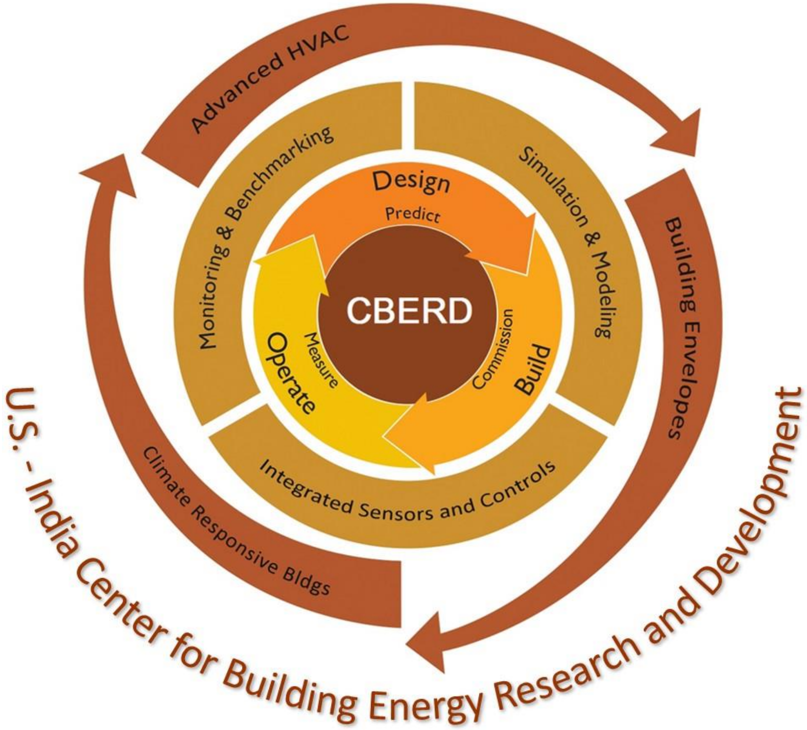
# CBERD Task 1 Simulation & Modeling

2017 Building Technologies Office Peer Review




U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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# Project Summary

**Timeline**:

Start date: 10/1/2013

Planned end date: 9/30/2017

Key Milestones

1. Beta-testing of ECBC ruleset for code compliance; 3/31/17

**Key Partners**:

| | |
|---|---|
| IIIT Hyderabad, India | UC Berkeley |
| CEPT University, India | NREL |
| California Energy Commission | HOK, Infosys |

**Budget**:

**Total Project $ to Date**:

- DOE: $700k
- Cost Share: $380K

**Total Project $:**

- DOE: $875K
- Cost Share: $430K

**Project Outcomes** :

- Improve building energy efficiency through the use of smart, integrated simulation tools for design and operation
- Develop new methods for reducing the energy consumption of existing and new buildings – controls, diagnostics

# Purpose and Objectives

**Problem Statement**:
As described in the MYPP, current simulation tools do not fully meet the needs of practitioners, particularly in early stage design and in operation. India lacks a tool for performance-based code compliance.

**Target Market and Audience**:
- Architects, mechanical engineers, code officials, control engineers, operators.
- New and existing commercial buildings in India and the US
- Enabling technologies, contributing to technical potential of 40% of 510 TWh/yr in India and 36% of 3200 TWh/yr in US by 2030

**Impact of Project**:
1. Products: Improved analysis tools for early design, rulesets for code compliance, optimum control strategies for radiant slab systems, diagnostic tools for dedicated outdoor air systems (DOAS) – creating add-on tools to increase simulation tool usage, per BEM R&D logic model
2. Impact metrics:
   a. Near-term: Adoption
   b. Intermediate-term: Case studies of benefits
   c. Long-term: Impact on building stock

# Approach

**Approach**: Identify needs/opportunities to improve tools and supporting data. Develop, implement and test new, high priority capabilities for existing tools and control systems. Leverage external R&D

**Key Issues** - selected for joint research interest and impact potential:

- early stage design analysis – optimization and design flexibility
- code compliance tools - extend ASHRAE 90.1 Appendix G capabilities to the India building energy code (ECBC), which is based on 90.1
- optimal control of passive thermal storage to exploit diurnal swing and shift load - model predictive control (MPC)
- automated diagnostics - test new and existing methods for DOAS, which are required by hydronic heating and cooling systems, including radiant

**Distinctive Characteristics**:

- leveraging of the OpenStudio (OS) implementation of 90.1 baseline building generation, exploiting the similarities between 90.1 and ECBC
- collaboration on test facility design

# Progress and Accomplishments – Early Design Optimization

**Accomplishments**: Early Design Optimization Tool (eDOT)

- On-line , multi-parameter optimization tool – implemented in Web2Py, uses EnergyPlus and GenOpt
- Recent work:
  - Amazon cloud implementation – no user need for major computing capacity
  - cluster analysis → identification of design strategies for high level guidance
- Current work: renewed focus on output visualization, following review by HOK:
  - exploitation of constraints from project brief to reduce design subspace
  - replace numerical presentation with geometrical images

**Market Impact**: Addresses cost barrier for tools for early design - too soon for measurable impacts

**Awards/Recognition**: (None as yet)

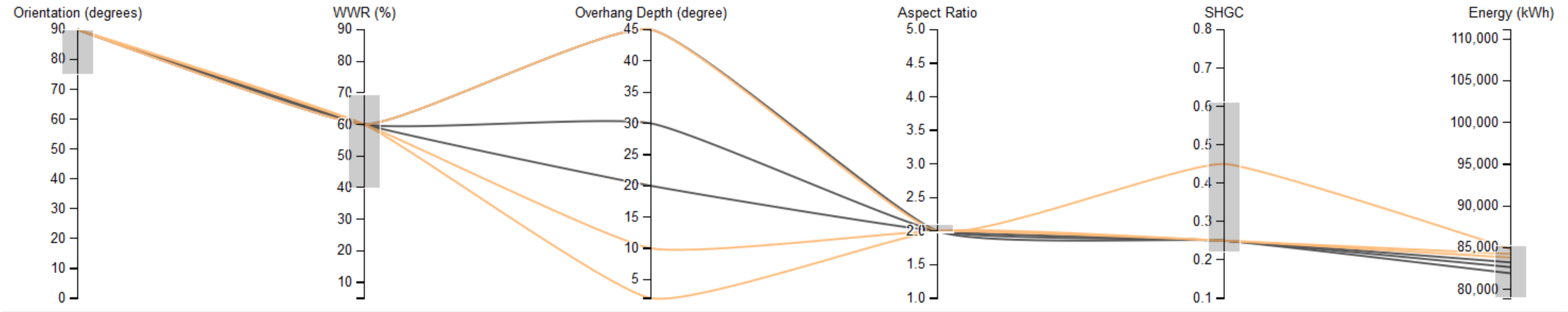
**Lessons Learned**:

- Clients are requiring progressively more early stage design analysis.
- Designers want energy-efficient solutions with minimum constraints on other aspects of design

# Progress and Accomplishments: eDOT - II

The current output GUI works well for engineers and computer scientists and as a temporary output for eDOT computational development but isn't useful for architects.

The intent is to show combinations of input parameters that result in low energy consumption. In the example below, the orientation and the aspect ratio are constrained by the site and the window-to-wall ratio (WWR) and the solar heat gain coefficient (SHGC) are constrained by view and glare requirements. The diagram shows that the lowest energy consumption results from a combination of a low SHGC and a medium sized overhang but that the energy performance with a higher SHGC and a range of overhang depths is nearly as good. An important goal is to show the designer where design parameter values must be respected and where there is design freedom, to encourage integration of the tool into the design process.




*Aim: make this visualization much more intuitive for architects*

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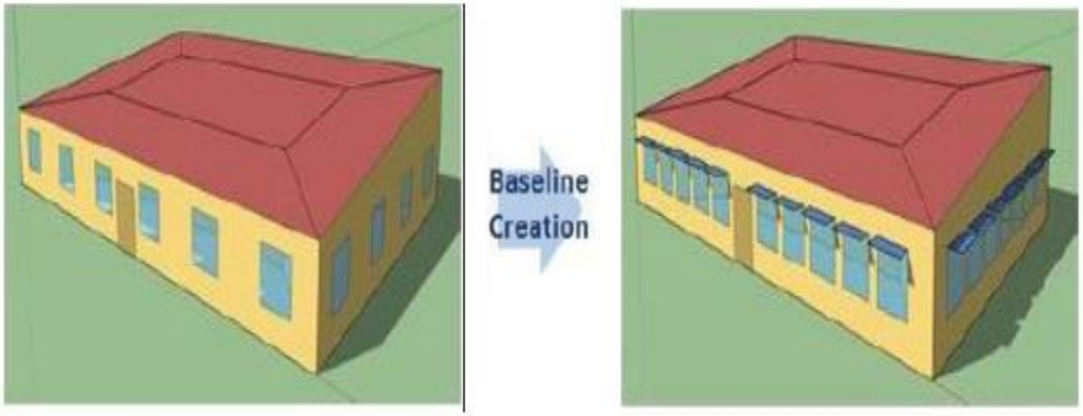
# Progress and Accomplishments – India building code (ECBC)

**Accomplishments**:

- IIIT performed detailed mapping of ECBC onto Appendix G
- LBNL adapted and implemented a California Energy Commission procedure for testing code compliance tools and applied it to Appendix G baseline generation, implemented as an OS 'measure'. Test results were fed back to NREL.
- IIIT adapted the Appendix G implementation to ECBC
- The test procedure is being adapted by IIIT to test the ECBC implementation.




*Compliance test example: On the left, the prototype design and on the right the expected baseline model*

**Awards/Recognition**: (None yet)

**Market Impact**: Addresses cost barrier for tools for code compliance - too soon for measurable impacts

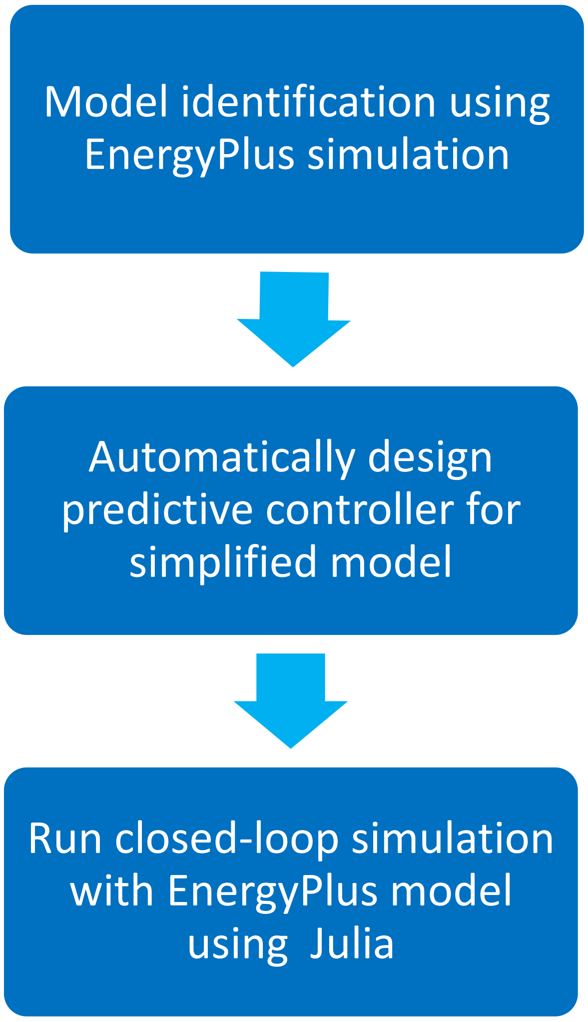
**Lessons Learned**：Easier access to performance-based code compliance tools needed

# Progress and Accomplishments – Model Predictive Control (MPC)

**Accomplishments**:

Algorithm and tool chain have been developed for radiant slab control and ported to open source:

- Given a simulation model (EnergyPlus or Modelica, encapsulated in an Functional Mockup Unit):
  - Identify model of system dynamics
  - Compute optimal control strategy
  - Use in real time or to inform heuristic control strategy development
- Software used:
  - Julia (optimization)
  - BCVTB (middleware)




**Market Impact**: (Too early for measurable impacts)

**Awards/Recognition**: (None as yet)

**Lessons Learned**: MPC may be best used off-line, to inform design of heuristic control strategies - more acceptable to operators

# Progress and Accomplishments – Fault Detection and Diagnosis (FDD) - I

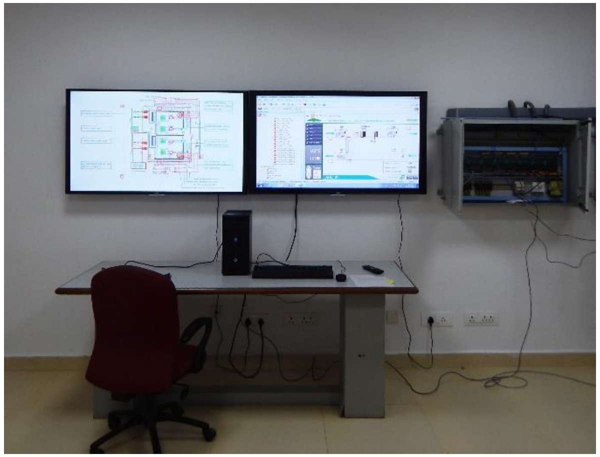
**Accomplishments**:

- A matched pair of test cells for developing and evaluating FDD algorithms for low energy cooling systems have been constructed and commissioned at IIIT Hyderabad:
  - Equipment includes air handling units with heat recovery wheels
  - Starting with DOAS, to complement radiant systems, which are becoming popular in India and have already established themselves in the US.

*Air-handling unit*

*Heat recovery wheel*

# Progress and Accomplishments – Fault Detection and Diagnosis (FDD) - II



*Control room for the FDD test facility at IIIT Hyderabad*

*Dedicated chilled water plant for the FDD test facility at IIIT Hyderabad*

**Market Impact**: (Too early for measurable impacts)

**Awards/Recognition**: (None as yet)

**Lessons Learned**: Construction and commissioning of small scale, experimental facilities is slow because the job is not of commercial interest to contractors with the necessary skills

# Project Integration and Collaboration - I

**Project Integration**:

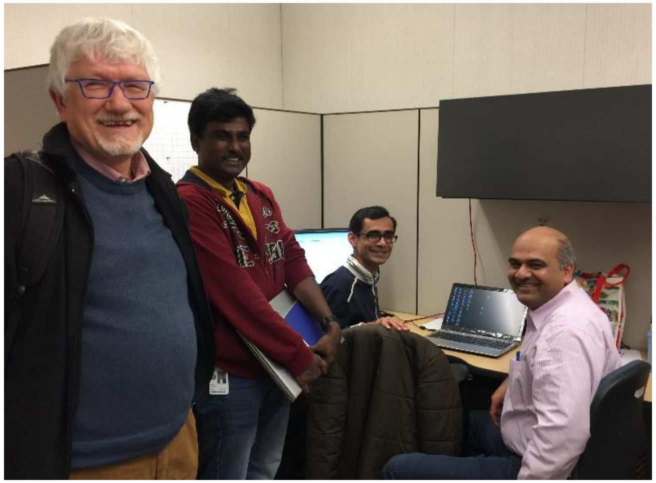
- Collaboration with NREL on development and implementation of code compliance measures for OpenStudio, in line with the MYPP

**Partners, Subcontractors, and Collaborators**:

- Collaboration with IIIT Hyderabad on eDOT and ECBC OpenStudio measure development
- Collaboration with UC Berkeley on development of model predictive control for radiant slabs and on eDOT interface design
- Collaboration with IIIT Hyderabad on design and commissioning of diagnostics test facility, using experience LBNL gained with FLEXLAB
- Collaboration with Infosys on testing and demonstration of MPC for radiant slab cooling

# Project Integration and Collaboration - II

**Exchanges**:



- Students from IIIT Hyderabad (Aviruch Bhatia) and IIT Bombay (Brijesh Pandy) spent six months at LBNL as BHAVAN Fellows in 2016-17
- Vishal Garg attended the ACEEE Summer Study at Asilomar in 2016 and visited LBNL in 2016 and 2017 to discuss CBERD projects
- Philip Haves visited IIIT in December 2015 to advise on FDD test chamber design and construction and to discuss other CBERD projects

# Communications

## Publications

- Garg, Vishal, Abhishek Mittal, Rounak Patni, Rathish Arumugam, Aviruch Bhatia, and Philip Haves. "WinOpt – An Early Stage Design Tool for Optimizing Window Parameters." *Proc 30th International PLEA Conference*. 2014
- Frank Chuang, Francesco Borrelli. "Optimality of certainty equivalence in expected value problems for uncertain linear systems." *Proc. IEEE CDC 2014*
- Frank Chuang, Francesco Borrelli. "Dynamic state and input aggregation." *Proc. American Control Conference 2015*
- Jingjuan (Dove) Feng, Frank Chuang, Francesco Borrelli, Fred Bauman. "Model predictive control of radiant slab systems with evaporative cooling sources," *Energy and Buildings,* **87**. 2015
- Haves, Philip; Garg, Vishal; T. V. S., Nikhil; Bhatia, Aviruch; "eDOT - An Early Stage Design Decision Tool for Building Energy Efficiency." *ACEEE Summer Study on Energy Efficiency in Buildings*. 2016.
- Parker, A., Jegi, S., Ravache, B., Garg, V. and Haves, P. "Development of Automated Procedures to Generate Reference Building Models for ASHRAE Standard 90.1 and India's Building Energy Code and Implementation in OpenStudio." Accepted for publication in *Proc Building Simulation 2017,* San Francisco, August 2017.

# Next Steps and Future Plans - I

- ECBC compliance tool:
  - Finish testing of ECBC implementation in OpenStudio
  - Set up beta testing with practitioners in India – this is expected to lead to Government and, subsequently, commercial support for code compliance software solutions based on EnergyPlus and OpenStudio

- eDOT early design tool
  - Focus on user interface, especially communication of results and integration into the design process

- Develop model-based fault detection and diagnosis (FDD) tools for low energy cooling systems, initially at the system and component levels:
  - Set up a simulation-based prototyping and testing environment, based on Modelica, at IIIT-Hyderabad, with assistance from LBNL
  - Test promising algorithms in IIIT-Hyderabad fault diagnostics test facility
  - Start with algorithms for DOAS, taking existing FDD approaches and algorithms as starting points

# Next Steps and Future Plans - II

- Continue development of model predictive control for thermal mass storage in low energy systems – radiant slab cooling:
  - Testing/demonstration of MPC toolchain in FLEXLAB
  - Performance testing/demonstration in Infosys office building in Hyderabad – side-by-side comparison to:
    - VAV
    - 'conventional' radiant slab control

  *Infosys has the largest estate of energy-efficient buildings in India and plays a strong leadership role nationally and internationally.*

# REFERENCE SLIDES

# Project Budget

**Project Budget**: $175k per year for five years, total $875 k
**Variances**: None
**Cost to Date**: ~$710 k ( until end-Jan 2017)
**Additional Funding**: $380k estimated cost share for FY2013-2015 is based on the California Energy Commission's investment in rule-based software for code compliance, which was initially adopted as the starting point for ECBC compliance software ($300k), $50k in-kind from AutoDesk Research (ADR) and $30k in-kind from HOK architects on early stage design tool requirements. $50k estimated cost share for FY2017 is for Infosys field testing of model predictive control.

| Budget History | | | | | |
|---|---|---|---|---|---|
| FY 2013– FY 2016 (past) | | FY 2017 (current) | | FY 2018 (planned) | |
| DOE | Cost-share | DOE | Cost-share | DOE | Cost-share |
| $700k | $380k | $150k (expected) | $50k | - | - |

# Project Plan and Schedule

| Project Schedule | | |
|---|---|---|
| Project Start: 10/1/12 | | Completed Work |
| Projected End: 9/30/17 | | Active Task (in progress work) |
| | ◆ | Milestone/Deliverable (Originally Planned) |
| | ◆ | Milestone/Deliverable (Actual) |

| Task 1: Simulation and Modeling | FY2013 Q1 (Oc | FY2013 Q2 (Jan | FY2013 Q3 (Ap | FY2013 Q4 (Jul | FY2014 Q1 (Oc | FY2014 Q2 (Ja | FY2014 Q3 (Ap | FY2014 Q4 (Ju | FY2015 Q1 (Oc | FY2015 Q2 (Ja | FY2015 Q3 (Ap | FY2015 Q4 (Ju | FY2016 Q1 (Oc | FY2016 Q2 (Ja | FY2016 Q3 (Ap | FY2016 Q4 (Ju | FY2017 Q1 (Oc | FY2017 Q2 (Ja | FY2017 Q3 (Ap | FY2017 Q4 (Jul |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Past Work (2013-2014)** | | | | | | | | | | | | | | | | | | | | |
| FY2013 Q2 Milestone: Design specifications for Simergy low energy enhancements | | | | | | | | | | | | | | | | | | | | |
| FY2013 Q3 Milestone: Define early stage design workflow for GUI | | | | | | | | | | | | | | | | | | | | |
| FY2013 Q3 Milestone: Stochastic MPC design for low energy HVAC systems | | | | | | | | | | | | | | | | | | | | |
| FY2013 Q4 Milestone: Tool to extract model predictive control (MPC) models from EnergyPlus | | | | | | | | | | | | | | | | | | | | |
| FY2014 Q1 Milestone: 90.1 and T-24 rule sets for CEC SDK | | | N/A due to change of strategy- no development for Simergy) | | | | | | | | | | | | | | | | | |
| FY2014 Q1 Milestone: Tool to generate model predictive control (MPC) design from reduced-order model | | | | | | | | | | | | | | | | | | | | |
| FY2014 Q2 Milestone: Simergy hybrid ventilation beta version | | | | | | | | | | | | | | | | | | | | |
| FY2014 Q3 Milestone: Comparison between sample-based and explicit methods for MPC | | | | | | | | | | | | | | | | | | | | |
| **Current/Future Work (2015-2017)** | | | | | | | | | | | | | | | | | | | | |
| FY2015 Q2 Milestone: Study on efficient MPC design for low energy HVAC systems with large number of coupled thermal zones | | | | | | | | | | | | | | | | | | | | |
| FY2015 Q3 Milestone: Development of commissioning plan for IIIT-H FDD lab | | | | | | | | | | | | | | | | | | | | |
| FY2015 Q3 Milestone: Design of MPC toolchain architecture | | | | | | | | | | | | | | | | | | | | |
| FY2015 Q4 Milestone: Beta testing of eDOTv1-initial assessment with HOK | | | | | | | | | | | | | | | | | | | | |
| FY2015 Q4 Milestone: AFDD method development | | | | | | | | | | | | | | | | | | | | |
| FY2015 Q4 Milestone: Implementation of MPC toolchain architecture | | | | | | | | | | | | | | | | | | | | |
| FY2016 Q1 Milestone: Commissioning of FDD lab at IIIT | | | | | | | | | | | | | | | | | | | | |
| FY2016 Q1 Milestone: Preliminary Testing of ASHRAE 90.1 Appendix G ruleset and development of ECBC ruleset | | | | | | | | | | | | | | | | | | | | |
| FY2016 Q1 Milestone: ALpha testing of ECBC rule set | | | | | | | | | | | | | | | | | | | | |
| FY2016 Q2 Milestone: Beta testing and release of ECBC rule set | | | | | | | | | | | | | | | | | | | | |
| FY2016 Q2 Milestone: Alpha testing of EnergyPlus MPC toolchain | | | | | | | | | | | | | | | | | | | | |
| FY2016 Q2 Milestone: AFDD DOAS and VAV | | | | | | | | | | | | | | | | | | | | |