2014 Annual Symposium

Singapore-Berkeley Building Efficiency and Sustainability in the Tropics

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Andrew S. Grove Distinguished Professor
Department of EECS, UC Berkeley
Director and CEO,
Berkeley Educational Alliance for Research in Singapore
A Partnership
Why Focus on Smart *Tropical* Buildings?

40% of the world's population lived in the tropics in 2008. By 2060 60% will live in the tropics, due to high birth rates and migration.

http://www.independent.co.uk/environment/climate-change/expanding-tropics-a-threat-to-millions-761326.html

Zones where year-round mean temperature is above 18 °C (64 °F).
What is SinBerBEST?

- Cooperative optimization of the interactions between the Grid, the Building and its Occupants, as an Ecosystem.
- Flexible, constrained optimization of energy consumption, CO₂ emissions, productivity, safety, comfort, healthfulness, and the entire building lifecycle.
The SinBerBEST View

= 

[Image of a skyscraper with green energy symbol]  

[Image of a factory emitting smoke]
The SinBerBEST Vision

Buildings respond to demand from occupants & processes

The Building “Plant”

- Energy
- Indoor Environment (IE)

Control
Scheduling
Planning
Plant Design

IE Specifications
IE Requirements

Occupants & Processes

- Sensing / Metrology
- Stat Process Control
- Supply Chain Control
- WIP Control
- Just-in-Time
- Forecasting
- Equipment Modeling
- Plant Diagnostics
- ...

- Polling
- Focus Groups
- Statistical Models
- Data Mining
- Abstraction
- Simulation
- CAD
- ...

January 8, 2014
SinBerBEST Research Thrusts

Thrust 6: Cyber/Physical Testbeds

- Holistic Hybrid Simulation
- Building Energy Conservation Technology
- Building Grid
- Model Development & Evaluation
- Monitoring

Thrust 1: Sensing, Data Mining and Modeling

Thrust 2: Multi-Level Optimal Control

Thrust 3: High Confidence Building Operating System

Thrust 4: Human-Building Interaction & the Environment

Thrust 5: Material, Design and Lifecycle
Information technology across the program

Initial model → Machine Learning → Fitted model

Real data

Off-line

Raw data

Data Reconciliation/Estimation

Processed data

On-line

Occupancy prediction

T2 Multi-level Optimal Control

Model Predictive Control

Calibrated model

T3 Building Operating System

Occupancy level/distribution; CO2 level, temperature

T4 Human-Building Interaction

Occupancy level/distribution; Model for control & optimization

January 8, 2014 SinBerBEST Overview
Building occupancy modeling inhomogeneous Markov Chains

- Building occupancy modeling in multi-occupant single-zone (MOSZ) and multi-occupant multi-zone (MOMZ) scenarios.
- MOSZ our model outperforms agent-based model.
- MOMZ, our model performs well for first arrival, and trend of total occupancy.

January 8, 2014 SinBerBEST Overview
HVAC Control and Optimization

• ACB primary design
  – Reduction of material thickness 28%
  – Increased cooling Efficiency
  – Ease of assembly with customer requirements

• Distributed optimal scheduling in precooling and pre-ventilation

• Scenario-based distributed control for temperature regulation in the presence of random disturbances
Liquid desiccant dehumidification system

- **Test bed**
  - High energy efficiency by integrating with VCRS

- **Soft sensing**
  - No hardware cost
  - Real-time concentration prediction
  - RE of prediction ≤10%

- **Dynamic modeling of LDDS**
  - Simple and high accuracy
  - Wide operating range
  - No iterative computations
Power Flow Management

- Privacy-aware Identification of personal indoor temperature valuations
- Optimal design of demand response programs
- Accurate model and prediction of demand: help power market operation

**Extension: utility learning model predictive control**
- real-time learning of a customer’s utility function
- the controller optimizes its strategy based on the learning
- data analytics for modeling and control of personalized systems
Protection in buildings from haze aerosol

I/O ratios (0.3-2.5 µm):
CREATE — 44%
PAR — 39%
⇒ ~ 2.2-2.6× protection

Fine Particle Exposure: 25 June 2013

Particle size range
- 0.3-2.5 µm
- 0.3-1 µm
- 0.3-0.5 µm

Park Ave Rochester
Commute (walk)
CREATE
Outside (UTown/NUS)
Park Ave Rochester
Commute (walk)
Energy-efficient thermal environments

**Concept 1:** Efficient thermal conditioning focuses on meeting human needs (rather than needs of unoccupied building spaces).

**Concept 2:** High air movement that creates draft in cool conditions is pleasant in warm environments.

**Concept 3:** Occupant control improves occupant satisfaction.
Particle Monitors as Activity Detectors

PM 0.5 Sensor

Fig. 8. Time series of filtered data over 7.8hr experiment. Top: Green lines mark camera obstruction occurrences and magenta line is the filtered camera occurrence rate. Bottom: Filtered $\geq 2.5\mu m$ outputs from DSM501A (average of 5).
Energy-efficient Building Envelope

TYPICAL COMPOSITE PANEL
A Light Concentrating Layer (Compound Parabolic Cones, CPC)
B Light Conduit Layer (Translucent Concrete, TC)
C Insulation Layer
D Light Scattering Layer

BUILDING ENVELOPE
Studies on Daylight Harnessing

January 8, 2014  SinBerBEST Overview 17
Manufacturability and Mechanical Properties of Energy Efficient Translucent Concrete Panels

**Construction Steps**

- Finished OF cage
- Finished formwork
- Adding plasticizer
- Placing & vibrating mortar
- Curing in the fog room
- TC panels after unmolding
- Sanding
- Under the sky
- Under the sun

**Mechanical properties**

- **Cylinders**
  - Average comp. strength:
  - NWM = 39.1 MPa
  - LWM = 58.8 MPa

- **Cubes**
  - Average comp. strength:
  - NWM = 49.1 MPa
  - LWM = 53.0 MPa

**Cylinders**
- Cylinder of NWM
- Cylinder of LWM

**Cubes**
- Cube of NWM
- Cube of LWM

**Stress-Strain Curves**

- Stress-Strain Curves of NWM
- Stress-Strain Curves of LWM

January 8, 2014

**SinBerBEST Overview**
Application of High Performance Green Hybrid Fiber Reinforced Concrete Double Skin Façade Systems

- Steel rebar in conventional solid façade replaced by fiber reinforced polymer bars.
- Cement replacement by 60% waste materials (45% slag + 15% fly ash).
- Total thickness of 120 mm remains the same (2x45 mm + 30mm air gap)
Photocatalytic Building Coating Materials

Effective removal of black carbons on building surface

Building coating with 0% TiO₂:
1. without soot loading,
2. with soot loading,
3. after 50 hrs of light exposure

Building coating with 40% TiO₂:
1. without soot loading,
2. with soot loading,
3. after 50 hrs of light exposure, photocatalytic removal of black carbon by TiO₂ is demonstrated
Energy-Efficient, Insulating Structural Materials

- Lightweight
- Low thermal conductivity
- Sufficient strength and elastic modulus
- Using by-product from thermal power plants

<table>
<thead>
<tr>
<th></th>
<th>Density, kg/m³</th>
<th>Thermal conductivity, W/mK</th>
<th>Reference/remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinary concrete</td>
<td>~2300</td>
<td>1.5-3.5</td>
<td>Mindess et al. 2003</td>
</tr>
<tr>
<td>Lightweight concrete</td>
<td>1360-1840</td>
<td>0.51-0.95</td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>-</td>
<td>0.03</td>
<td>On-going work, 28-d strength ~50MPa</td>
</tr>
<tr>
<td>Lightweight cement composite</td>
<td>1415</td>
<td>~0.3</td>
<td></td>
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</tbody>
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3D tomography:
Observe features that can lead to understandings of the microstructure providing the low thermal conductivity.

Identify and quantify cenospheres in lightweight cement composite.
Integrative Test Bed Design

1. Solar Daylight emulator
2. Façade testing partition
3. Side partition wall
4. False Ceiling Grid
5. Raised Floor
6. Permanent air tight partition Wall
7. Replaceable Active Chilled Beam unit
8. Controllable Lighting
9. Fixed air tight ceiling panel
10. Air Duct Supply (purple)
11. Air Duct Return (yellow)
12. Under Floor Air Duct
Integrative Test Bed Design

- Bench tests
- Integrative test bed area
- Fabrication
- ACVM Plant
- Micro Grid
- Control

 Completely “Manufactured” weather (outdoor air, thermal loading, and daylight)

Completely configurable Façade, MVAC & Lighting
Open source test bed model: Integrating Berkeley, Tsinghua and CREATE Test beds

- A smart office space to demonstrate co-existence of experimental and off-the-shelf sensors/actuators
- Create inter-operability amongst subsystems by protocol translation
- Local devices connected to a private network to guarantee security
- Users access sensor data and operate devices through augmented reality human-environment –interface (HEI).
# 2014 SinBerBEST Symposium

## Wednesday, 8 January 2014

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00 - 09:20</td>
<td>Welcome Remarks and Overview&lt;br&gt;Prof. Costas S. Spanos, BEARS Director and SinBerBEST Program Leader&lt;br&gt;University of California, Berkeley</td>
</tr>
<tr>
<td>09:20 - 09:40</td>
<td>Thrust 1 – Tunable Integrated Building Model&lt;br&gt;Prof. Alexandre M. Bayen, University of California, Berkeley</td>
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<tr>
<td>09:40 - 10:00</td>
<td>Thrust 2 – Multi-level Optimal Control&lt;br&gt;Prof. Xen Liu, Nanyang Technological University</td>
</tr>
<tr>
<td>10:00 - 10:30</td>
<td>Tea Break &amp; Poster Session</td>
</tr>
</tbody>
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## Thursday, 9 January 2014

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00 - 09:45</td>
<td>Keynote Lecture – Occupants as Partners in Energy Savings – Intelligent Dashboards for Communication, Expert Consulting and Control&lt;br&gt;Prof. Yiyan Jia, Carnegie Mellon University</td>
</tr>
<tr>
<td>09:45 - 10:00</td>
<td>SinBerBEST Research Paper – Multi-Functional Building Materials for Energy Efficiency&lt;br&gt;Dr. Vanessa Rheinheimer, National University of Singapore</td>
</tr>
<tr>
<td>10:00 - 10:30</td>
<td>Tea Break &amp; Poster Session</td>
</tr>
<tr>
<td>10:30 - 11:15</td>
<td>Keynote Lecture – Residential Thermal Comfort and Patterns of A/C Usage&lt;br&gt;Prof. Richard L. O’Dell, The University of Sydney</td>
</tr>
<tr>
<td>11:30 - 11:45</td>
<td>SinBerBEST Research Paper – A Social Game for Energy Reduction&lt;br&gt;Mr. Ioannis Konstantakopoulos, University of California, Berkeley</td>
</tr>
<tr>
<td>11:45 - 12:00</td>
<td>SinBerBEST Research Paper – New Building Envelope for Energy Efficient Lighting&lt;br&gt;Ms. Nuria Casquerio Mooreno, University of California, Berkeley</td>
</tr>
<tr>
<td>12:00 - 13:00</td>
<td>Lunch &amp; Poster Session</td>
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## Friday, 10 January 2014

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>13:00 - 13:45</td>
<td>Keynote Lecture – Singapore haze 2013: Particle exposures and building protection factors&lt;br&gt;Prof. Victor Chang, Nanyang Technological University</td>
</tr>
<tr>
<td>13:45 - 14:00</td>
<td>SinBerBEST Research Paper – PDE-Based Modelling and Estimation of the Human’s Effect in the CO2 Dynamics of a Conference Room&lt;br&gt;Mr. Kevin Weekly, University of California, Berkeley</td>
</tr>
<tr>
<td>14:00 - 14:15</td>
<td>SinBerBEST Research Paper – Dynamic Market for Distributed Energy Resources in the Smart Grid&lt;br&gt;Mr. Edwin Chan, Nanyang Technological University</td>
</tr>
<tr>
<td>14:15 - 14:30</td>
<td>SinBerBEST Research Paper – Dynamic Contracts with Partial Observations: Application to Indirect Load Control&lt;br&gt;Mr. Insoo Yang, University of California, Berkeley</td>
</tr>
<tr>
<td>14:30 - 14:50</td>
<td>Keynote Lecture – BCA Progress in Developing a Rotating Testbedding Facility&lt;br&gt;Jeffrey Nong, Stephen Moly Building and Construction Authority</td>
</tr>
<tr>
<td>14:50 - 15:05</td>
<td>SinBerBEST Research Paper Presentation: Computational Models of Energy Efficient Facades for Daylighting&lt;br&gt;Mr. Aashish Ahuja, University of California Berkeley</td>
</tr>
<tr>
<td>15:05 - 15:45</td>
<td>Tea Break &amp; Poster Session</td>
</tr>
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Panel Discussion Moderator: Prof. William Nazarroff, University of California, Berkeley

15:45 - 16:45 Panel Discussion – Metrics for Building Performance and Sustainability

16:45 - 17:00 Closing Remarks