2014 Annual Symposium

Singapore-Berkeley Building Efficiency and Sustainability in the Tropics

Costas J. Spanos

Andrew S. Grove Distinguished Professor

Department of EECS, UC Berkeley

Director and CEO,

Berkeley Educational Alliance for Research in Singapore

A Partnership

National Research Foundation Singapore

CREATE Campus for Research Excellence And Technological Enterprise

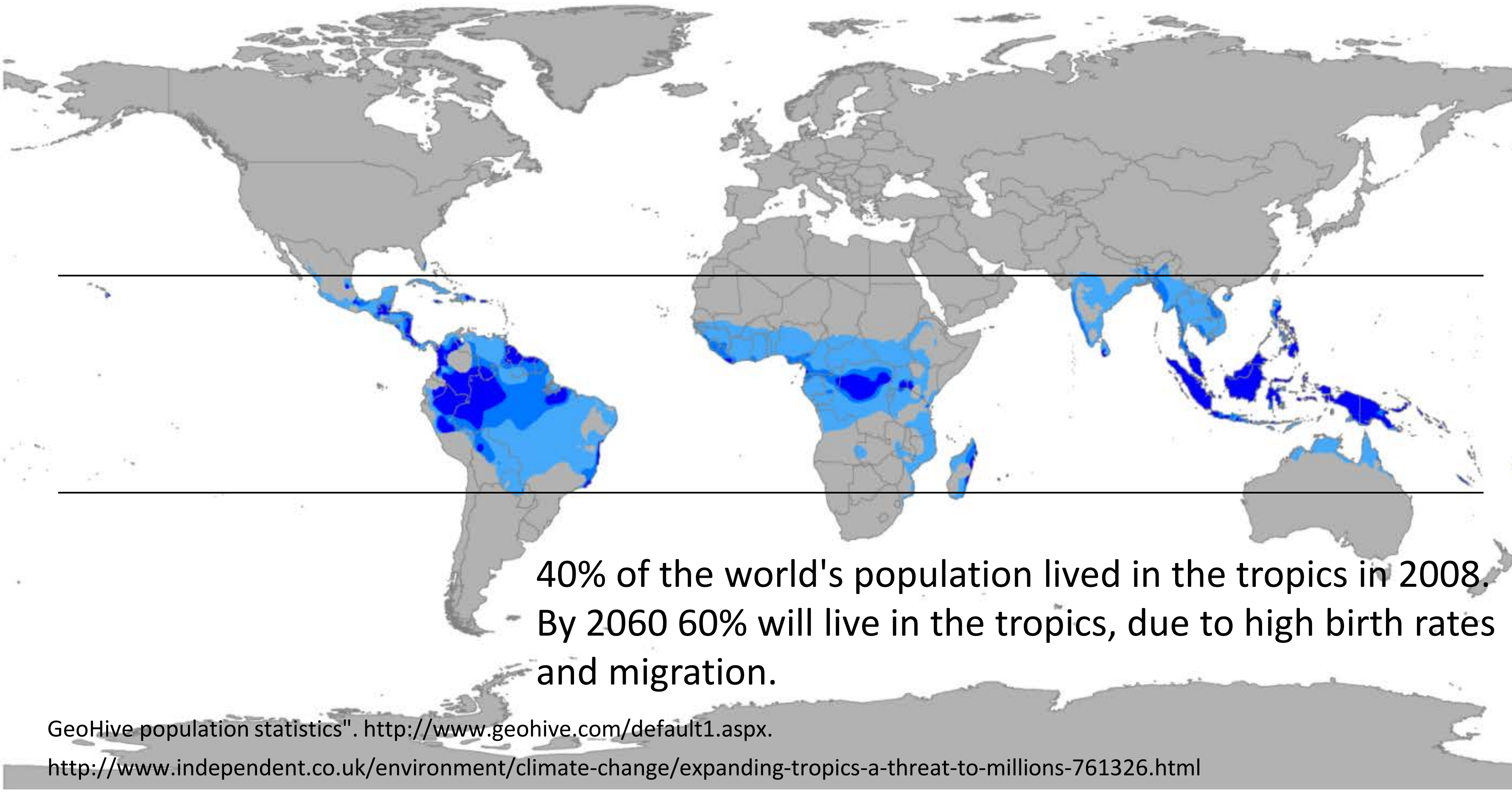
BEARS Berkeley Education Alliance for Research in Singapore Limited

Berkeley University of California

Nanyang Technological University

NUS National University of Singapore

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.

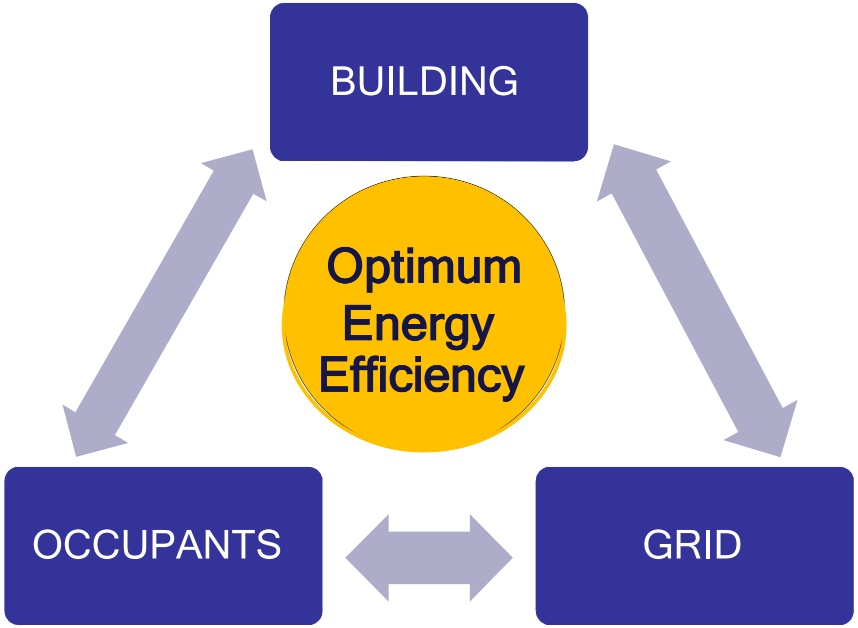
GeoHive population statistics". http://www.geohive.com/default1.aspx.

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, CO_2 emissions, productivity, safety, comfort, healthfulness, and the entire building lifecycle.



The SinBerBEST View

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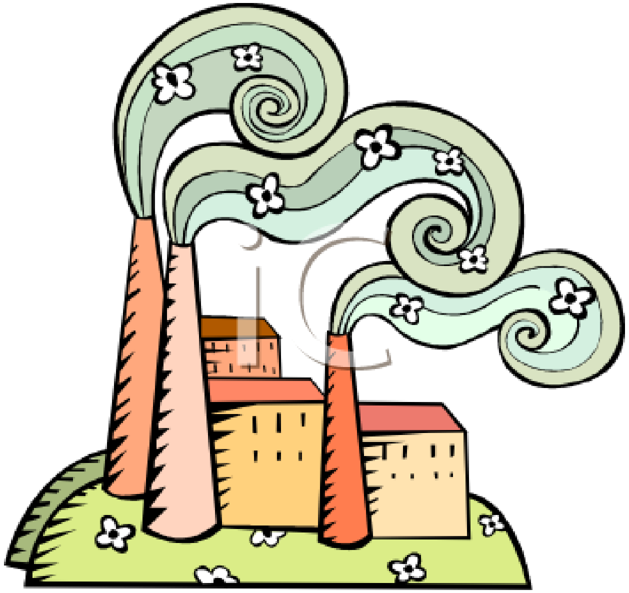
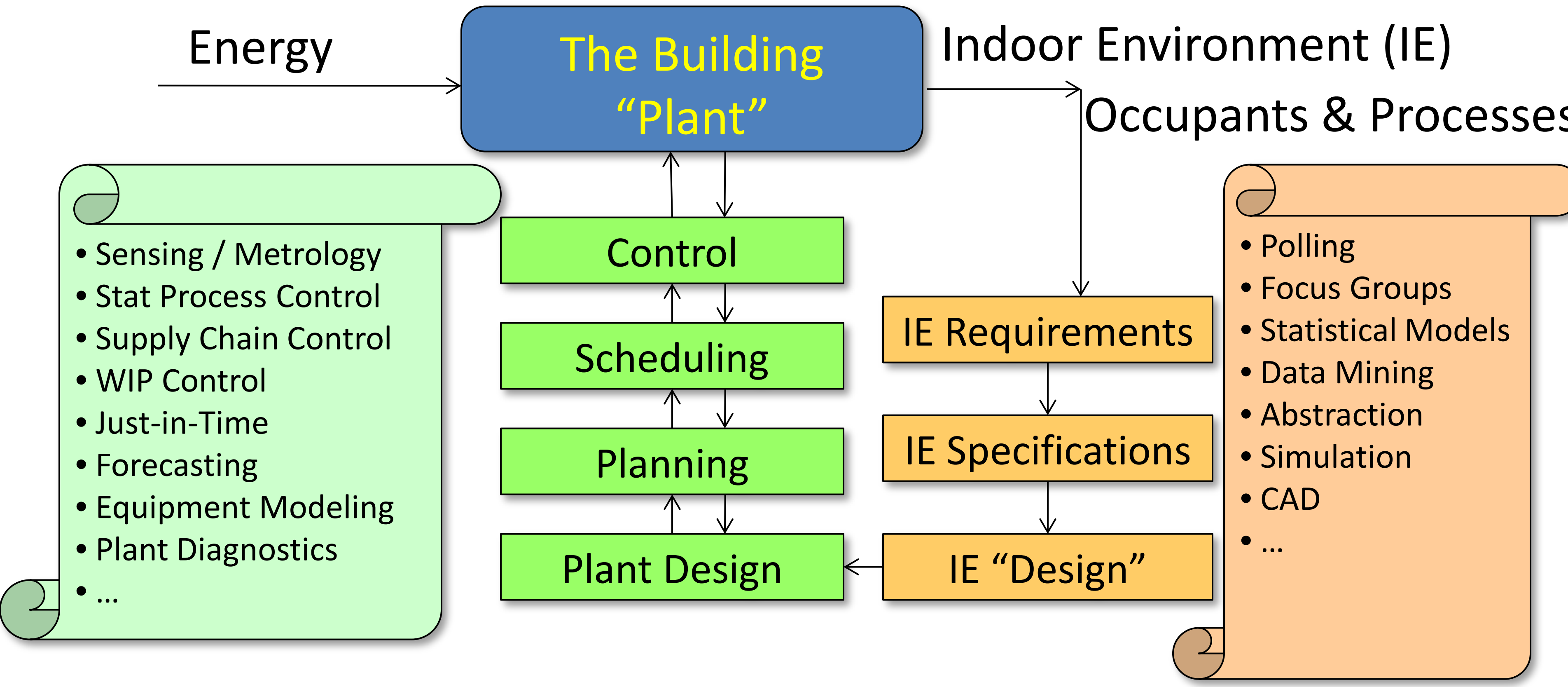
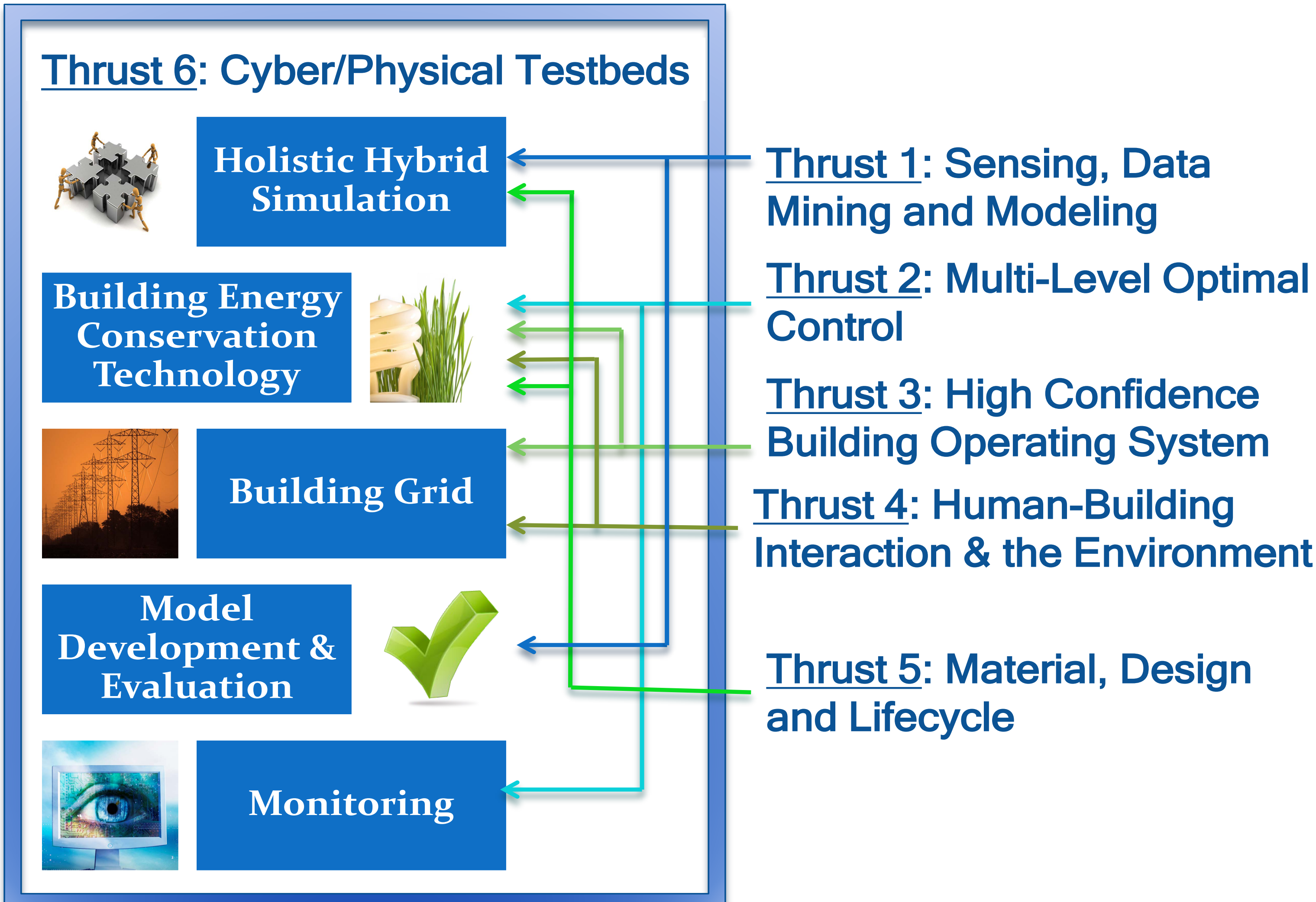


The SinBerBEST Vision

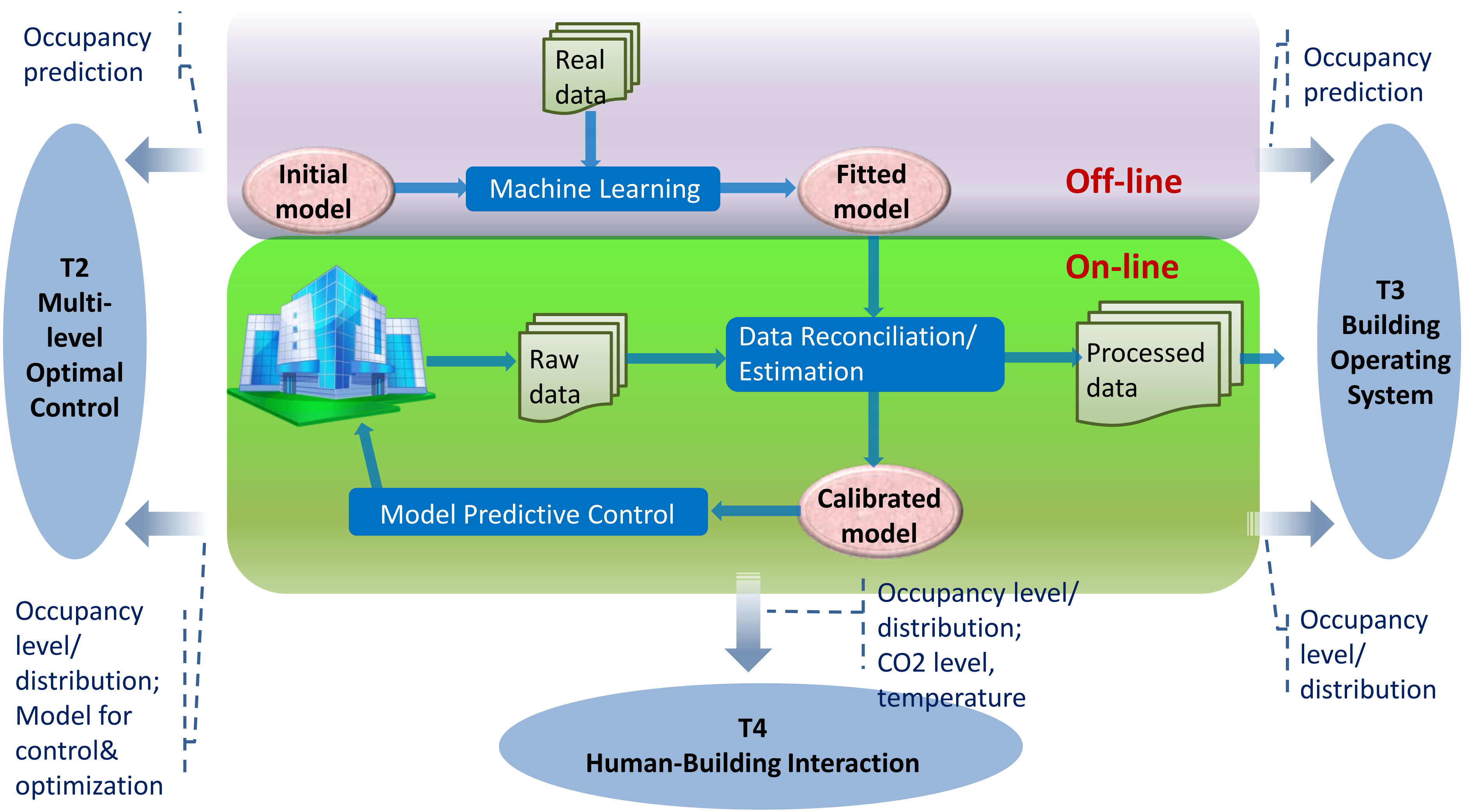
Buildings respond to *demand* from *occupants & processes*



SinBerBEST Research Thrusts

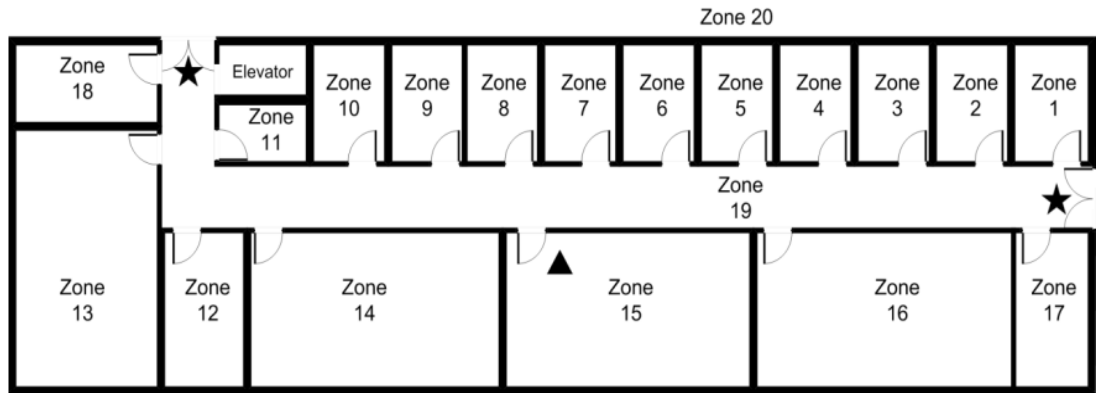


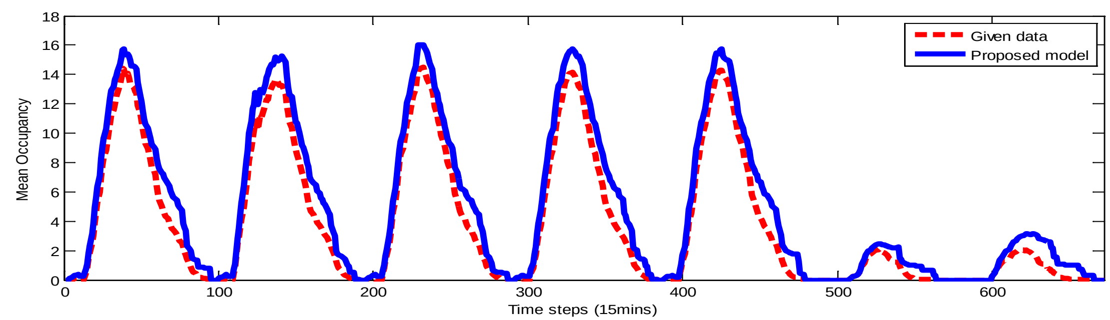
Information technology across the program

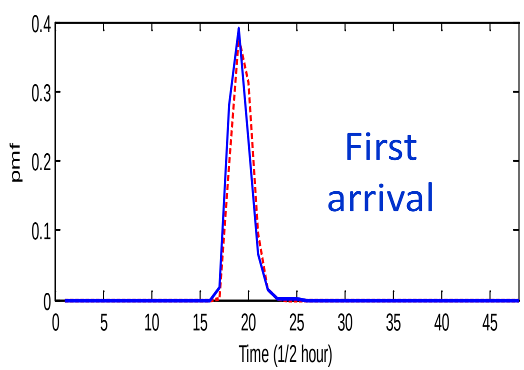


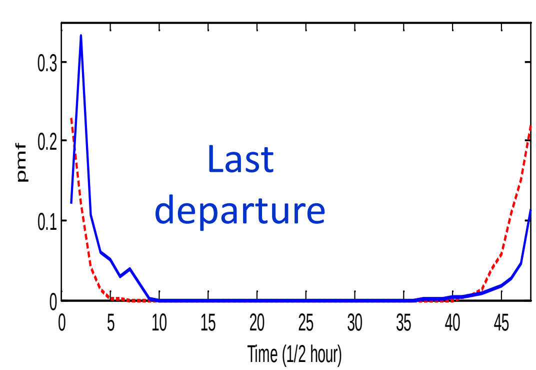
Building occupancy modeling using inhomogeneous Markov Chains

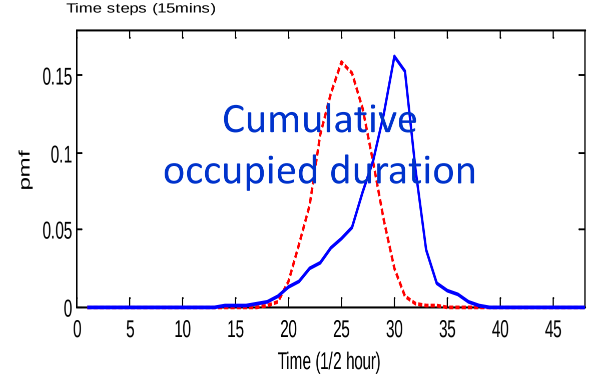
- Building occupancy modeling in multi-occupant single-zone (MOSZ) and multi-occupant multi-zone (MOMZ) scenarios.
- MOSZ our model outperforms agent-based model.
- MOMZ, our model performs well for first arrival, and trend of total occupancy.





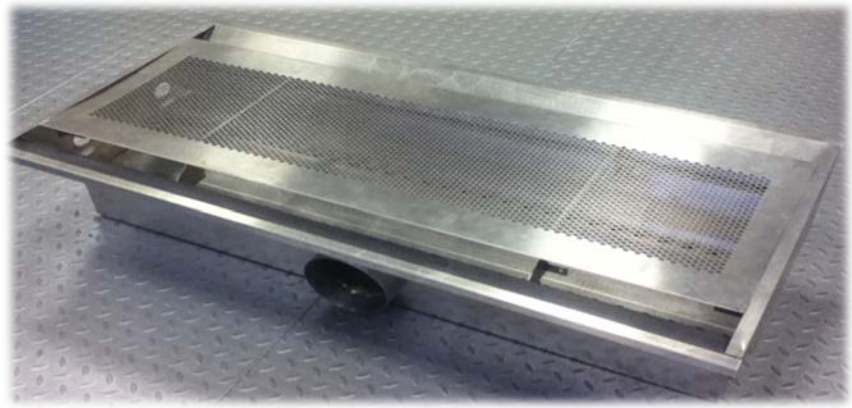




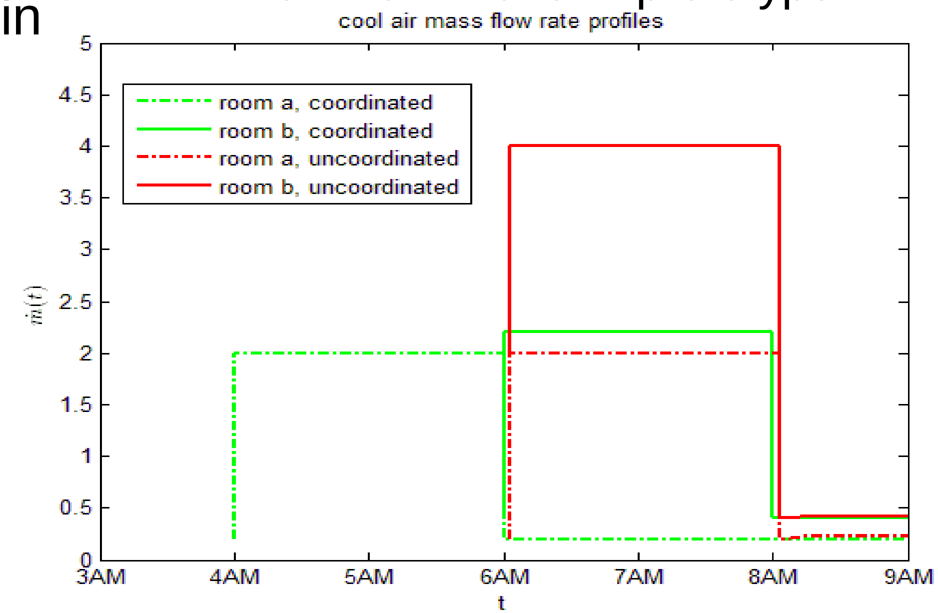


HVAC Control and Optimization

- 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

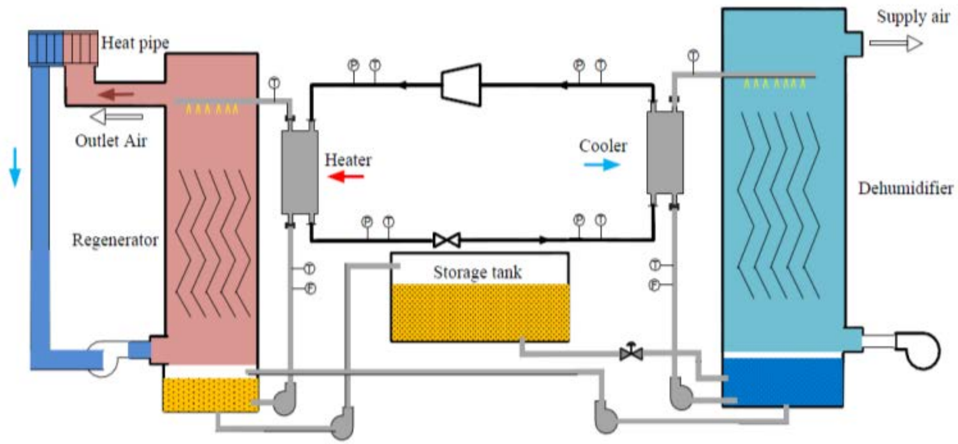


ACB terminal unit prototype

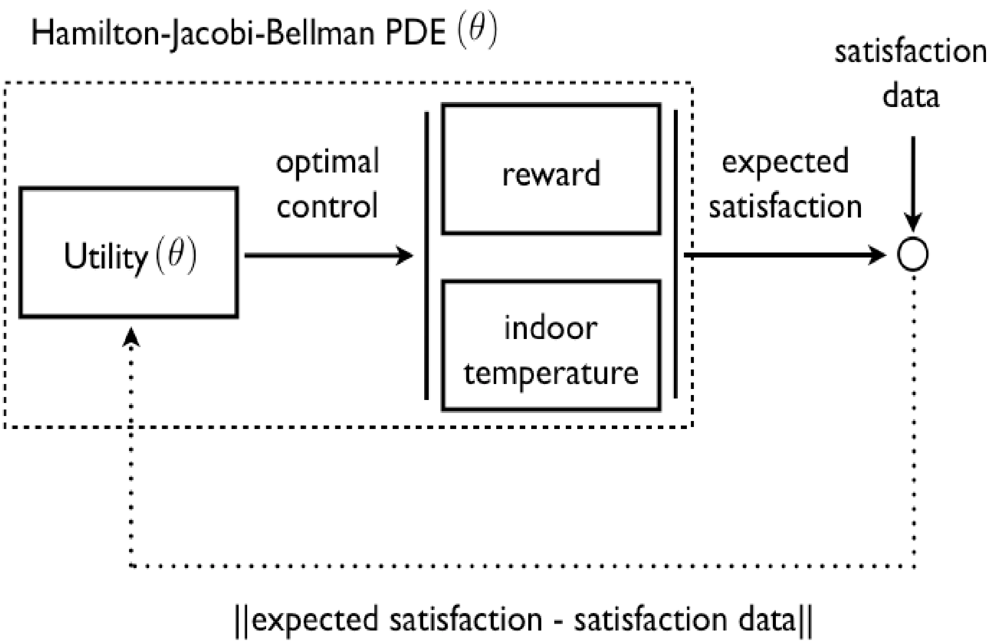


Liquid desiccant dehumidification system

- 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

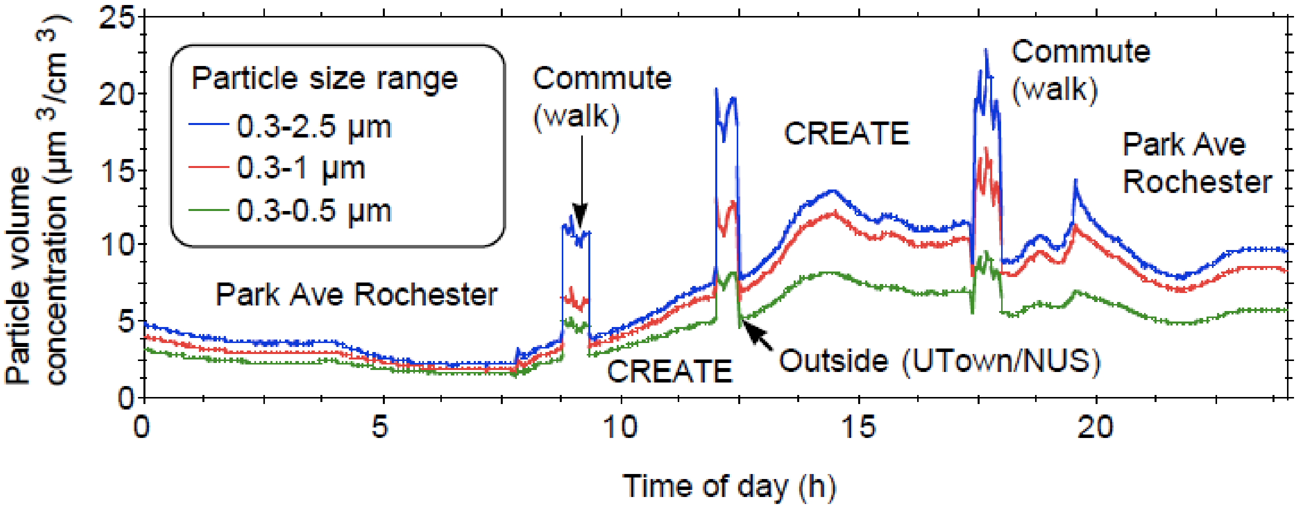


- Privacy-aware Identification of personal indoor temperature valuations
- Optimal design of demand response programs
- Accurate model and prediction of demand: help power market operation

- 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

Fine Particle Exposure: 25 June 2013

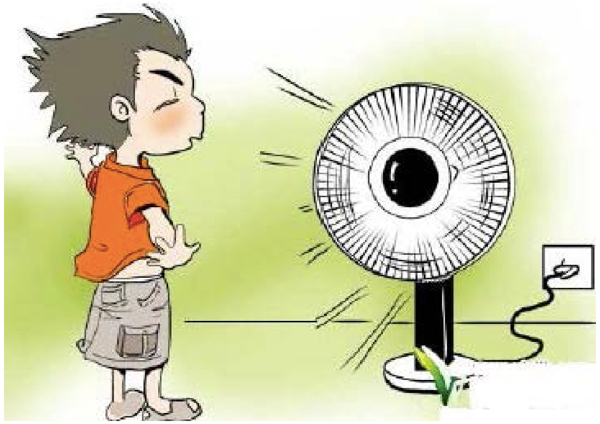


I/O ratios (0.3-2.5 μm):
CREATE — 44%
PAR — 39%
⇒ ~ 2.2-2.6× protection

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

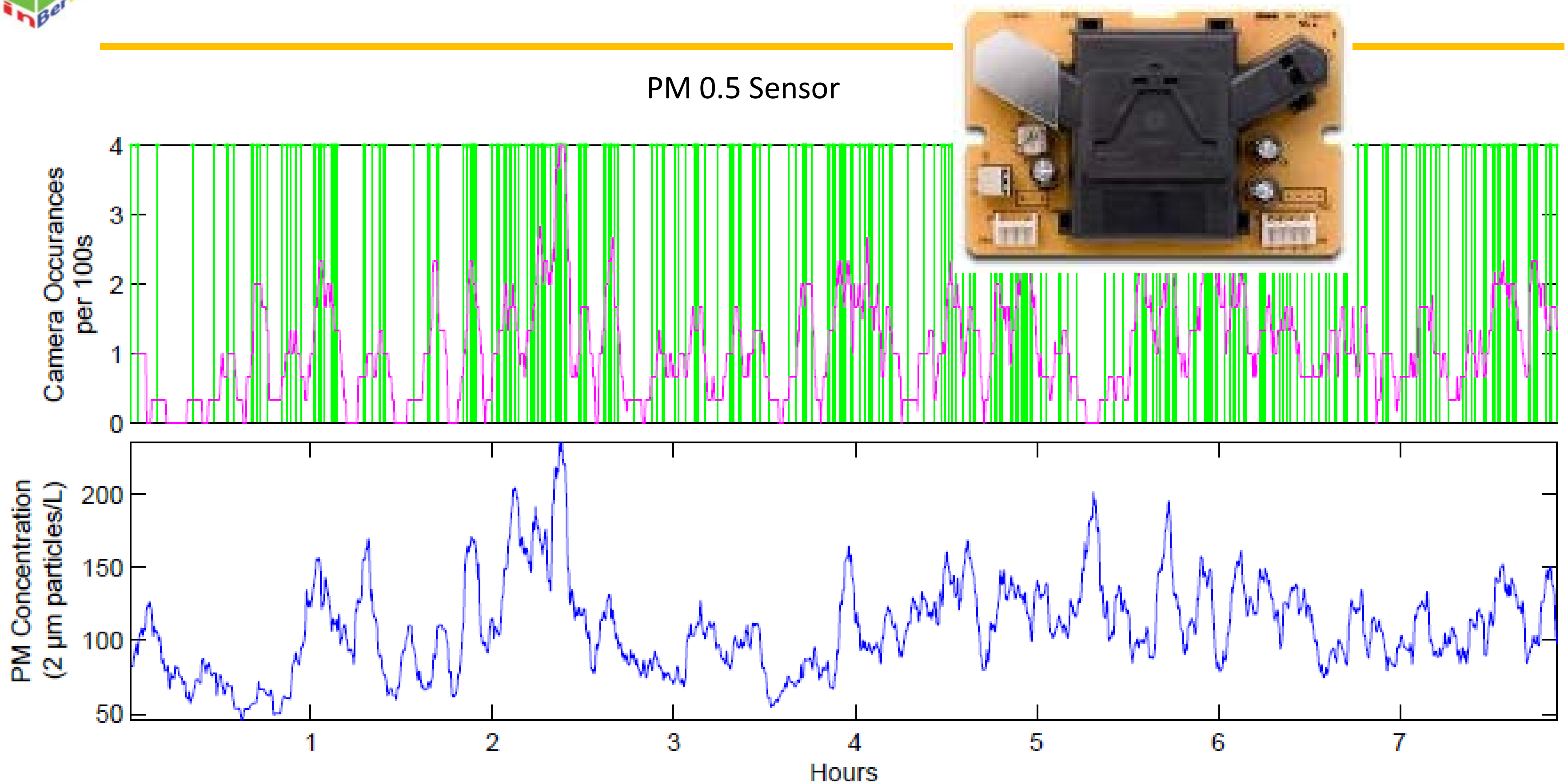
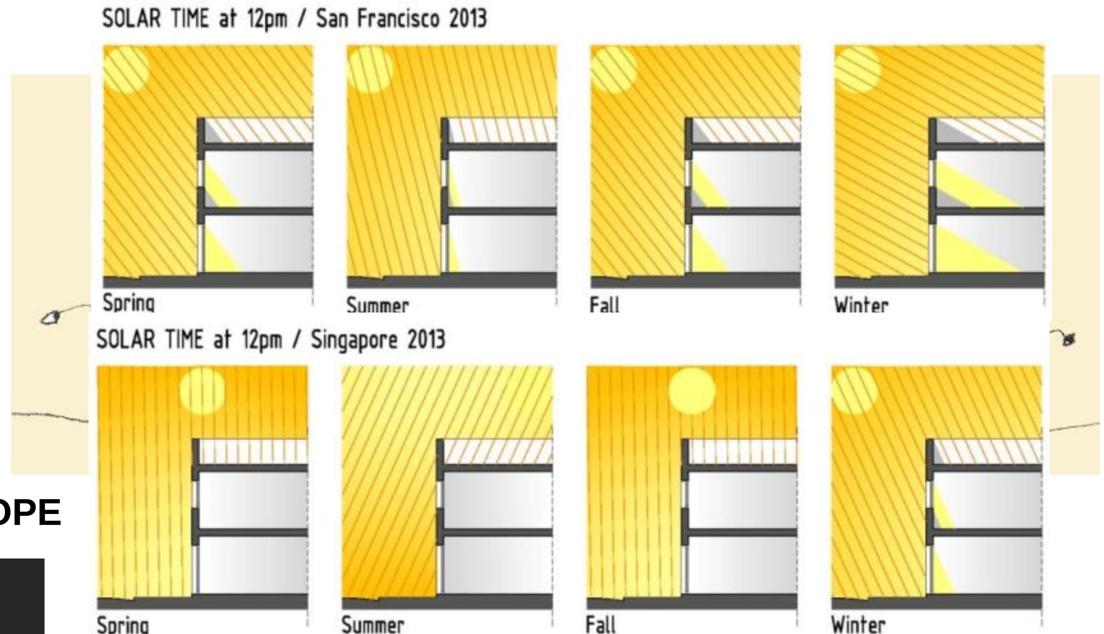
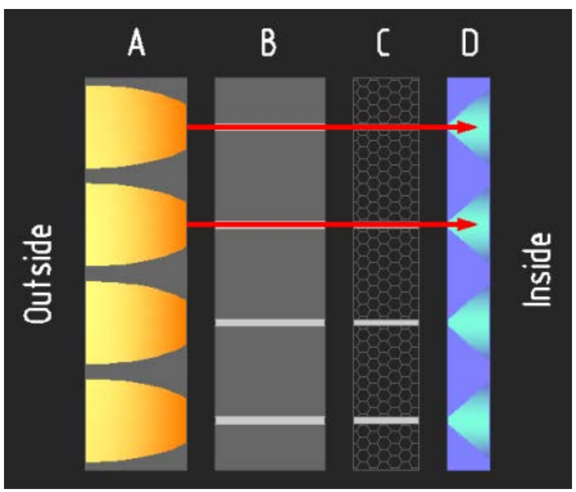


Fig. 8. Timeseries of filtered data over 7.8hr experiment. Top: Green lines mark camera obstruction occurrences and magenta line is the filtered camera occurrence rate. Bottom: Filtered $\geq$ 2.5µm outputs from DSM501A (average of 5).

Energy-efficient Building Envelope

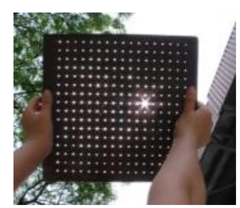


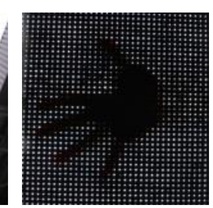
BUILDING ENVELOPE



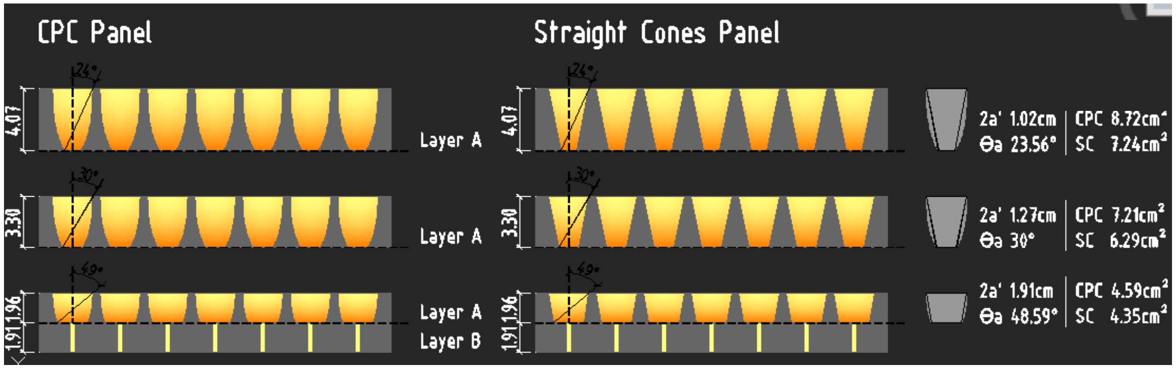
TYPICAL COMPOSITE PANEL

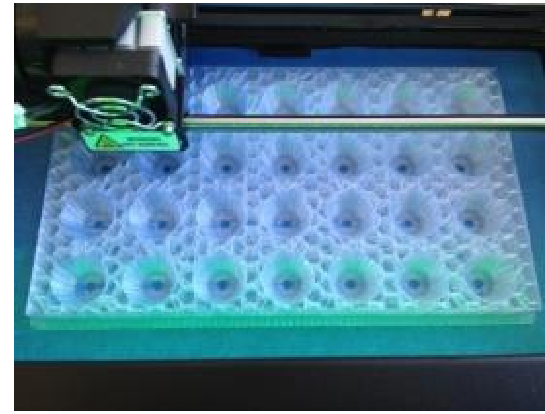
A Light Concentrating Layer (**Compound Parabolic Cones, CPC**)
B Light Conduit Layer (**Translucent Concrete, TC**)
C Insulation Layer
D Light Scattering Layer

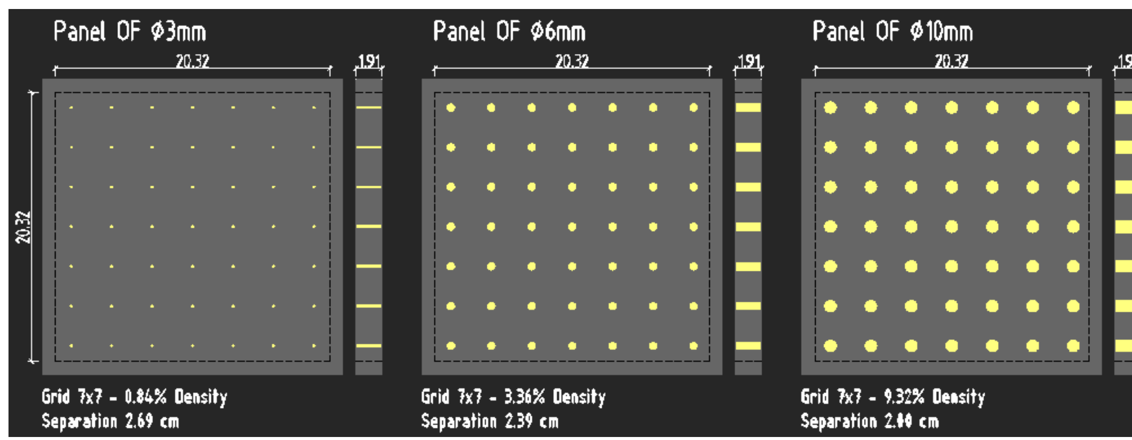




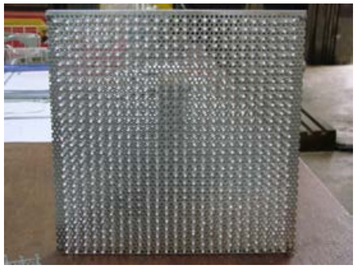
Studies on Daylight Harnessing

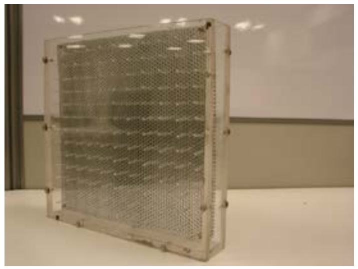






Manufacturability and Mechanical Properties of Energy Efficient Translucent Concrete Panels


Finished OF cage


Finished formwork

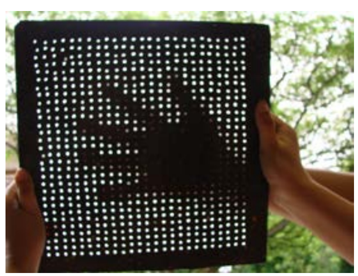

Adding plasticizer

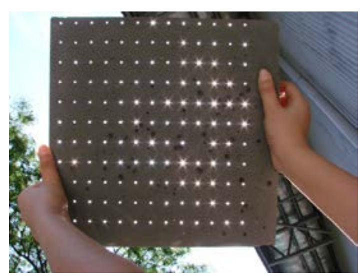

Placing & vibrating mortar


Curing in the fog room


TC panels after unmolding


Sanding


Under the sky


Under the sun

Construction Steps


Cylinder of NWM


Cube of NWM

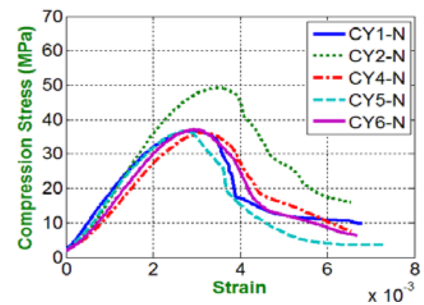
Cylinders
Average comp. strength:
NWM = **39.1 MPa**
LWM = **58.8 MPa**


Cylinder of LWM

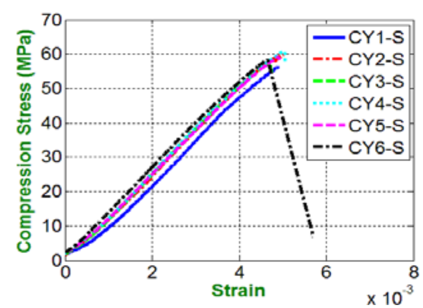

Cube of LWM

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

LWM: Light Weight Mortar, NWM: Normal Weight Mortar



Stress-Strain Curves of NWM

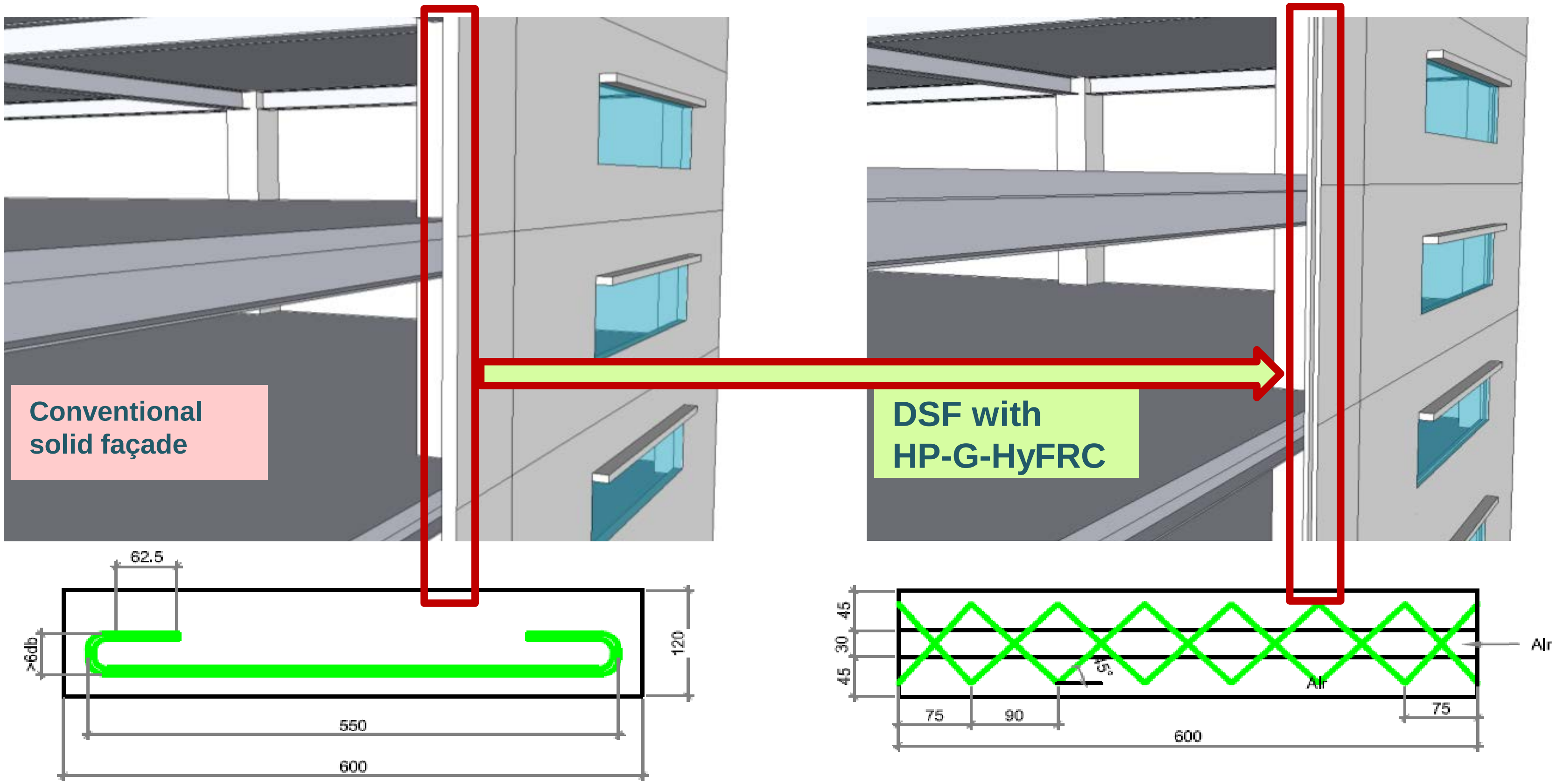


Stress-Strain Curves of LWM

Mechanical properties

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

1 2 3

Building coating with 0% TiO_2:

1. without soot loading,
2. with soot loading,
3. after **50 hrs** of light exposure

Building coating with 40% TiO_2:

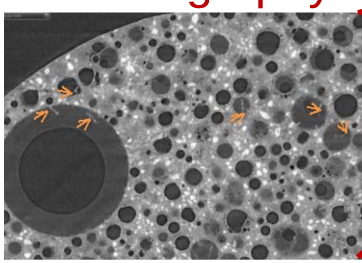
1. without soot loading,
2. with soot loading,
3. after **50 hrs** of light exposure, photocatalytic removal of black carbon by TiO_2 is demonstrated

Energy-Efficient, Insulating Structural Materials

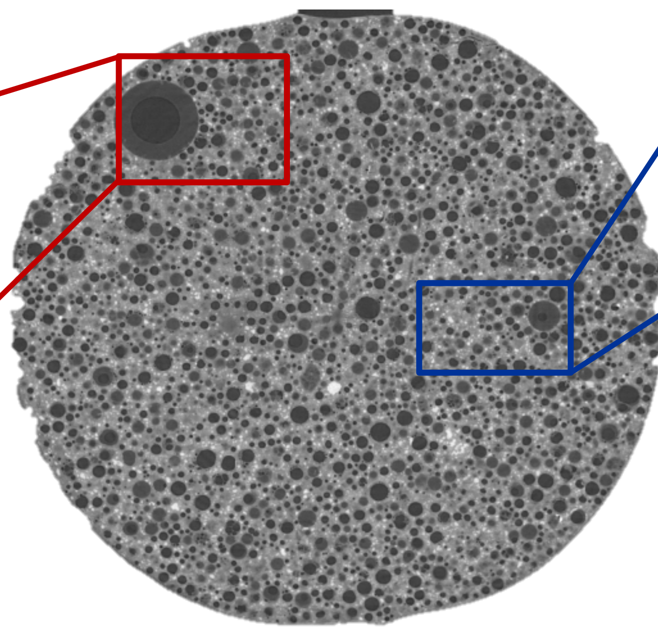
- Lightweight
- Low thermal conductivity
- Sufficient strength and elastic modulus
- Using by-product from thermal power plants

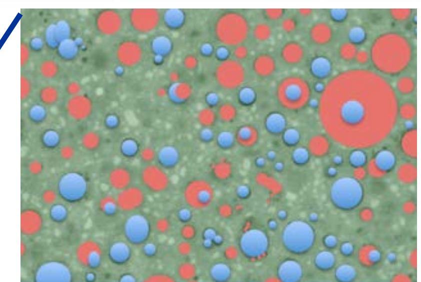
	Density, kg/m^3	Thermal conductivity, W/mK	Reference/ remark
Ordinary concrete	~2300	1.5-3.5	Mindess et al. 2003
Lightweight concrete	1360-1840	0.51-0.95	
Air	-	0.03	
Lightweight cement composite	1415	~0.3	On-going work, 28-d strength ~50MPa

3D tomography:



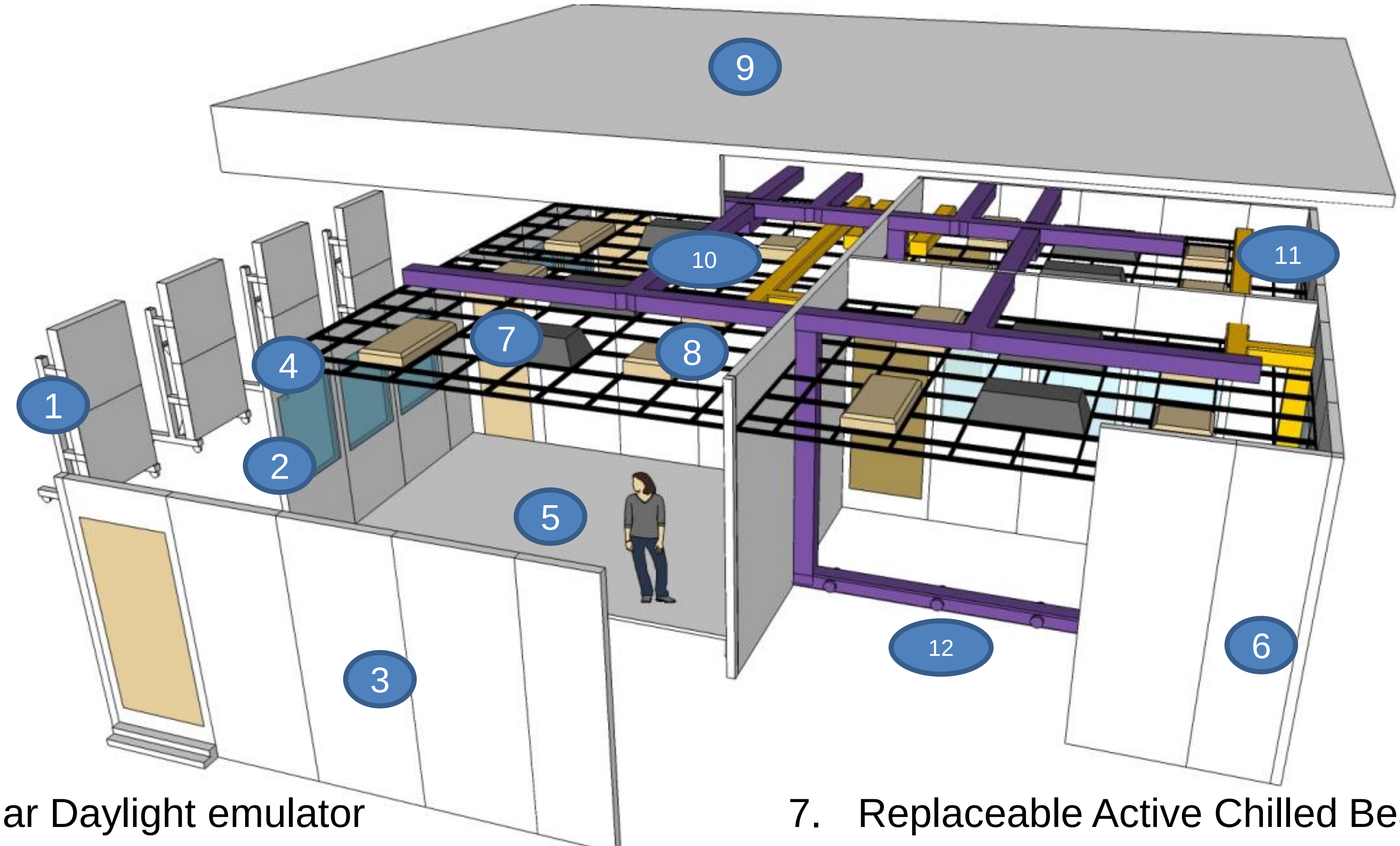
Observe features that can lead to understandings of the microstructure providing the low thermal conductivity.





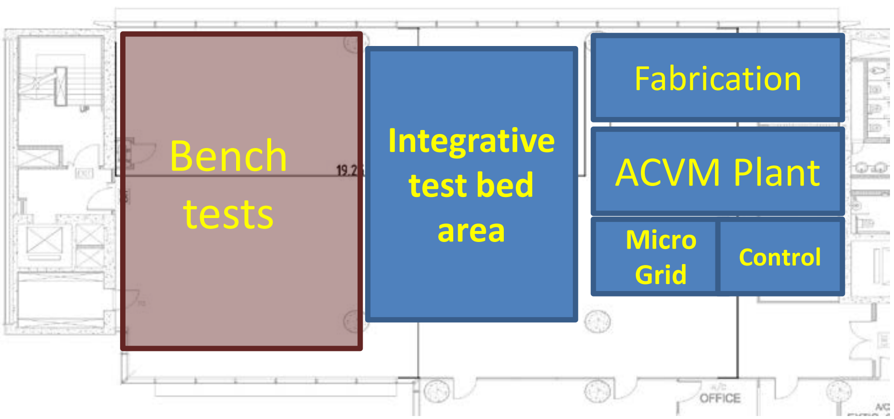
Identify and quantify cenospheres in lightweight cement composite

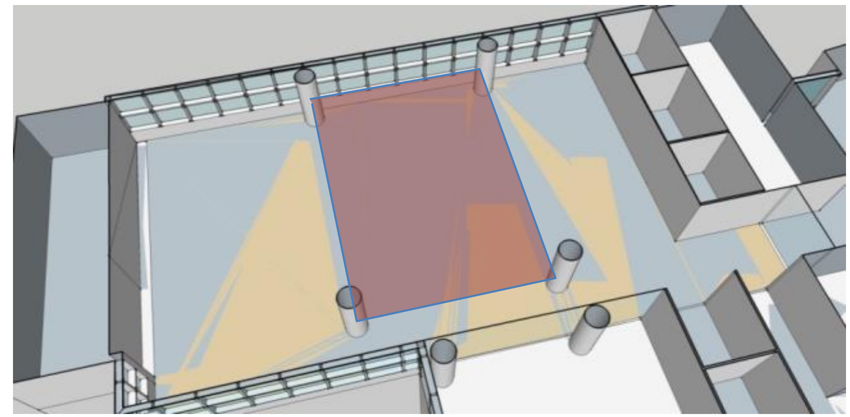
Integrative Test Bed Design

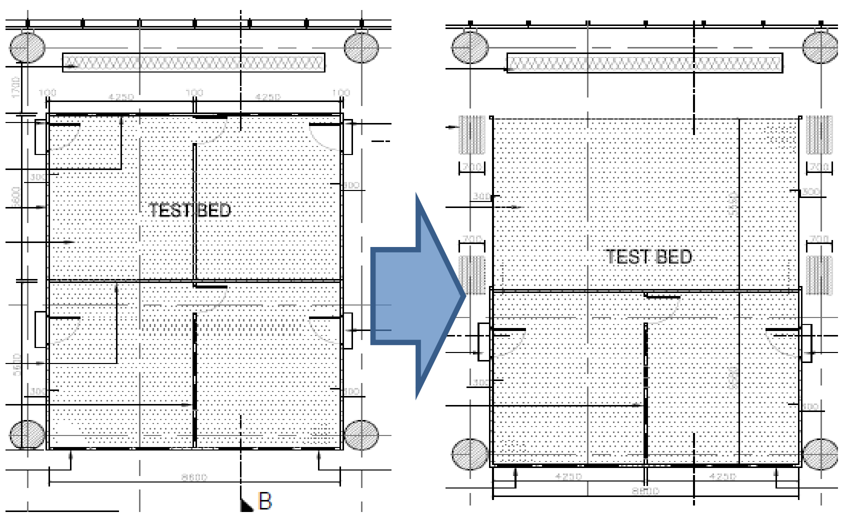


1. Solar Daylight emulator
2. Façade testing partition
3. Side partition wall
4. False Ceiling Grid
5. Raised Floor
6. Permanent air tight partition Wall
7. Replaceable Active Chilled Beam unit
8. Controllable Lighting
9. Fixed air tight ceiling panel
10. Air Duct Supply (purple)
11. Air Duct Return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

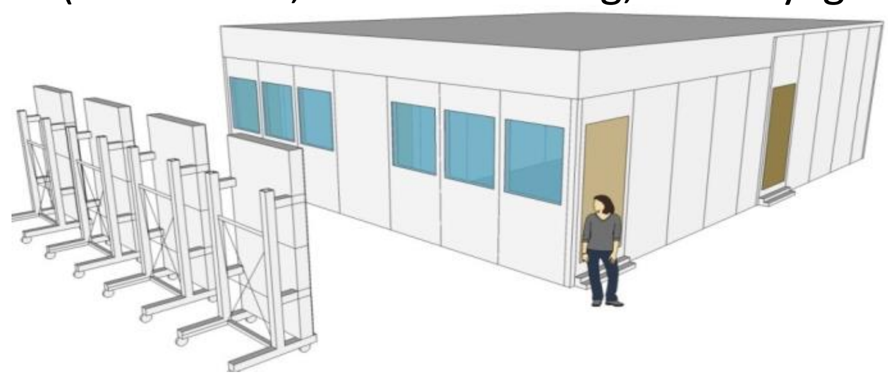
Integrative Test Bed Design





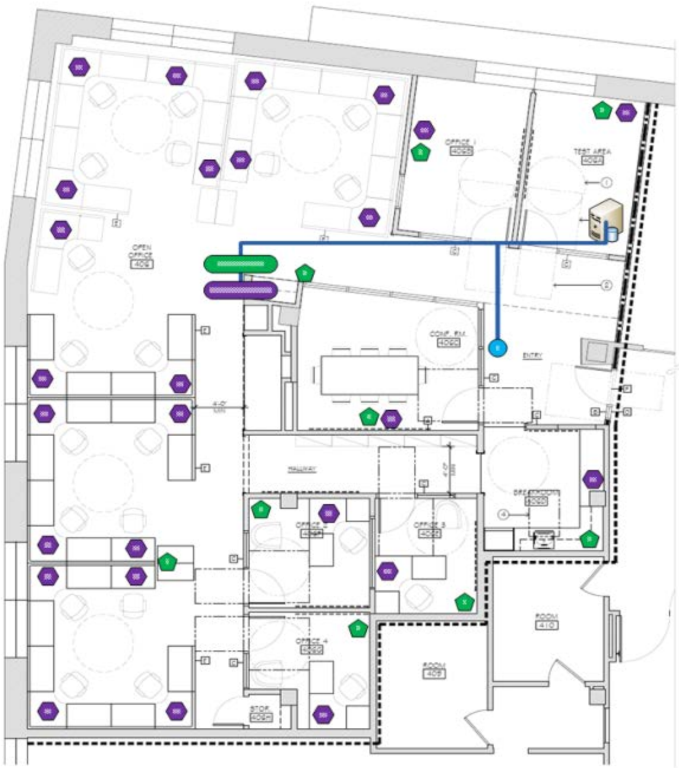


Completely “Manufactured” weather (outdoor air, thermal loading, and daylight)



Completely configurable Façade, MVAC & Lighting

Open source test bed model: Integrating Berkeley, Tsinghua and CREATE Test beds

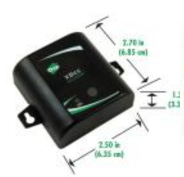


- A smart office space to demonstrate co-existence of experimental and off-the-shelf sensors/actuators
- Create inter-operability amongst subsystems by protocol translation
- Local devices connected to a private network to guarantee security
- Users access sensor data and operate devices through augmented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

Tweet-a-watt Plug Meter

ACMe Plug Meter

Li-nuo Plug Meter



Zigbee Light-Humidity-CO2 Sensor

PM 0.5 Sensor

Sun Blinds

Occupancy Sensors

LED Panels

User devices

2014 SinBerBEST Symposium

Wednesday, 8 January 2014

Session Chair: Prof. Khalid Mosalam, University of California, Berkeley

09.00 – 09.20	**Welcome Remarks and Overview** Prof. Costas J. Spanos, BEARS Director and SinBerBEST Program Leader University of California, Berkeley
09.20 – 09.40	**Thrust 1 – Tuneable Integrated Building Model** Prof. Alexandre M. Bayen, University of California, Berkeley
09.40 – 10.00	**Thrust 2 – Multilevel Optimal Control** Prof. XIE Lihua, Nanyang Technological University
10.00 – 10.30	**Tea Break & Poster Session**

Session Chair: Prof. HU Guoqiang, Nanyang Technological University

10.30 – 10.50	**Thrust 3– High Confidence Building Operating System** Prof. TSENG King Jet, Nanyang Technological University
10.50 – 11.10	**Thrust 4 – Human-Building Interaction and the Environment** Prof. William Nazaroff, University of California, Berkeley
11.10 – 11.30	**Thrust 5 – Materials, Design, and Lifecycle** Prof. Khalid Mosalam, University of California, Berkeley
11.30 – 11.50	**Thrust 6 – Cyber-Physical Test Bed** Prof. Khalid Mosalam, University of California, Berkeley (tentative)
11.50 – 13.00	**Lunch and Poster Session**

Session Chair: Prof. YUNG C. Liang, National University of Singapore

13.00 – 13.45	**Keynote Lecture – Solar power – getting ready for the conquest of the world** Prof. Armin Aberle, Solar Energy Research Institute of Singapore
13.45 – 14.00	**SinBerBEST Research Paper – A Distributed Optimization Method in Scheduling of ACMV Precooling Operations for Energy Saving** Dr. SU Yang, Nanyang Technological University
14.00 – 14.15	**SinBerBEST Research Paper – Smart Metering for Aiding Building Management Systems** Mr. Krishnanand K. R., National University of Singapore
14.15 – 15.00	**Keynote Lecture – Unveiling the Built Environment: Energy Efficiency and Indoor Environmental Quality** Prof. Stefano Schiavon, University of California, Berkeley
15.00 – 15.15	**SinBerBEST Research Paper – Transport, transformation, and energy efficient control of air pollutants in tropical buildings** Dr. Elliott Gall, Nanyang Technological University
15.15 – 15.45	**Tea Break & Poster Session**

Panel Discussion Moderator: Prof. William Nazaroff, University of California, Berkeley

15.45 – 16.45	**Panel Discussion– Metrics for Building Performance and Sustainability**

Thursday, 9 January 2014

Session Chair: Prof. Claudia Ostertag, University of California, Berkeley

09.00 – 09.45	**Keynote Lecture – Occupants as Partners in Energy Savings - Intelligent Dashboards for Communication, Expert Consulting and Control** Prof. Vivian Loftness, Carnegie Mellon University
09.45 – 10.00	**SinBerBEST Research Paper – Multi-Functional Building Materials for Energy Efficiency** Dr. Vanessa Rheinheimer, National University of Singapore
10.00 – 10.30	**Tea Break & Poster Session**

Session Chair: Prof. YANG En-Hua, Nanyang Technological University

10.30 – 11.15	**Keynote Lecture – Residential Thermal Comfort And Patterns Of A/C Usage** Prof. Richard de Dear, The University of Sydney
11.15 – 11.30	**SinBerBEST Research Paper – Innovative Facade System for Sustainable and Energy Efficient Buildings** Mr. Rotana Hay, University of California, Berkeley
11.30 – 11.45	**SinBerBEST Research Paper – A Social Game for Energy Reduction** Mr. Ioannis Konstantakopoulos, University of California, Berkeley
11.45 – 12.00	**SinBerBEST Research Paper – New Building Envelope for Energy Efficient Lighting** Ms. Nuria Casquero Modrego, University of California, Berkeley
12.00 – 13.00	**Lunch & Poster Session**

Session Chair: Prof. YU Liya, National University of Singapore

13.00 – 13:45	**Keynote Lecture – Singapore haze 2013: Particle exposures and building protection factors** Prof. Victor CHANG, Nanyang Technological University
13.45 – 14.00	**SinBerBEST Research Paper – PDE-Based Modelling and Estimation of the Humans' Effect in the CO2 Dynamics of a Conference Room** Mr. Kevin Weekly, University of California, Berkeley
14.00 – 14.15	**SinBerBEST Research Paper – Dynamic Market for Distributed Energy Resources in the Smart Grid** Mr. Edwin Chan, Nanyang Technological University
14.15 – 14.30	**SinBerBEST Research Paper - Dynamic Contracts with Partial Observations: Application to Indirect Load Control** Mr. Insoon Yang, University of California, Berkeley
14.30 – 14.50	**Keynote Lecture - BCA Progress in Developing a Rotating Testbedding Facility** Jeffery Neng/ Stephen Mok, Building and Construction Authority
14.50 – 15.05	**SinBerBEST Research Paper Presentation: Computational Models of Energy Efficient Facades for Daylighting** Mr. Aashish Ahuja, University of California Berkeley
15.05 – 15.45	**Tea Break & Poster Session**

Panel Discussion Moderator: Prof. Alexandre Bayen, University of California, Berkeley

15.45 – 16.45	**Panel Discussion – Disaster Prevention for Sustainable Buildings**
16.45 – 17.00	**Closing Remarks**