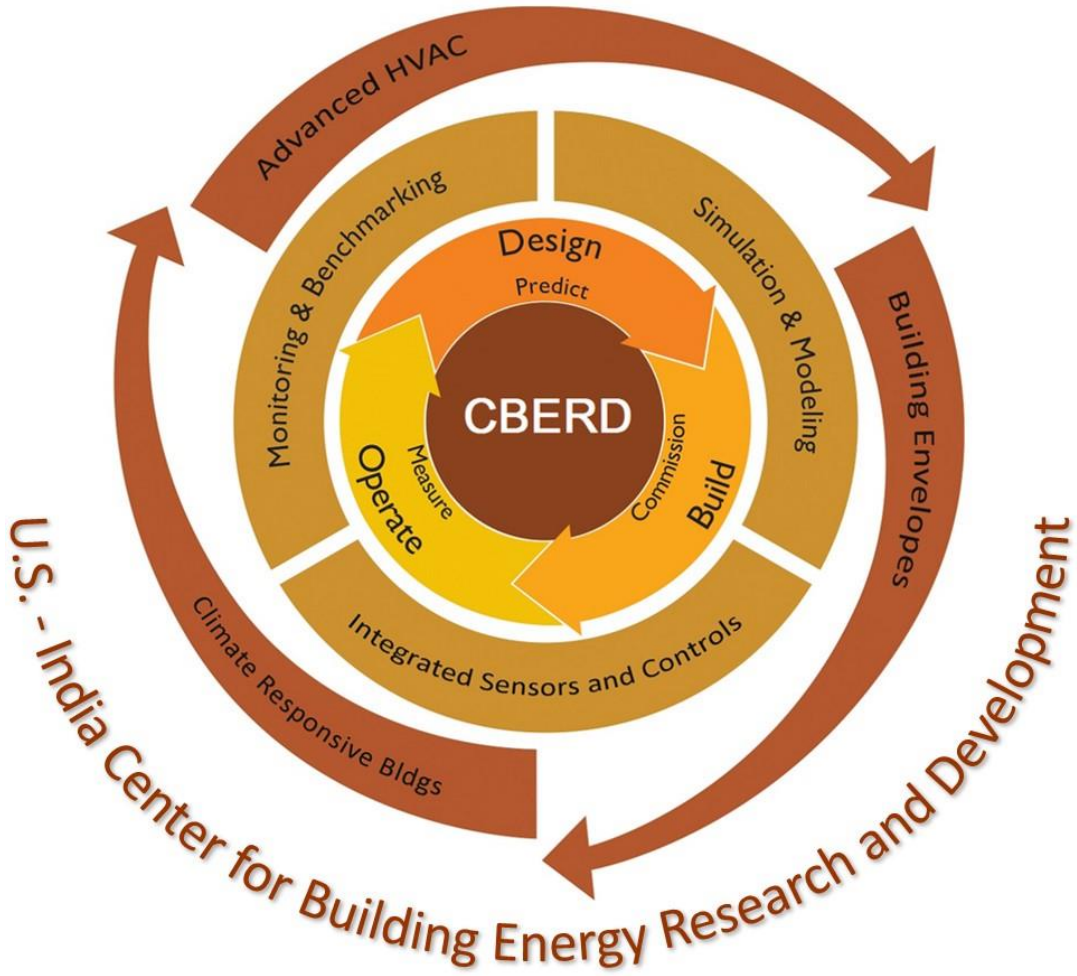


U.S-India International Collaboration on Building Energy Efficiency

Mary Ann Piette. Lawrence Berkeley National Lab

BTO Peer Review, March 15th, 2017

mapiette@lbl.gov

Presentation Outline

1. Introduction and Vision of CBERD
2. CBERD's Distinctive Model
3. Progress and Achievements
4. Impact
5. Next Steps

CBERD Introduction and Vision

2009 PACE announced:

U.S.-India Partnership to Advance Clean Energy (PACE)

2013-17 CBERD awarded:

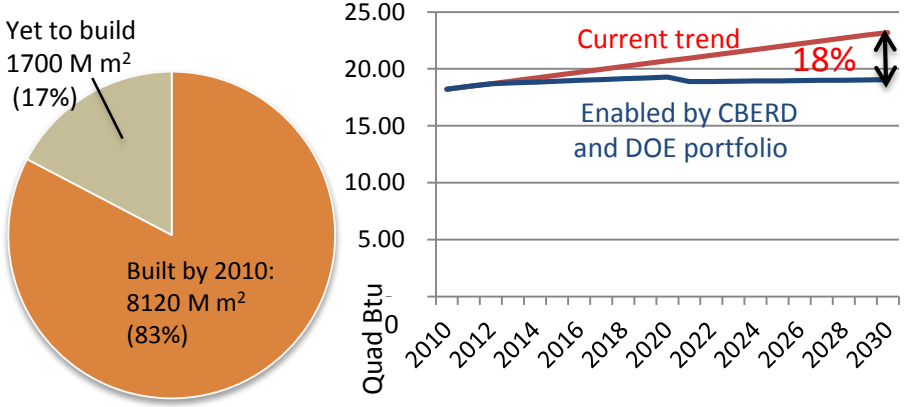
$20M, 5-year program with joint investment from government and industry

Problem Statement:

Buildings consume 33% of total energy in India, ~40% in U.S.

Vision:

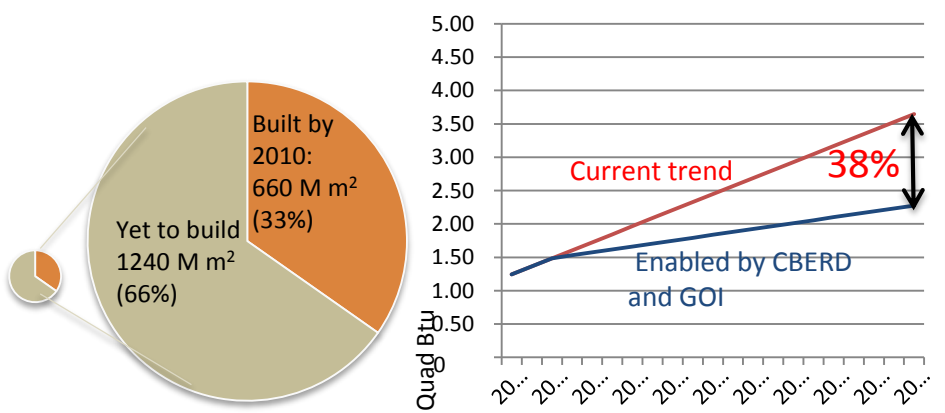
Deliver robust R&D solutions for improvements in energy efficiency of buildings



U.S. 2030:

Commercial stock: 10.3 B m²

Retrofit and New Construction Focus



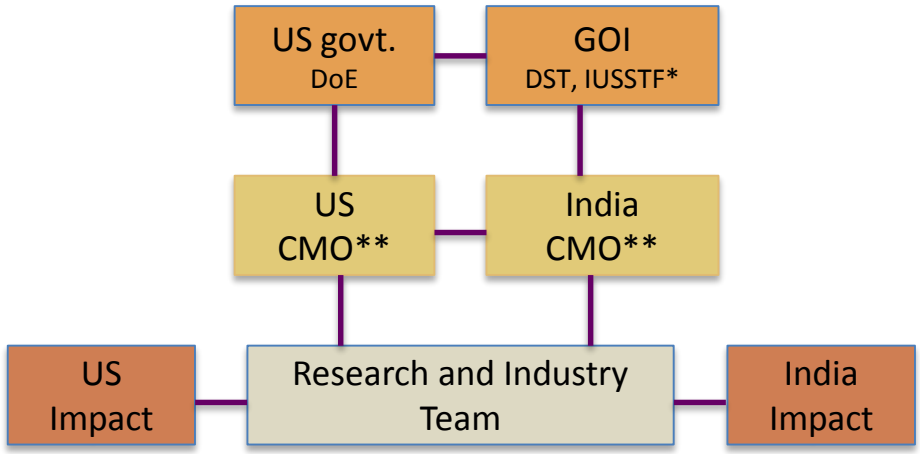
INDIA 2030:

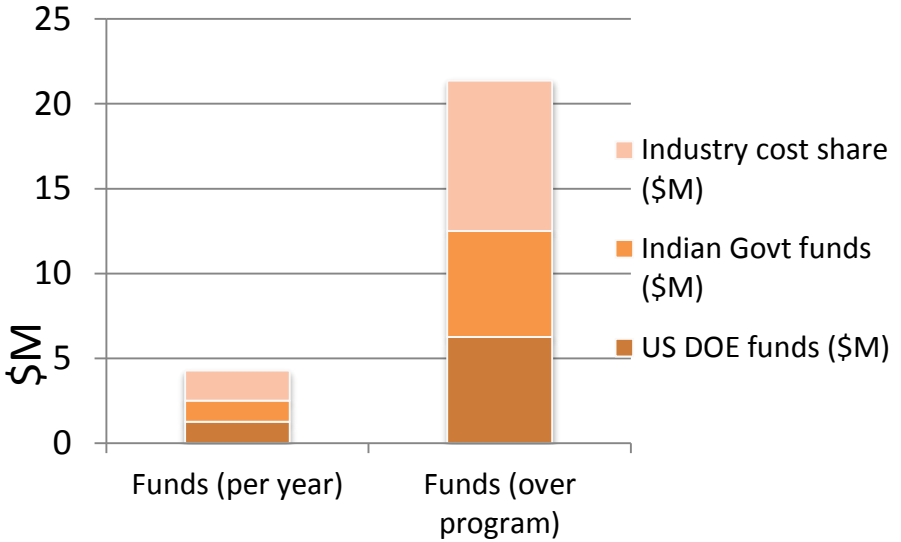
Commercial stock: 1.9 B m²

New Construction Focus

CBERD Distinctive Model

3X3: Government, Research, Industry





- Solve complex critical global problems requiring interdisciplinary non-competitive collaborations
- Achieve substantial energy savings in both countries' buildings sectors through public-private sector collaboration focused on building systems integration

- US$ 12.5 M for 5 yrs from U.S. and Indian govt
- US$ 15.9 M for 5 yrs from U.S. and Indian industry
- 20 career scientists & ~50 researchers
- 45 Industry cost share and institutional partners

DST: Department of Science and Technology; IUSSTF: Indo US Science and Technology Forum;
CMO: CBERD Management Office, LBNL (U.S.), CEPT University (India)

CBERD's Distinctive Model

Leveraging Country Strengths and Needs

Importance of Building Operation in US

Strengths

- Building energy modeling, data and information
- Automated controls & communications
- Advanced pre-fab materials and assemblies
- High-performance HVAC and lighting equipment
- Grid integration

Appetite for cost-effectiveness

Approach

Develop and test bed innovations: tools, techs, methods
Bring back lessons from experience and demos

Importance of New Construction in India

Strengths

- Software and service solutions
- Climate responsive passive/daylight design
- On-site fabrication and craftsmanship
- Modular HVAC, natural, mixed-mode operations
- Cost-effective methods and labor

Appetite to leapfrog

Approach

Leapfrog with new technology demos
Develop and foster nascent building science

Fill industry R&D gaps. Drive cost-effective energy efficiency. Focus across building sector

CBERD: Distinctive Approach

Coordinating and dovetailing joint R&D

Lawrence Berkeley National Laboratory – US Lead

- Oak Ridge National Laboratory
- University of California at Berkeley
- Carnegie Mellon University
- Rensselaer Polytechnic

CEPT University – India Lead

- International Institute of Information Technology
- Malaviya National Institute of Technology
- Indian Institute of Technology Bombay
- Indian Institute of Management Ahmedabad
- Auroville Centre for Scientific Research

CBERD Distinctive Model

Thriving public-private collaboration with 45 entities

Supported by U.S. Department of Energy and India Ministry of Science Technology, with:

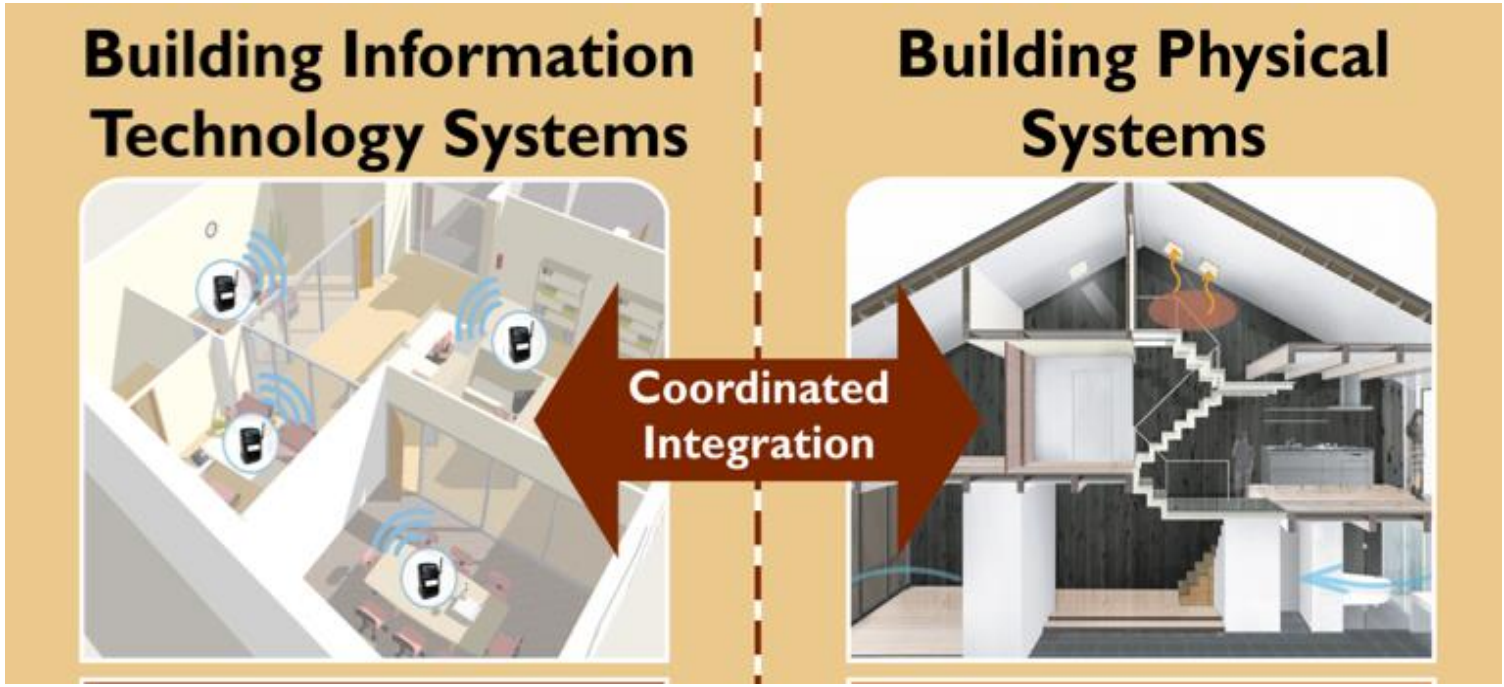
11 U.S. and India research partners

Building Information Technology	Building Physical Systems	Collaboration and Deployment

34 U.S. and India industry partners and collaborators

CBERD Distinctive Model

R&D with integration of building physical and IT systems



- Provide a backbone for every stage of the building lifecycle
- RD&D with broad applicability for Indian new construction US retrofits
- Evaluation of active cooling, passive strategies, and comfort technologies through innovation, analyses, surveys
- Enhance capabilities through test bedding and field demos

CBERD Distinctive Model

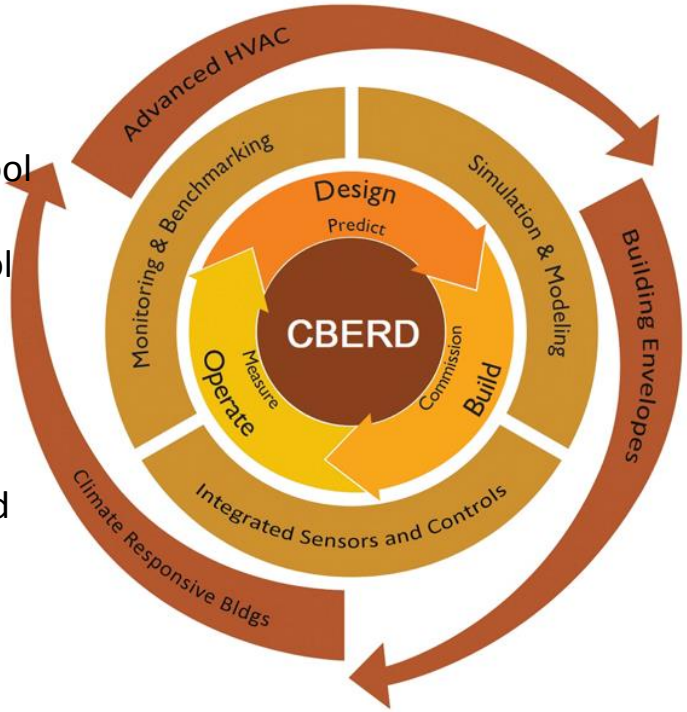
Key tasks and outputs using a Building Lifecycle Approach

Building Information Technologies

1: Simulation and Modeling
- **eDOT** Early design optimization tool
- **ECBC compliance** rulseset
- **MPC** Model predictive control tool

2: Monitoring & Benchmarking
- **EIS-in-a-box** Packaged, scalable energy information systems
- **Graduated benchmarking** method

3: Integrated Sensors & Controls
- **I-SPACE** Integrated workstation controls hub
- **Transactive controls**
- **Smart plug strip**



Building Physical Systems

4: Advanced HVAC Systems
- **MCHX** Energy efficient microchannel heat exchanger
- **New non-compressor** based cooling methds

5: Building Envelopes
- **PCM** Phase Change Material tiles
- **Cool Roof** materials
- **Laser cut panels**, windows, daylighting and shading tools,

6: Climate-Responsive Buildings
- **Mixed mode** operations
- **Occupant thermal comfort**

Triple Bottom Line Cost Framework

CBERD Selected Highlights

- Energy Information Systems (EIS) demonstrations installed by Schneider and Wipro-UT in 7 buildings across India (2016)
- Joint IP filing for CBERD technology I-SPACE (2016)
- LBNL's Cool Roofs wins outstanding research award at 4th International Conference on Countermeasures to Urban Heat Islands (2016)
- Triple Bottom Line Analysis of Energy Efficiency strategies gains traction through new USGBC LEED point (2017)

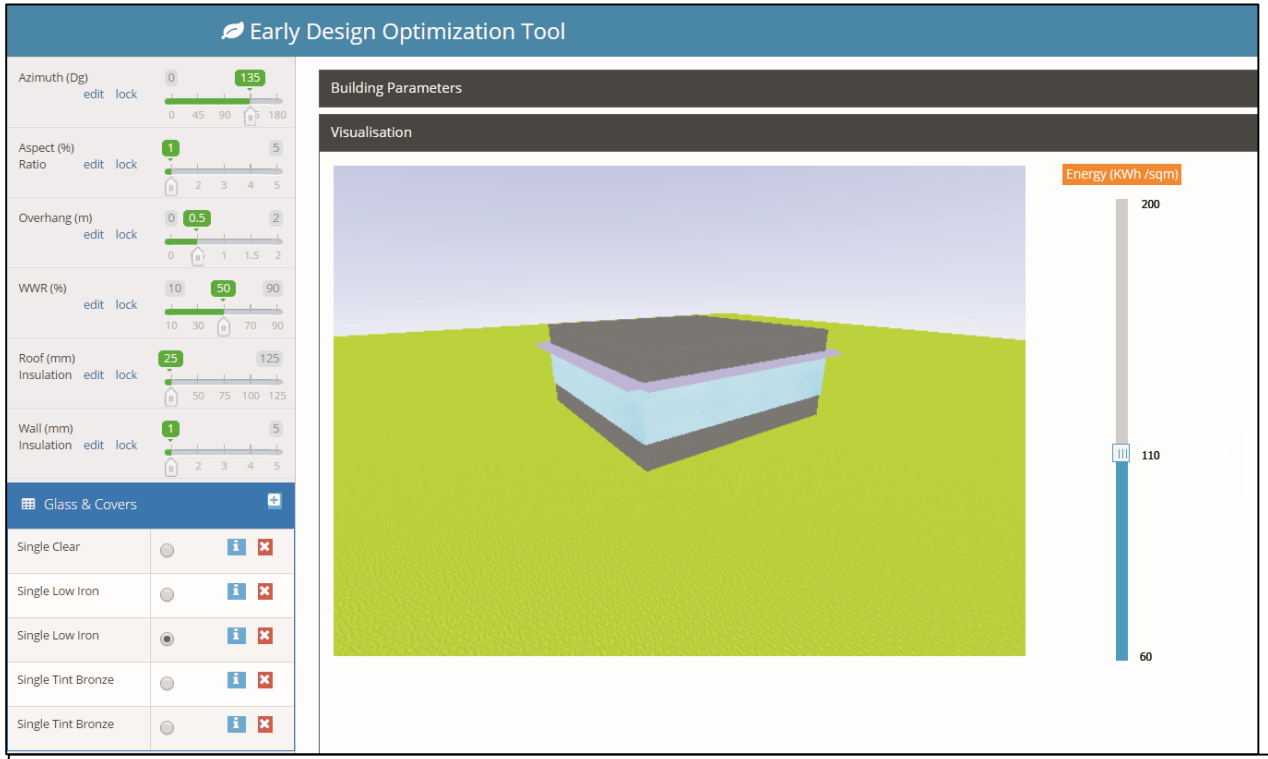
Fern hotel, an EIS demo site

I-SPACE energy controls hub

New LEED pilot point for triple bottom line framework for energy efficiency investments

Outstanding research award

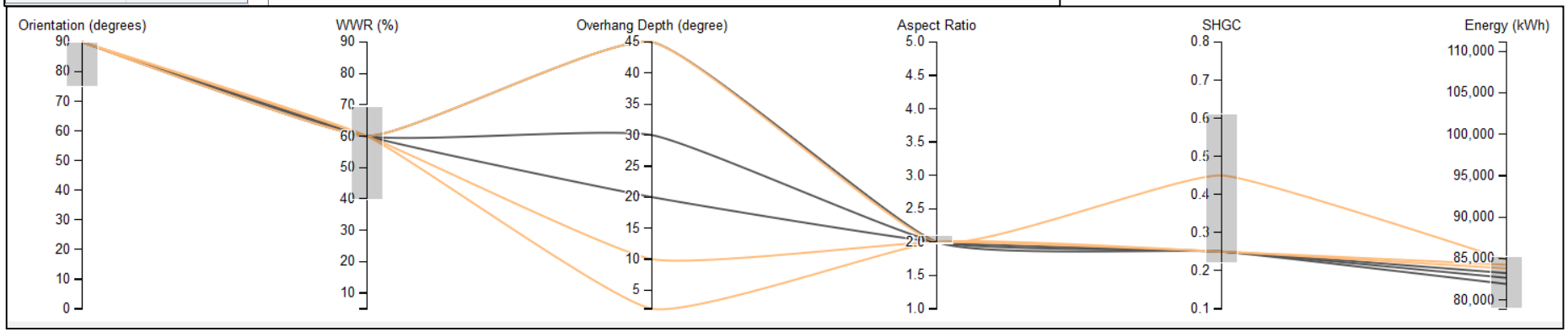
CBERD Progress and Achievements: Tools (being tested)



eDOT
Early Design Optimization Tool

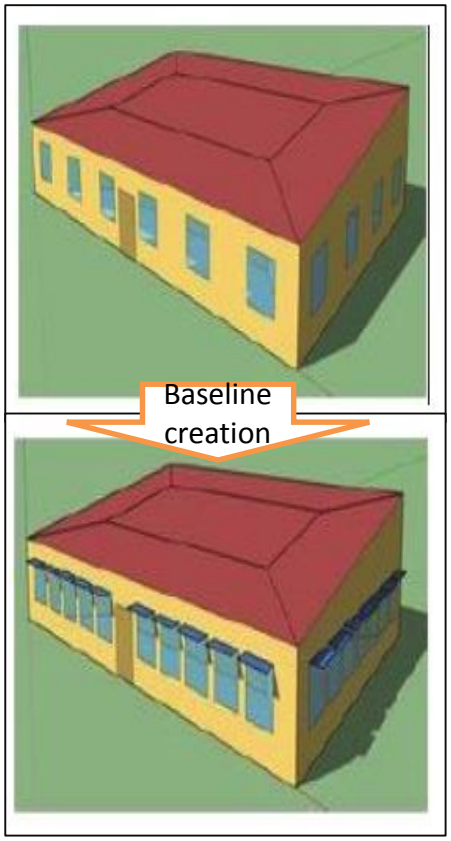
On-line, multi-parameter optimization

Projected energy savings:
42 TBtu/year (U.S.);
6.7 TBtu/year (India)



Alpha version of new CBERD eDOT tool

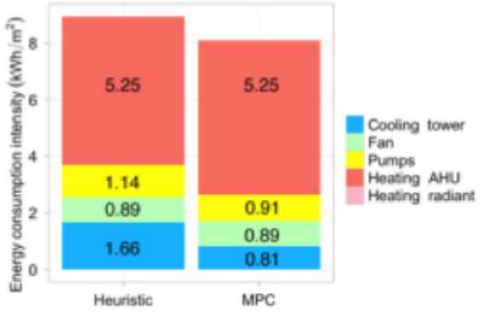
CBERD Progress and Achievements: Tools (being tested)



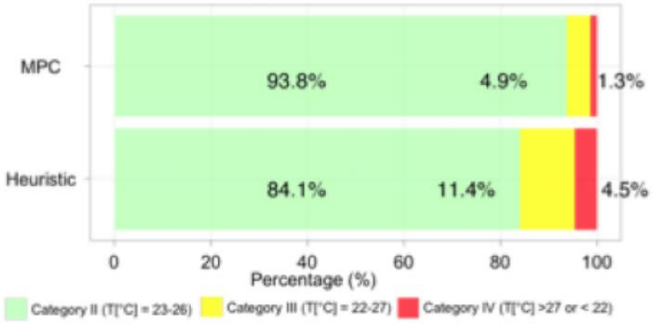
Prototype design (top), expected baseline model (bottom)

Model predictive control of radiant slabs

- saves energy (12%):



- and improves comfort (84% → 94%):



Projected energy savings using MPC on radiant cooling system

Model identification w/EnergyPlus simulation

↓

Automatically design predictive controller for simplified model

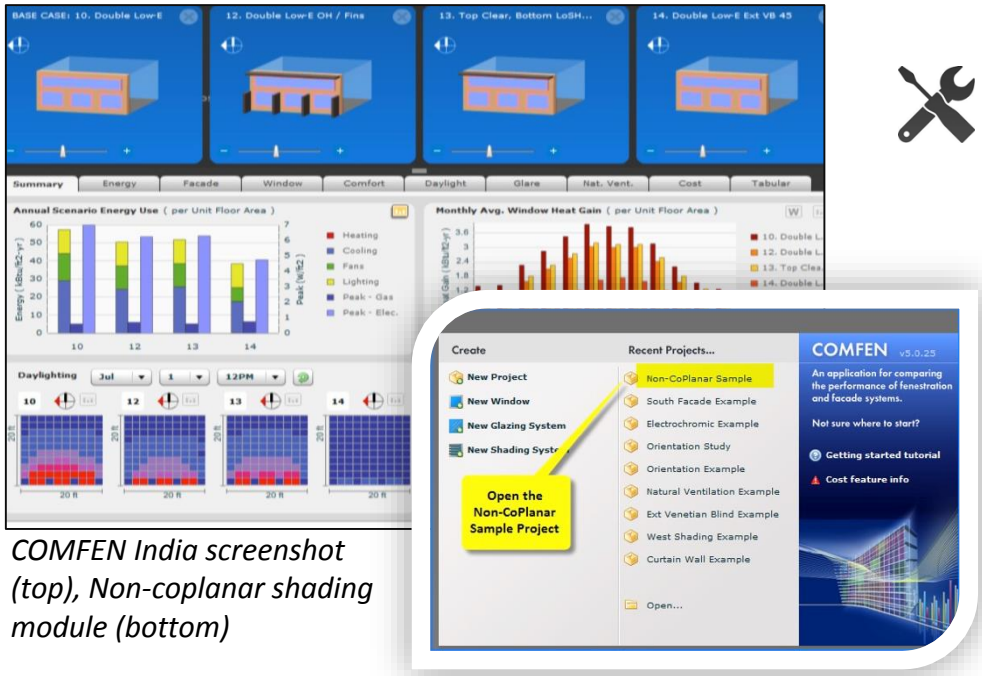
↓

Run closed-loop simulation w/EnergyPlus model using Julia

Code compliance tool: for Energy Conservation Building Code (ECBC, India)

Model Predictive Control: Algorithm and tool chain developed for radiant slab control, ported to open source

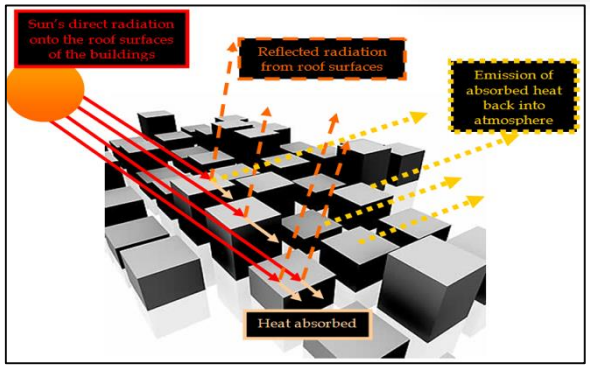
CBERD Progress and Achievements: Tools (complete)



COMFEN India screenshot (top), Non-coplanar shading module (bottom)

COMFEN-India launched as free, online fenestration and façade design software tool.

New module on non-coplanar shading (2017) relevant to DOE's COMFEN tool



Information provided about cool roof benefits at Cool Roof Calculator website

Cool Roof Calculator Calculates energy savings and life cycle cost for cool roof materials and technologies

Available at www.cberd.org

CBERD Progress and Achievements: Technologies (being tested)

EIS demo at a building site

Energy information system 'EIS-in-a-box'

- 6 demos in hotels, hospitals, offices
- Integrates meters, gateway, software, user interface
- ~30% cost reduction

Projected savings:
68.4 TBtus/year (U.S.); 6.7 TBtu/year (India)

ISPACE hub and smart strip

I-SPACE prototype development and testing

Intelligent System for Personalized Ambient Comfort, and Energy Efficiency

- Provisional Patent filed, joint US-India IP
- Hyper-local controls and comfort delivery
- Transactive controls responsive to occupancy, grid outages, DR and real time electricity prices

Smart Plug strip

- Identifies loads through power characteristics
- Combines with occupancy information to control outlets and switch loads

Projected savings:
42 TBtu/year (U.S.); 6.7 TBtu/year (India)

CBERD Progress and Achievements: Technologies (being tested)

MCHX Prototype development and testing

Mahle's Microchannel heat exchanger evaporator

- Integrated in 1.5 TR unitary system
- ~ 32% less cost; ~50% less size
- COP ~ 3.66 (8% better than 5 star rating for split AC)
- Extends application of low GWP, flammable refrigerants

Dedicated Outdoor Air System (50 – 2,000 CFM units)

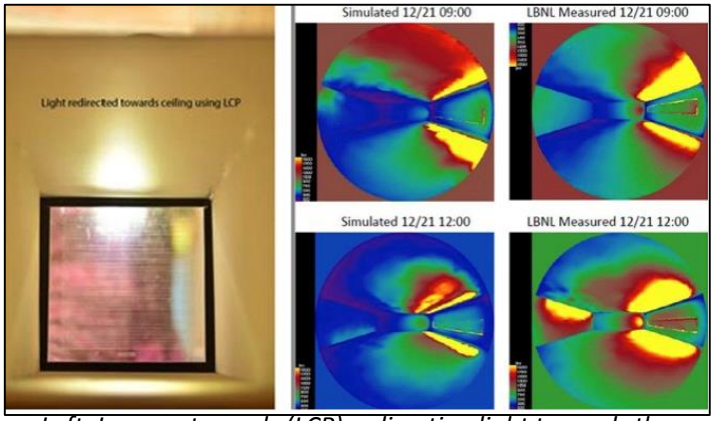
- Rotating contacting device evaporative precooling
- Plastic Heat Exchanger
- Heat exchangers for liquid desiccant based dehumidifier

Compact DOAS device (left); Radiant office cubicle prototype (right)

Personalized radiant cooling system

- Modular system
- Phase change material (PCM)

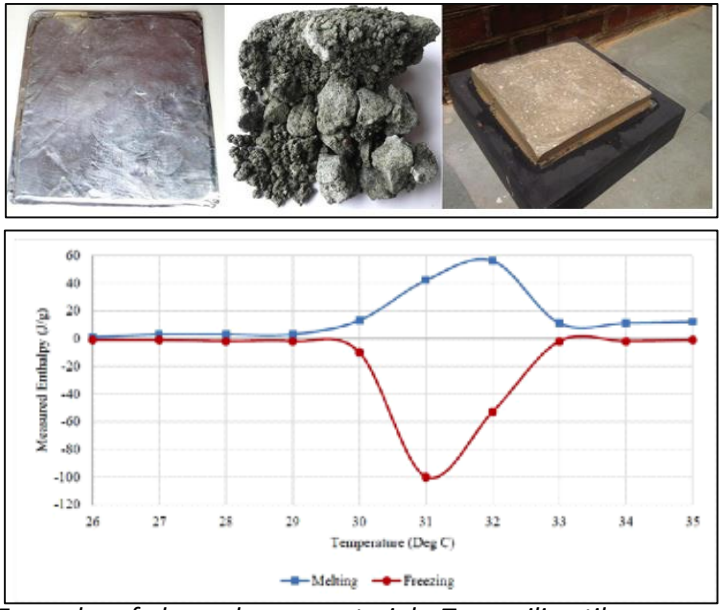
CBERD Progress and Achievements: Materials (being tested)



Left: Laser cut panels (LCP) redirecting light towards the ceiling. Right: Simulated and measured results.

Development of laser cut panels to help enable deeper daylight penetration into buildings

- Optical properties characterized with goniophotometer, simulated with Radiance-genBSDF program
- 65-75% lighting energy savings for buildings with 30% window-to-wall ratio, south- facing



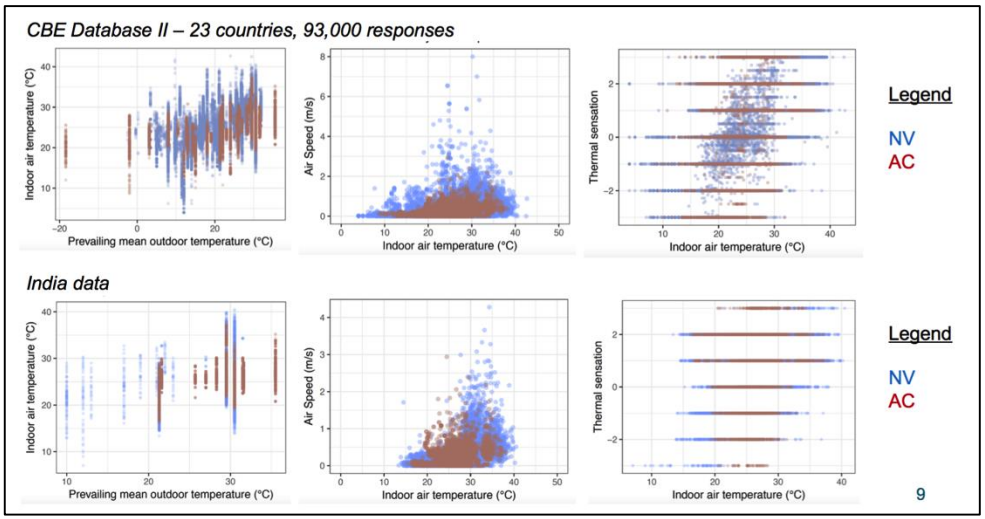
Examples of phase change materials. Top: ceiling tiles, cement concrete, and cement plaster. Bottom: Testing thermal properties of PCMs

Phase Change Material Tiles and Masonry Units

Tiles suitable to US and India

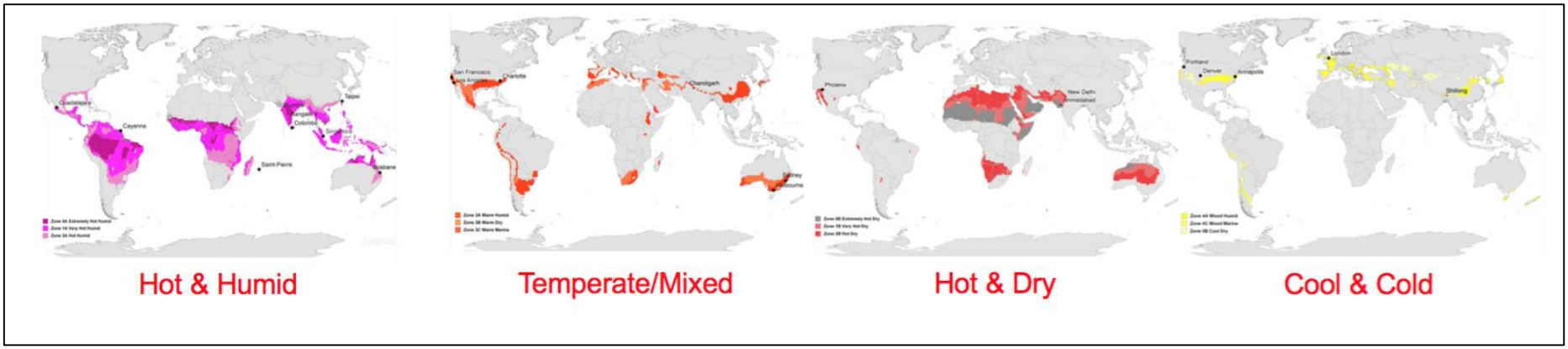
- Energy and comfort benefits of 5%–15% simulated
- Existing or new buildings; as an inside or outside envelope layer or a series of layers

CBERD Progress and Achievements: Methods and Guidelines



Climate Responsive Buildings Methods: Analyzed performance of well designed passive buildings, with focus on:

- Natural ventilation & mixed-mode
- Thermal mass & nighttime ventilation
- Role of air movement



CBERD Progress and Achievements: Methods and Guidelines

Financial Capital: Economic impact	Natural Capital: Environmental impact	Human Capital Personnel impact
First Cost/ Mortgage savings	CO2	Task performance
Energy savings	Methane	Absenteeism
Facilities mgmt. savings	SO_X	Headaches
Churn costs	NO_X	Colds and Flus
Waste savings	Particulates PM2.5	Skin and Eye irritations
Real estate value/vacancy	Water	Asthma and Allergies

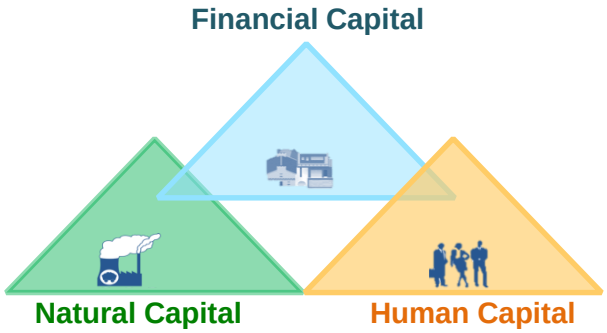
Financial + Natural + Human Capital

Benefits of Light Redirection Louvers

	Per sq ft	Per employee
Absenteeism Savings (15% of 1.7%)[1]	$0.58	$115
Productivity increase (3%)[2]	$2.25	$450
Cumulative ROI (Economic + Environment + Equity)	**158%**	
Payback Period	**Less than 1 year**	
15 year Net Present Value (10% discount rate)	**$195,000**	

Triple bottom line (TBL) method:

Life cycle data sets for energy efficiency technologies to overcome first-least-cost decision making patterns by building decision-makers.



CBERD Progress and Achievements: Test labs



FDD test facility at IIIT Hyderabad, modelled after FLEXlab at LBNL.
Control room (left) and dedicated chilled water plant (middle) and heat recovery wheel (right).




Low energy cooling/HVAC testing facilities at (left) MNIT Jaipur, and IIT Bombay (right). Thermal comfort chamber at CEPT University, with technical assistance from UC Berkeley.



Cool Roofs tested with Saint Gobain cost-share at 4 locations in India. Envelope and daylighting testing instrumentation at CEPT University. Daylight simulation lab (left) and hygrothermal characterization instrument (right)

CBERD Progress and Achievements: Scientific exchanges

- 40+ researcher exchanges
- 15 joint workshops and conferences
- BHAVAN: First ever fellowship program on buildings energy efficiency instituted

CBERD Progress and Achievements: A snapshot today

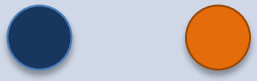
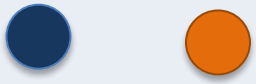
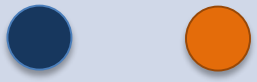
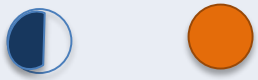
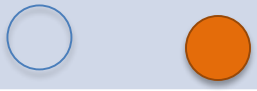
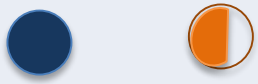
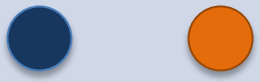
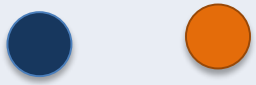
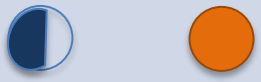
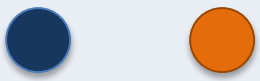
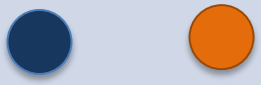
By end CBERD	By Jan 2017		
45	45	Industry partners and collaborators	Deployable/ pathways
11	8	Prototype technologies and materials leading to products	
5	2	Software Tools for public use	
6	4	Methods, guidelines and specifications	
9	6	Demonstrations	
118	106	Journal pubs, Conference Proceedings, Technical Reports	New Knowledge, dissemination
18	15	Conferences, workshops, and joint events	
40	35	Researcher Exchanges	Technical Assistance
9	6	Research infrastructure/ instruments initiated in India	

CBERD Impact: Deployable Outcomes

Research

Deployment

	Research	Development	Demo/testing	
Tools	Model Predictive Control Shading Tool	eDot Tool	COMFEN-India Cool Roof Tool	**A&E practitioners**
Materials			Lasercut glazing prototype Phase change materials	**Product industry**
Data, Methods		Mixed mode and comfort methods Triple bottom line method	Benchmarking methods	**Policy and Regulatory institutions**
Technologies		Microchannel heat exchanger Dedicated outdoor air system Indirect evaporative space cooling	Wireless motion sensor prototype Smart power strip prototype Energy information system packages	**Technology industry** **Developers, Professional entities**

	Name of Deployable Outcome	Applicability KEY U.S. INDIA	Value to U.S. industry
Tools	eDOT Early design optimization tool		✔ U.S. architects
	Non coplanar shading tool		✔ Free software
	Model predictive control tool for radiant cooling		✔ Free software
	Building energy code compliance tool		✔ Free software
	COMFEN –India Commercial Fenestration Tool for façade design		✔ Free software
Technologies	I-SPACE workstation hub Intelligent system for personalized ambient comfort and energy efficiency		✔ U.S. controls and office furniture companies
	Smart strip and low-power wireless motion sensor		✔ U.S. controls companies
	Cost –effective, scalable EIS-in-a-box (Energy Information System)		✔ U.S. Services and product companies
	HVAC: Dedicated outdoor air system, Efficient AC unit with Microchannel heat exchanger; Radiant cubicle		✔ U.S. equipment manufacturers
Materials	Laser cut panels for glazing		✔ US Glass companies
	Phase change materials tiles		✔ US PCM companies

CBERD Impact: Value to U.S. industry

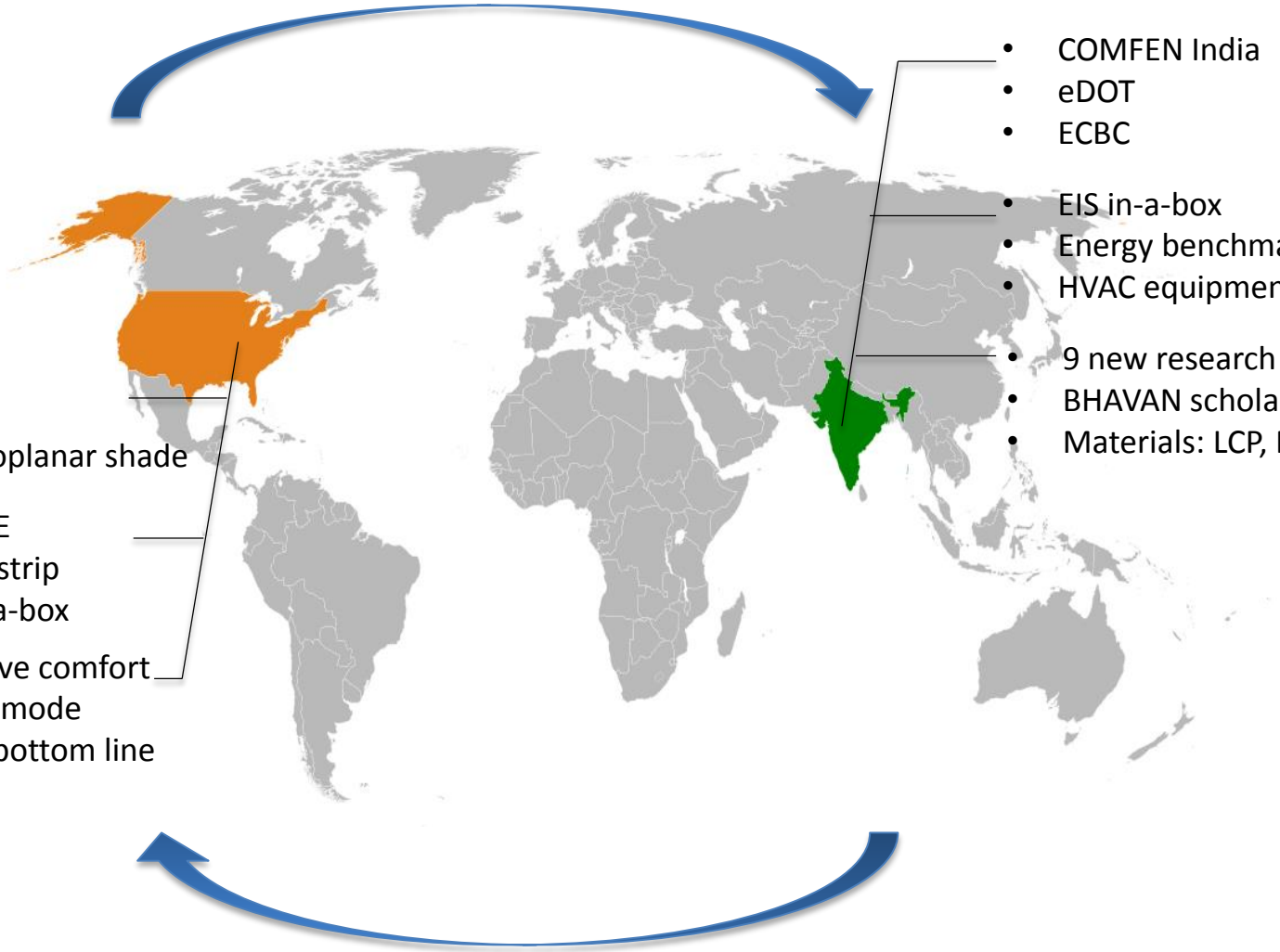
Introduction of U.S industry services and new products to India, e.g.

- Mazzetti opened office in Bangalore, received interest in pilots in India for healthcare EIS
- enLighted conducted lighting demo with LBNL, and subsequently at Infosys in India
- Architectural Applications, start up from Portland, demonstrating heat-moisture membrane in MNIT lab, Jaipur
- Philips demonstrating new luminaire technology at LBNL test bed, with Indian market interest

New products for US industry uptake:

- EIS-in-a-box solution for scale and adoption of energy information systems
- ISPACE controls for integrated workstation controls and grid response
- PCM for peak load management
- HVAC MCHX for higher efficiency, lower mass, low-GWP adaptability

CBERD Impact: Bi-directional value



- COMFEN India
- eDOT
- ECBC

- EIS in-a-box
- Energy benchmarking
- HVAC equipment

- 9 new research labs
- BHAVAN scholarships
- Materials: LCP, PCM

- eDOT
- MPC
- Non-coplanar shade

- I-SPACE
- Smart strip
- EIS in-a-box

- Adaptive comfort
- Mixed mode
- Triple bottom line