Thrust 6: Cyber-Physical Testbeds

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Dynamic Interaction for Optimum Energy Efficiency within SinBerBEST

Consumed energy in building construction and operation can be reduced by intelligent interaction between the grid, the building and its occupants/apparatuses. This requires a transformational paradigm-shift in designing, commissioning, & retrofitting.
Thrust 6: Mission Statement and Plan

Cyber-Physical Testbeds

Verify the actual performance, efficiency and effectiveness of all developed technologies *in other thrusts* as an *integrated* system.

1) Survey existing testbeds in Singapore and UC-Berkeley
2) Close communication with other thrusts to understand needs for future testing and soliciting cross-thrusts proposals:
   - Middleware services for testbed integration
   - Cyber-infrastructure for data management
3) Develop a decision-making assessment framework
Thrust 6: PI’s

1) Khalid Mosalam (Professor, Structural Engineering, Mechanics, and Materials, CEE, UC-Berkeley, Thrust Co-Leader)
2) Sing-Ping Chiew (Associate Professor, Structures and Mechanics, CEE, NTU, Thrust Co-Leader)
3) Costas Spanos (Professor, Electrical Engineering and Computer Science, UC-Berkeley, Co-PI)
4) King Jet Tseng (Associate Professor, Power Engineering, Electrical and Electronic Engineering, NTU, Co-PI)
5) Hock Beng Lim (Director, R&D, Intelligent Systems Center, NTU, Collaborator)
6) Stefano Schiavon (Assistant Professor, Center for the Built Environment, Architecture, UC-Berkeley, Collaborator)
We should design indoor environments that are better than the best environment found in nature

— Ole Fanger
Building Lifecycle Assessment and SinBerBEST Innovations

**Building LCA platform**

- **Material Production**
  - **Innovation:** Local Lifecycle Inventory (LCI) model

- **Construction**
  - **Operation**
  - **End of Life**

- **Thrusts 1, 2, 3 & 5:** Whole building energy simulation in the tropics, e.g. BIM

- **Thrust 4:** Thermal comfort & IEQ

- **Thrust 5:** Material, design, analysis, & decision making

- **Thrust 6:** Cyber-physical Testbeds

- **Innovation:** Local repair & maintenance scheme

- **Innovation:** Evaluation matrix for overall sustainability considering environment (GWP), social (health), and economic (productivity)
Displacement Ventilation & Chilled Ceilings

Manitoba Hydro Building, Canada, by KPMB

David Brower Center, US, by Solomon/WRT
Displacement Ventilation & Chilled Ceilings

Laboratory experiments for typical U.S. interior zone office to investigate how:

1. Ratio of cooling load removed by CC over the total cooling load
2. Percentage of active ceiling area (radiant surface temperature) affect:
   i. Air stratification
   ii. Air change effectiveness

http://escholarship.org/uc/item/980931rf

Center for the Built Environment
A Testbed for Increasing the Heat Load

SinBerBEST Testbed Initiative in Collaboration with Thrust 3

- **Thrust 3**: **High Confidence Building Operating System** focus on reducing energy consumption in interior lighting by developing efficient and intelligent lighting grids using solid-state devices and natural light.

- A project between SinBerBEST & Energy Research Institute (ERI@N) started to use SinBerBEST space as a testbed for assessing visual performance metrics.
SinBerBEST Testbed – Office Environment
SinBerBEST Testbed – Office Environment

Daily sun path

10:00 am, Dec 21, 2012

Zone 2

Zone 1

Zone 2

4:00 pm, Dec 21, 2012

Zone 1
Other Testbeds (UC-Berkeley + ERI@N)

Sensor Selection and Placement for CO₂ and Temperature Fields
- Data collected includes Temp., RH, CO₂ concentration, Occupancy, & Supply airflow rate in the defined spaces.
- **Idea:** Use sparse sensor array, occupancy info., models → CO₂ & Temp fields in a networked rooms.

- 7 office spaces
- 1 discussion room
- 1 holding area + hallway
- Served by same AHU

SMPS Building, Level 4

- 12 office spaces
- 1 hallway
- Served by same AHU

SADM Building, level 4
Sensor Network Testbeds

SinBerBEST sensor network testbeds deployed at:
- SinBerBEST office space
- BCA test chambers
- ETH BubbleZERO

ETH BubbleZERO Testbed

SinBerBEST Testbed

BCA Testbed
“... of interest is the SinBerBEST's wireless sensing system ... meant to connect test labs from various sites in Singapore to a central monitoring server so that building technology researchers could share data and align research activities on facades or indoor environment quality going forward.”
Deployment Status

Deployed heterogeneous sensor networks:
- MicaZ with TinyOS
- TelosB with Contiki OS
- iMotes, IRIS

Sensing functionality:
- Temperature, light, humidity, CO₂ levels
- Example: humidity readings from TelosB

Data Stream
- Sensor data streaming from SinBerBEST testbed to Berkeley’s Sensezilla
Demo Prototype

Dashboard Interface:
- Heat map
- Network topology
- Real time sensor data
Future Extension: Data Management and Analytics Framework for Smart Buildings

Motivation:

- Building Information Model (BIM) are required for all building design submissions
- Current BIM provides building information that is mainly architectural & physical in nature without sensing and information of energy consumption.
- BIM has the potential to be a universal data aggregation platform.

Objective:

Develop a data management and analytics framework to share data from different building testbeds and to integrate with BIM.
CREST† 406 Bubble: A Testbed in Cory Hall, UC-Berkeley

†Center for Research in Energy Systems Transformation
CREST 406 Bubble
Data Connectivity in a Sensing Bubble

Objectives:
- Build a local bubble gateway
- Interface with all types of sensors/actuators in 406
- Provide Augmented Reality (AR) view/control on Android Pad
- Preliminarily implement the data-centric infrastructure with space-time and semantic searching interface

EnergyEyes app uses QR codes & real-time data flow from devices to an end-user to find energy waster

Coverage of a Sensing Bubble

Physical Server

- WiFi-DotCloud
  (sMap)

- DotCloud
  (sMap)

Data Repository

External
Web Portal
Server

Virtual Server

Serial Port or USB

- * HTTP
  sMAP

BAC/IP
Device

sMAP
Device

ZigBee
Device GW

Non-standard
Device GW

Non-standard
Port Device

* Ethernet-IP

* Ethernet-IP

* Ethernet-IP

* Ethernet-IP

* Ethernet-IP
Performance-based Engineering (PBE) for “Best” Decision of Energy-efficient & Sustainable Building Design

Objective:

Develop a framework to make the best decision for building design satisfying:

- Energy-efficiency
- Sustainability
- Safety
- Economical constraints, etc.

considering interests of stakeholders & sources of uncertainties during lifecycle.

Various interests
Uncertainties
Life cycle

Multicriteria + Probabilistic + LCA

Framework

Energy-efficient Sustainable Safe Economical : 
Holistic design
Decision-Making Process:

**MIVES** (Model for Integration of Values for Evaluation of Sustainability)

4 steps:
- Tree Construction
- Value Function
- Weight Assignment
- Selection Amongst Alternatives

PBE-Approach to the Holistic Best Design Decision
**Testbed for PBE-MIVES Approach**

**Example building:** UCS building at UCB

Details are presented tomorrow by Dr. Hyerin Lee


Plan view of the UCS building located at UC-Berkeley campus

Lee & Mosalam, 2006

*Loss Curve*

Mosalam & Günay, 2011

SinBerBEST 2013
Future Extension: PBE-MIVES

- Selecting major indicators (including those for safety and health in construction activities) and corresponding weights in office building design

- Collecting data/defining probability distributions & correlations for office buildings in the tropics

- Accounting for results obtained from various testbeds, e.g. on newly developed façade systems

- Evaluating the efficiency of a newly developed technologies, e.g. novel façade systems
Thank You!

Questions? Comments?