The buildings equipment and controls industry, specifically the partners involved in this task, stand to benefit through early access to and joint development of these technologies.

Notable Achievements

Design and production of power meter for plug monitoring in India. Development of preliminary algorithms that identify plug loads appropriate for on/off power control.

3.0: Building Physical Systems

Sub-task 3.1: Envelope / Passive Design

This task focuses on physical building systems to address specific end uses and advanced technologies within buildings that are important to the indigenous needs of India.

Background

This task has been divided in four sub-tasks - 1) Energy Efficient Building Materials and Advanced Shells; 2) Cool Roof; 3) Windows and Day lighting 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. Develop and test cool roof technologies and advance the state-of-the-art technologies for both nations.
3. Development, testing, demonstration and validation of high performance glazing and daylight harvesting solutions.
4. Developing India-centric numerical tools to help architects and engineers make informed design decisions.
5. Generating a performance database of products and technologies available in India and enhancing test facilities to develop and evaluate complex fenestration systems available in India.
6. Scientifically evaluate passive design strategies used in buildings in India, develop prototypes and share 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

Affiliation	Name
Windows and Day lighting Team	
CEPT	Rajan Rawal, Sanyogita Manu, Yash Shukla, Agam Shah, Pranav Kishor, Vinod Patel
LBNL	Christian Kolher, 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 Nonekeri

Progress so far

Research Sub-task 3.1A: Energy Efficient Building Materials and Advanced Shells

The first phase of physical infrastructure for testing thermo-physical and hygrothermal properties of building materials has been designed and developed. This includes the design and construction of a Guarded Hot Box (GHB)in accordance with ASTM C236, to test wall, fenestration and floor and complex assemblies up to 1000m x 1000mm 350 mm thickness, thus making it very contextual to India. Another unique capability is the ability to conduct dynamic guarded hot box 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 m/s. GHB metering chamber temperature can be controlled from 22 to 28 ˚C.

The development of the hygrothermal facility includes procurement, installation and calibration of pressure plates, climate chamber, drying ovens, inert gas oven and ancillary equipment. The CBERD project team has identified ASTM C1498, C1699, E96, ISO 15148 and C518 as standards. This facility will have a climate chamber with RH controllability

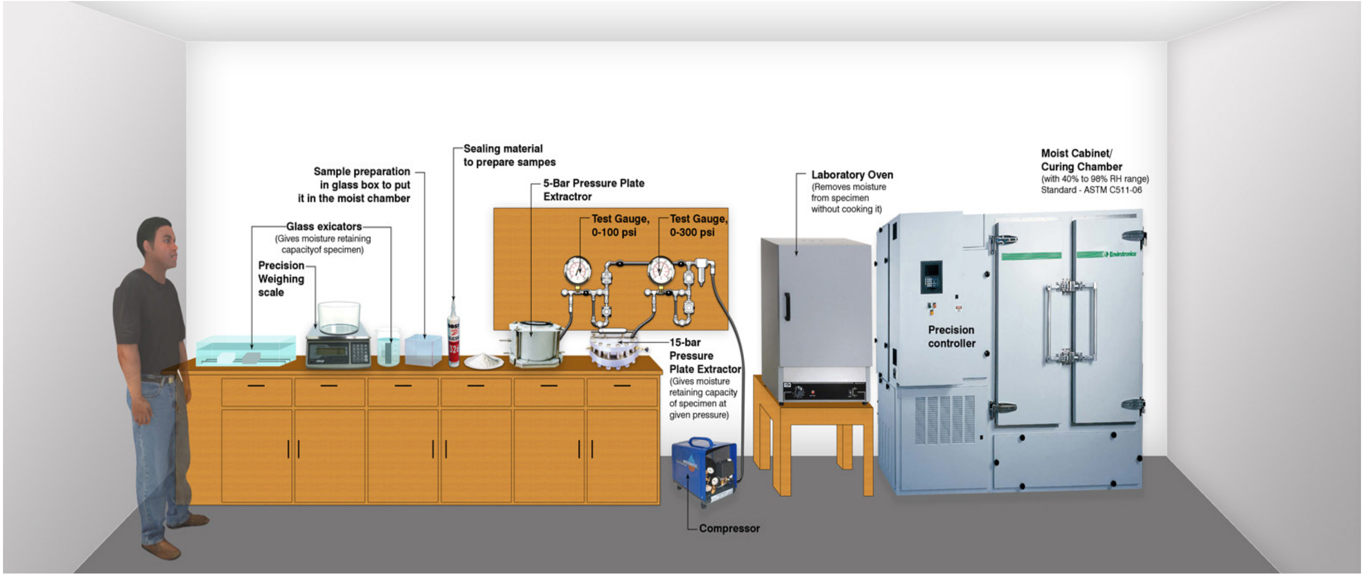


Figure 11: Artist's image of Hygrothermal characterization facility for building material

between 20% and 95% with precision of 3%. Output pressure can be regulated from 0.7 to 16 Bar. For guarded hot box and hygrothermal task facilities, the CEPT team has worked with ORNL. Installation and calibration of these will be finished by first quarter of Q2.

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 building being monitored for energy and environmental performance. To accomplish this a state-of-the-art, one of its kind facility at CEPT will be used. CEPT and ORNL are working with industry partner BCIL to expand the materials database. BCIL is helping CEPT team to 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. Advancement of this has shown encouraging results by developing form stabilized PCM panels.

Research Sub-task 3.1B: Cool Roofs

Approximately 120 cool roof materials are being tested in accordance with ASTM E903 standards at CEPT. 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 un-conditioned building has been identified for 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, 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 information should help the US-India team develop a variant of LBNL's accelerated aging protocol suitable for roofing product in Indian climates.

Research Sub-task 3.1C: Windows and Day lighting:

The main objective of this sub-task is to develop, test, demonstrate and validate cost effective, high performance glazing, shading and daylight harvesting solutions. Characterization of glass for their optical properties such as visual transmittance, absorptance and reflectance has

Figure12: Testing of window with daylighting system for Solar Heat Gain Coefficient

been carried out in accordance with ISO 9050 and EN 410 and in solar range as well as near IR range. The CEPT team has tested approximately 200 glazing samples available in the Indian market, which covers approximately 80% of the glass samples available in the Indian market from organized sector. These test results are available in the public domain. The results will be added to the COMFEN database and will

Figure 13: Artificial Clear Sky and Mirror Box

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. This will be constructed in Q2 of CBERD project. A mirror box is used to simulate overcast sky conditions for building models, which help architects and engineers understand day lighting inside the building and make necessary design improvements 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 day lighting is placed inside the mirror box 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

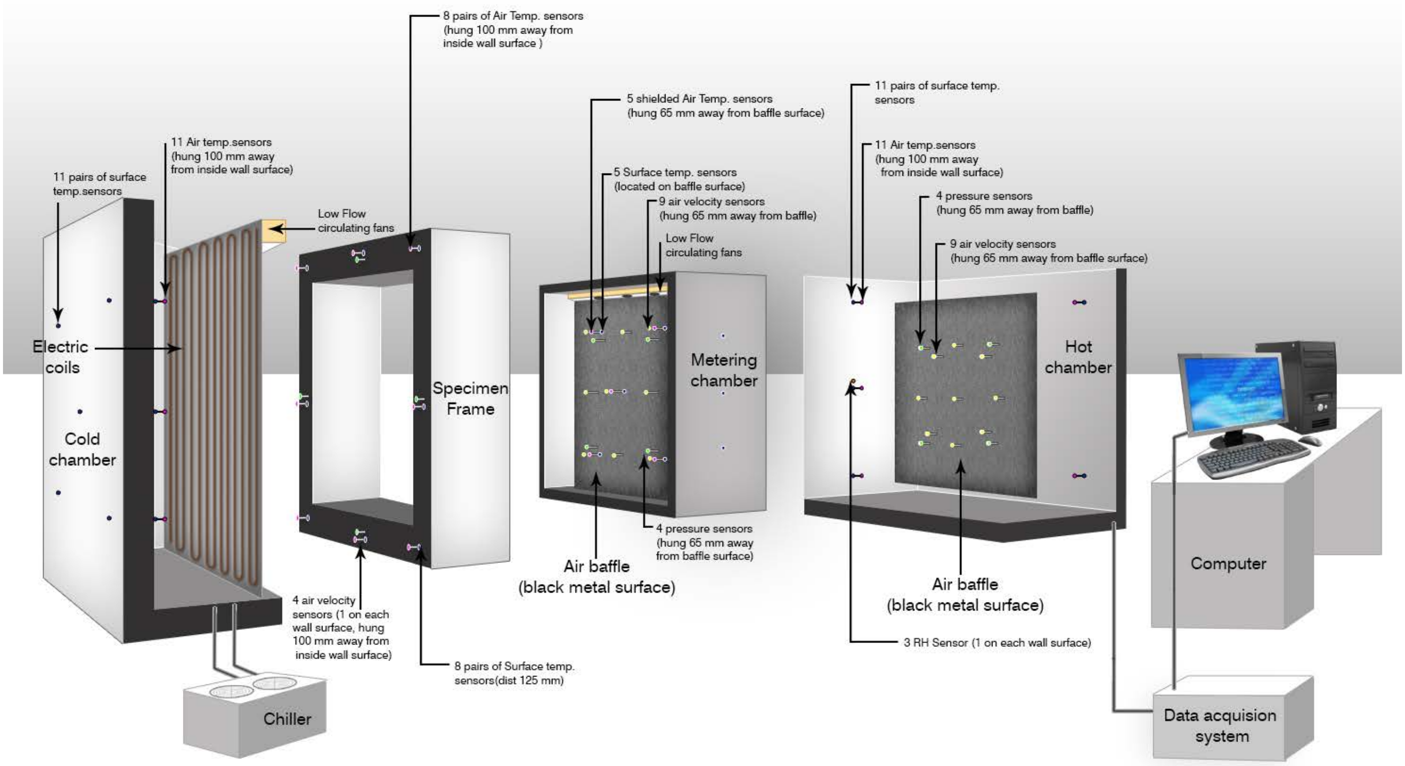


Figure 14: Artist's image of guarded hot box

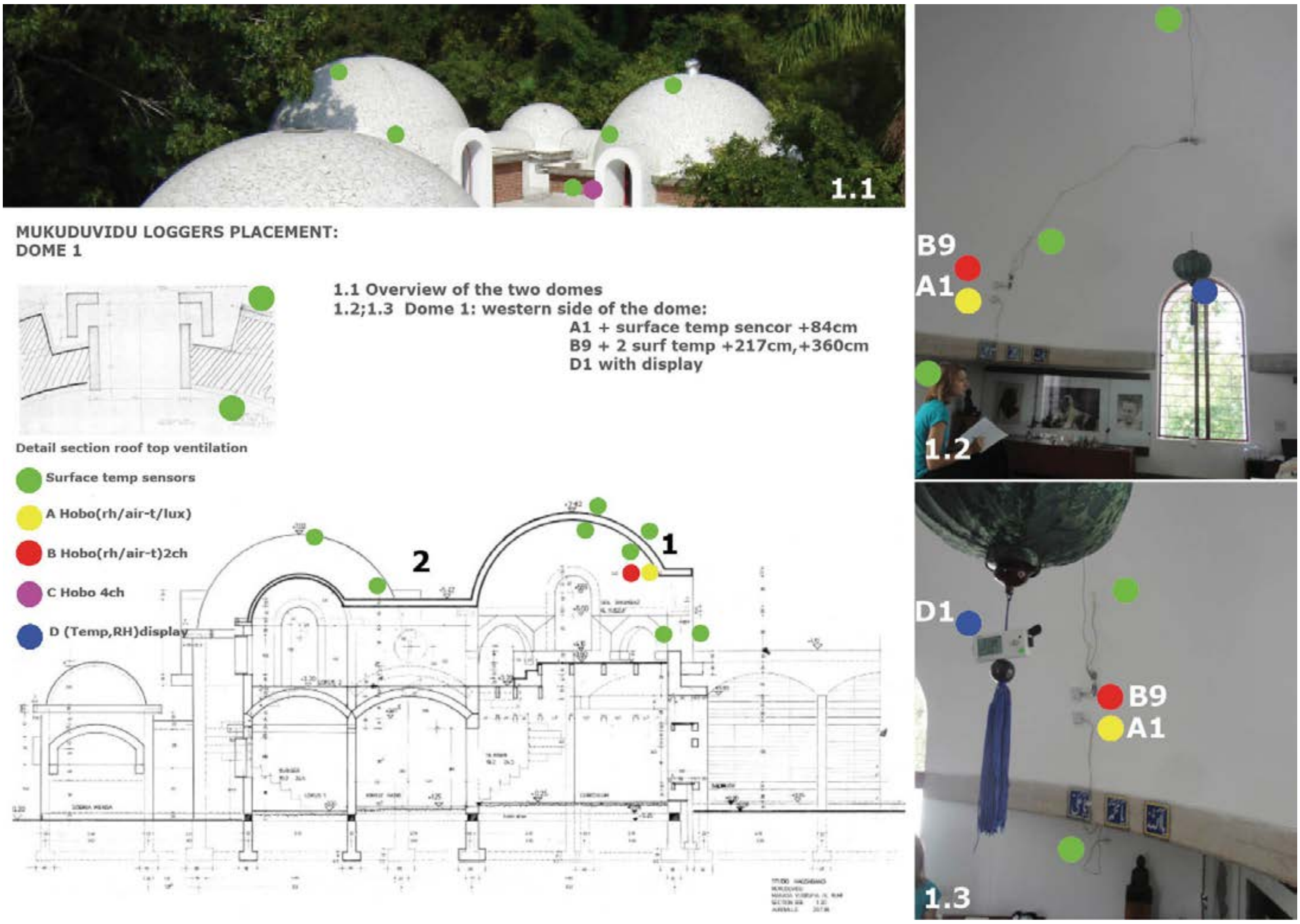


Figure 15: Passive design, field measurements at auroville

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. Turntable can rotate the model about two axes. This turntable received 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. COMFEN 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 toward optimal fenestration design choices for their project. The CBERD project team has developed a COMFEN India version.

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 day-time and 24x7 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 US team at LBNL has developed and documented the design for LBNL an angular properties 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.

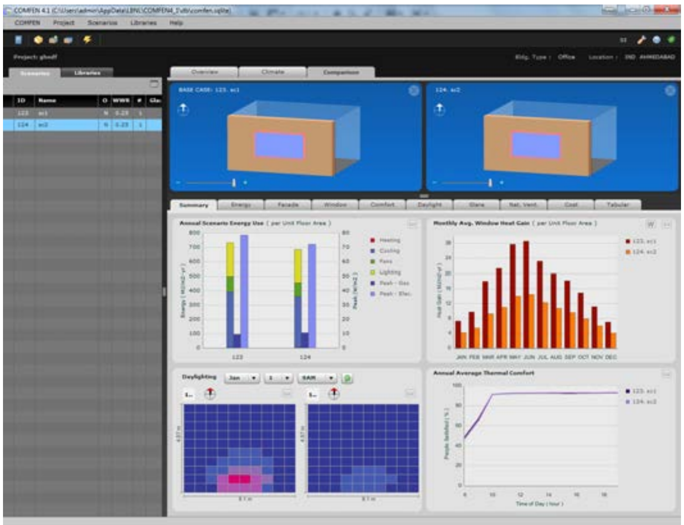


Figure 16: COMFEN India version screenshot

The CEPT and LBNL teams are working with Sky Shade and Infosys to characterize laser cut panels (LCP), which have capabilities to transport daylight into the building floor space. This will help in reducing dependence on electric light during the daytime. With the help of a Photo goniometer, theCBERD team is working on Bidirectional Scattering Distribution function (BSDF) to characterize LCPs. This will help with simulating LCPs into building energy models such as radiance.

Research Sub-task 3.1D: Passive Design

The criteria of selection for naturally ventilated buildings to be monitored have been defined and a matrix prepared listing all possible candidates for the study. 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 buildings for monitoring of a specific strategy. These buildings have been monitored since August 2013.

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. Haryana Renewable Energy Development Agency building (HAREDA), Chandigarh. Building of Environmental Sanitation Institute (ESI), Ahmedabad. Building of Comptroller Auditor General,(CAG) Jaipur, Foundation for Liberal and Management Education (FLAME), Pune and Institute of Rural Research and Development, (IRRAD), 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.

Sub-task 3.2: Advanced Technologies

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

Background

Sub-task 3.2 Advanced Technologies, consists of two tasks, (1) Advanced HVAC and (2) Advanced lighting.

Under the Advanced HVAC task, work is being carried out in order 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 proven.

Team members

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

Progress so far

Sub-task 3.1A: 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 framework of analysis of existing chillers and prevailing practices has been completed. A comprehensive methodology for the performance evaluation 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 Underwriters (UL) Test labs at Chennai and Hyderabad was conducted to assess the test facilities for chillers and unitary AC's. UL has offered the use of their test facilities until one is available at MNITJ.

The radiant cooling system offers significant saving options in chilled water systems. Presently the installations are limited in India. The simulation based analysis of radiant systems and validation with measured parameters has been carried out for Tech - Mahindra, Hyderabad and similar work is being carried out for Infosys, Hyderabad.

As an extension of innovative ways for using chilled water systems for optimization purposes, a radiant table for personalized cooling was developed and performance evaluation was carried out, both through simulation and validation with actual deployment data.

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. MNITJ has actively participated in the finalization of these standards for the Indian context. This will help in appropriate sizing of chillers as per our climatic conditions. MNIT has conducted comfort surveys and carried out extensive statistical analyses for conditioned, hybrid and unconditioned buildings in 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 DOAS have the potential to reduce the overall energy consumption in Indian HVAC systems by 30 to 80%

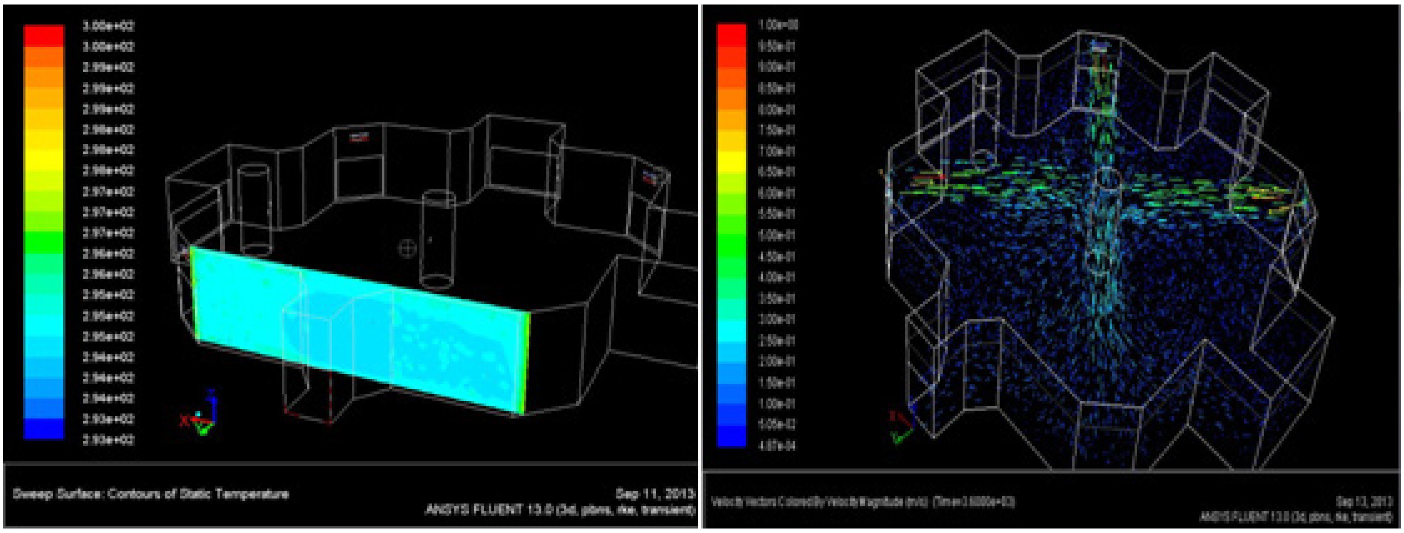


Figure 17: Snap shot of CFD model for radiant cooling system at Tech- Mahindra.

depending on the outdoor and indoor design conditions when deployed to treat ventilation air. It is understood that the potential for saving increases with a corresponding increase in outdoor DBT and DPT or RH. Amongst the various options identified for DOAS systems, an Air-to-Air Heat Exchanger systems and Liquid Desiccant System for Fresh Air Dehumidification are being considered as an important component for further development.

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.

Sub-task 3.2B: Advanced Lighting

For establishing the test facility for LED lighting at IIIT – H, RPI and IIIT - H teams are finalizing the list of equipment and the design of test set-up.

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

RPI has offered admission and scholarship to a student from India to pursue graduate studies in Lighting (total value of 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.

Well-received workshops on Advanced Lighting in two Indian cities

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

Sub-task 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 climate chamber and in commercial buildings in India.

Background

This sub-task 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 – Jaipur	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 US 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 detailed design and specification for a Thermal Comfort Chamber (TCC) as part of the CBERD project. TCC is a specially designed chamber measuring 5mx4mx3m, representing a typical office space. The chamber can precisely simulate a wide range of indoor

Figure 19: Thermal Comfort Chamber

environmental conditions with temperatures ranging from 15°C to 35°C and relative humidity from 20% to 80%, along with changing air distribution patterns as well as speed. These conditions are maintained and monitored by sophisticated air conditioning systems as well as control devices. The purpose of 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 off 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 give 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 focusing on exploring the grid responsiveness and renewable integration for commercial buildings, coordination of R&D expertise and industry for building integrated photovoltaic (BIPV) technology development and its application in terms of roof, walls and window-mounted versions. Another objective is the preparation of final specifications for public dissemination, preparation of guidelines and renewable energy (RE) products that are ready for deployment.

Background

This work task is divided into three sub-tasks: 1) Grid Responsive Buildings, 2) Renewable Integration and 3) Cost Optimization. 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
MNITJ	Dr Jyotirmay Mathur, Lalit . K. Joshi, Kamlesh Jagratwal, Sumit Sharma, Dharmendra Kumar Kumawat, Sanjay
CEPT	Rajan Rawal , Agam Shah, Sanyogita Manu
CMU	Vivian Loftness, Rohini

Progress so far

Grid Responsive Buildings

This activity has produced a framework to integrate building technologies to the Smart Grid through collaborative knowledge and industry partnerships, including identifying the key sectors for intervention for grid responsiveness. These activities will help develop integrated building technologies for both energy efficiency and needs of the Smart Grid.

Extensive literature review of smart grid initiatives/projects in India and international, grid responsive buildings, Automated Demand Response (AutoDR), various building automation and control technologies etc. systems to supply-side have been conducted. A load survey of various institutional buildings, malls, commercial buildings, hospital buildings, hotel buildings etc. has been completed. A Grid Responsive Building (GRB) implementation draft proposal has been prepared.

Renewable Integration

The BIPV/BAPV technology has been short listed by the US 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 efforts have been to design the different BIPV prototypes at an early stage for deployment at the facility. Performance monitoring would be done by MNITJ. Some of the prototype designs are shown in the figure below.

For concept validation and to test the performance of BIPV/ BAPV systems an in-house design of 'flexilab' has been developed (Figure 21). The test facility would have

Figure 20: BIPV prototype developed and being monitored

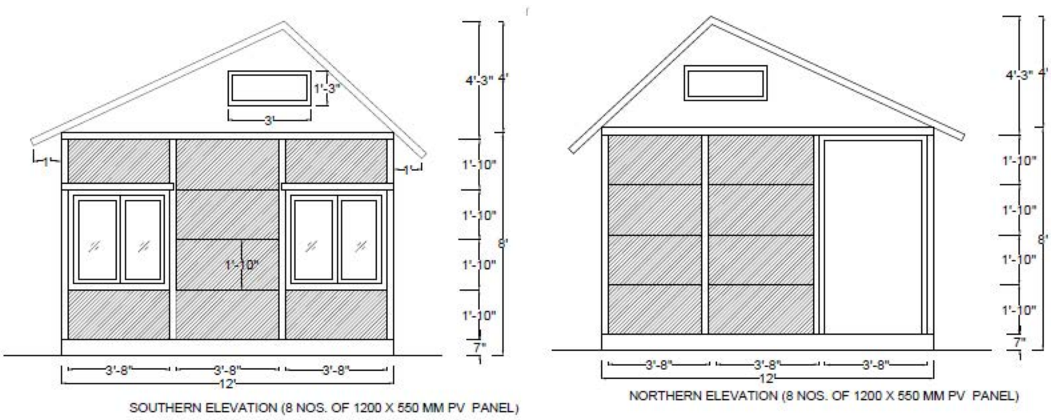


Figure 21: 'Flexilab' in-house facility for testing BIPV/BAPV system

the capability of studying the energy yield of configurations at different orientations/directions, effect on indoor day lighting and altered heating/cooling needs due to use of BIPV products. Additionally, the performance evaluation of existing RE systems has been carried out at ten locations

Cost Optimization

The UN'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. Additionally, collaboration with LBNL should provide environmental data on particulate emissions and water use from coal power plants as well in year 2 of this project.

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 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.

Passive design strategies beneficial to achieving energy efficiency and thermal comfort in Indian buildings have been identified in order to create a repository of passive design techniques that can be promoted in the US and India. Using the results from the two climate models, ten passive strategies and the percentage of time within each strategy were 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 the 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 buildings energy efficiency.

Background

This activity is distinct from workforce development (or capacity building) that is 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) will help us develop training and curricula, including any necessary student and R&D staff exchange while keeping in mind intellectual property issues and U.S. and India government policies.

Progress so far

An internal collaboration tool, the 'Project Pier' has been constructed. This will enable sharing of CBERD management and R&D documents, and 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 interacted with LBNL and ORNL experts for the purposes of training on hygrothermal laboratory equipment, simulation/modeling, and cool-roof equipment testing protocols.

A CEPT researcher visited UCB and LBNL for a period of 4-weeks to work jointly on Windows/ Daylighting, Thermal Comfort and Passive Design R&D sub-tasks. The researcher was trained in the design and operation of 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 sub-task.

A calendar of conferences/workshops that can be leveraged has been prioritized 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, 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 half of CBERD activity has had a significant emphasis on creating a vibrant consortium of 11 R&D partners, over 30 industry partners and organizational partners in both countries. CBERD is gaining momentum on joint research, collaboration, and setting out towards technical goals. There was also a substantial focus on initiating a productive collaborative relationship with CBERD industry partners, which included work sessions, ongoing communications, and development of an over arching common technology management plan for intellectual property (or IP management plan). While there was a major thrust to manage and coordinate a project of this magnitude, researchers in both countries have worked together as a collaborative team to conduct joint R&D with first year contributions towards technical R&D outcomes, research exchanges and publications, as detailed below:

Technical R&D Outcomes

The R&D outcomes for each task/sub-task are categorized by contributions in energy analysis and tools, methodology 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 Energy Plus 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 and passive design R&D team's outcomes included an early stage, web-based windows and facade 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. 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 center EIS guide, which is a methodology for selecting and installing appropriate energy information systems. This has been adopted by the U.S. and Indian industry partners towards interfacing with their clients. An outcome of Advanced HVAC systems R&D team included the creation of a new methodology for chiller performance evaluation. The research outcome of the Thermal Comfort R&D team included providing new methods for assessing Indian clo values for adaptive thermal comfort.

C. Technology Development:

The R&D team on Controls and Communication developed a new smart, wireless luminaire controller with temperature, illuminance, electrical power and occupancy sensors, A low cost energy meter was developed 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 also 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. Technical assistance was provided by the US team on the development of equipment and instruments for the purpose of building test-beds at Indian team institutions. This included (i) angular tubes spectrometer accessory prototypes for accurate windows/ daylighting measurements, (ii) Guarded hot-box and hygrothermal facilities, and (iii) Fault detection and diagnostics lab.

Research Exchanges and Workshops

In February 2013, LBNL hosted a 2-day visit by representatives from 5 of the 6 Indian R&D institutions (CEPT, IIT-B, IIIT-H, MNIT-J, and CSR) to review the scope and respective work products and also familiarize with researchers in 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. The workshops also allowed information exchange on the latest LED developments; LED product characteristic and performance needs for successful lighting applications in commercial buildings, indoor and outdoor, in India; and LED lighting standards and recommended practices in the US and India.

To better facilitate PACE-R and PACE-D collaboration, the U.S. and Indian CMOs continues to engage 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 Indian and US R & D team in development of "Gap analysis" document as well as in preparation of "Gap Analysis Relative to Current State of the Art in Indian Benchmarking".

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

Gail Brager visited CEPT University to progress activities on thermal comfort research, whilst Rohini visited CEPT University to progress work on cost-optimisation.

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

- Indian industry partner Sky Shade visited RPI-LRC to gain understanding about fritted panels and their daylight performance
- An Indian researcher visited ORNL and LBNL experts for the purposes of gaining 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 two, for fault detection and diagnosis in simulation tools
- A researcher from CEPT was stationed for a period of 4 weeks at UCB and LBNL to work on Windows/ Daylighting, Thermal Comfort and Passive Design R&D sub-tasks. The researcher trained in the design and operation of controlled environment chamber, as well as methods of data collection, instrumentation, data analysis.
- A researcher from MNIT visited ORNL to work on Advanced HVAC sub- task.

Publications

R&D Work Task 2.0

1. Garg, V. et al. Development and performance evaluation of a methodology, based on distributed computing, for speeding EnergyPlus simulation, 2013. Paper submitted to the journal "Building Simulation".
2. Brunswick, S., et al. Simergy Interfaces for Low Energy System Design, 2013. Report will be hosted on the CBERD website's public interface.
3. Mathew, P., Sarraf, S., Singh, R. et al. Building Energy Benchmarking in India: an Action Plan for Advancing the State-of-the-Art, January 2014. This is under review by the Indian Bureau of Energy Efficiency.
4. A data collection model for Indian benchmarking effort has been adopted by the Indian Bureau of Energy Efficiency for buildings energy ongoing data collection
5. Singh, R., et al. Guidelines for Data Center Energy Information Systems, December 2013. This guidelines document on Energy Information Systems "has been completed, and is being piloted by CBERD industry partner in the US.
6. Cheung, I. and Steven Lanzisera. Evaluation of the market and products enabling energy efficiency lighting, plug-loads, and HVAC in buildings, 2014.
7. Chuang, F, etal. Performance guarantees for certainty equivalence control with uncertain linear dynamical systems. Application to low energy HVAC systems, 2013.
8. Haves, P. ,etal. Workflow for the use of Energy Modeling in Low Energy Design, 2013.

R&D Work task 3.0

9. Desjarlais, A., et al. Use of Exterior Insulation Systems to Reduce Building Energy Demand, 2013. White paper describing the history and current state of exterior insulation systems drafted and shared with the India team. This will be expanded to include ASTM International standard specifications for relevant insulation materials and envelope components.
10. A report on facilities located across India for thermo-physical-optical testing of materials has been prepared. This has established the contextual framework for CBERD capabilities as well as will help in future for Inter Laboratory Comparison required for accreditation for laboratories.
11. Slack, J. ,etal. Angular Tubes Spectro meter Accessory, 2013. The US team has developed prototypes as well as a document for the design of angular tubes accessory for measuring angular properties of scattering materials (e.g., shade fabrics). The design documentation consists of 2-D drawings (DXF exchange file format) and 3-D drawings(Solid Works), report detailing the fabrication process. The report also includes the step-by-step process of installing tubes into the spectrometer instrument
12. Paper entitled "Effect of Roof Insulation on Energy Consumption in Office Buildings with Cool Roof in India" has been submitted to the journal Energy and Building" and Paper entitled "Optimizing Roof Insulation for Roofs with High Albedo Coating and Radiant Barriers in India" has been submitted to the journal Solar Energy Materials and Solar Cells" submitted by IIIT-H team
13. Milind V. Rane, Shreyas Chavan, 2014. DOAS with Evaporative Precooling of Exhaust Air Using Rotating Contacting Device. In First International Conference on Energy and Indoor Environment for Hot Climates February 24-26, 2014, Doha, Qatar
14. Milind V. Rane, Shreyas Chavan, 2014. Indirect Evaporative Precooling of Fresh Air using Heat Exchangers with Enhanced Flow Passage. In First International Conference on Energy and Indoor Environment for Hot Climates. February 24-26, 2014, Doha, Qatar
15. Milind V. Rane, Narendra Singh, 2014. Multi Utility Evaporative Cooler with Diabatic Contacting Device. In First International Conference on Energy and Indoor Environment for Hot Climates. February 24-26, 2014, Doha, Qatar
16. Mathur,J., et al., Radiant cooling system: A case study of assessment of energy savings in an office building, 3rd National Conference on Refrigeration and Air Conditioning, 2013.

R&D Work task 4.0

17. C Basu. G. Ghatikar, and P. Bansal, 2013. Enabling Efficient, Responsive, and Resilient Buildings: A Collaboration Between the United States and India; Proceedings of the IEEE Great Lakes Symposium on Smart Grid and the New Energy Economy, Chicago, U.S., 2013
18. A research paper titled "An assessment of household electricity load curves and corresponding CO_2 marginal abatement cost curves for Gujarat state, India" has been submitted to Energy Policy (Elsevier) Journal.

Key Next Steps

2.0: Building Information Technology

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

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.

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.

3.0: Building Physical Systems

Natural exposure of Indian roofing products will begin 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.
Continue further characterization of glass products sold in India and submission for inclusion in IGDB and extension of COMFEN features that benefit India's team
Provide advice on the refinement of Testbed design and guidance on the fabrication of angular tubes

- Refine characterization of range of mixed-mode building types in India and procure monitoring equipment and weather station
- Finalize review of simulation criteria for naturally ventilated buildings
- New layouts and design nomographs for Earth Air Tunnels, which would be applicable to U.S. buildings as well.

- Revision of online survey form for Indian context
- Selection of buildings for deployment of online survey
- Initial deployment of online comfort survey in pilot buildings to test new methods
- On-going design & construction of Thermal Comfort Chamber at CEPT
- Demonstration and training of NEAT physical instrumentation from CMU

Supplemental Applications

- Minimization of roof glare. Work will start as per the schedule provided in M&D - 1st April 2015 - 30th September 2015
- Effect of cool roof and insulation. Work will resume as per the schedule provided in M&D (2015).
- 63 samples from Asahi India Glass Limited and 130 samples from Saint Gobain Glass India will be tested for characterization of optical properties
- Analysis report of performance assessment of BIPV / BAPV products application in buildings.
- Fabrication of concept validation BIPV test lab at MNITJ and performance assessment of evolved innovative BIPV products.
- Design document of evolved BIPV products for dissemination and adaptation by industry.
- 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 buildings energy efficiency for grid-responsiveness.
- Illustrate the range of technologies that are or can be available in the Indian context, with value to the US industry as well, and gather cost, performance specification and benefit information from those industries.
- Initiate cost-benefit analysis, inclusive of technology first costs, known O&M costs, and simulated or measured energy savings (1st bottom line).
- Initiate second bottom line calculations with GHG and water costs for the corresponding energy sources in the five regions (2nd bottom line).
- Initiate research on human benefits that might be gained through these ECMs (future 3rd 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:

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

US - India Joint Centre for Building Energy Research and Development

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