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Berkeley National Laboratory

The Two-Day CERC-BEE Forum on Building Integrated Design and Occupant Behavior: Presentations and Summary

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Environmental Energy Technologies Division

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Disclaimer

2013 CERC-BEE Forum on Human Behavior and Integrated Design for High Performance Buildings

Announcement, May 29, 2013

Buildings consume about one-third of the world's primary energy. Reducing energy demand and improving energy efficiency in buildings is critical to reducing energy use in buildings. As Steve Jobs said "Design is not just what it looks like and feels like. Design is how it works." Buildings are becoming more complex, they are systems of systems. Design without integrated consideration of operation, maintenance, and human behavior will not lead to high performance buildings.

As part of the research program under the U.S. - China Clean Energy Research Center for Building Energy Efficiency (CERC-BEE), Lawrence Berkeley National Laboratory and Tsinghua University, China have been working together to study human behavior and integrated design to achieve high performance buildings. We will present our research findings and progress, and seek your input and feedback. You are invited to present your related research work and join us in open discussion.

The first day of the forum on July 17, 2013 will focus on integrated design: what are common technologies employed in high performance buildings? how do these technologies perform? why do these technologies sometimes under-performance? what new scientific knowledge and tools are needed to guarantee building performance?

The second day of the forum on July 18, 2013 will focus on human behavior. Human behavior is an important but under-researched topic due to its multi-disciplinary nature, inherent uncertainty, and complexity. Quite often behavior is over-simplified in the design and operation of buildings. Human behavior can be an effective low-cost or zero-cost way to save energy, but a few key questions need to be answered: what are the human behaviors that impact energy use in buildings? how should we describe those behaviors? how should we model them? what are the interactions between building operators, occupants and energy services systems? how should we evaluate the impact of human behavior on energy and the environmental performance of buildings?

It is my pleasure to invite you to the two-day forum on these two important topics.

Date: July 17 and 18, 2013
Time: 9am – 5pm
Location: LBNL, 1 Cyclotron Road, Berkeley, California

Contacts:

For questions on the forum, contact Tianzhen Hong, (510) 486-7082, email: thong@LBL.gov
For questions on logistics, contact Caroline Hutchinson, (510) 495-2286, email: CHutchinson@LBL.gov
For information on CERC-BEE, contact Brian Heimberg, (510) 495-8010, email: bsheimberg@lbl.gov

Tianzhen Hong, LBNL, Forum Chair

Da Yan, Tsinghua University, China, Forum Co-Chair

CONTENT

Agenda

The Two-Day CERC-BEE Forum on

Building Integrated Design and Occupant Behavior

July 17, 2013

Forum on Building Integrated Design and Operation
Location: Building 70A, Room 3377

Opening speech and introduction
- Tianzhen Hong, LBNL 9:00-9:15am

An overview of CERC-BEE research program

- Nan Zhou, LBNL 9:15-9:45am

An overview of the CERC-BEE Project Integrated Design

- Tianzhen Hong, LBNL 9:45-10:15am

Performance and technologies of high performance buildings

- Cheng Li, LBNL 10:15-10:45am

Break 10:45-11:00am

An overview of research at BTUs

- Jessica Granderson, LBNL 11:00-11:30am

Integrated building design and tools:
accelerating innovation and sustainability
- Jinlei Ding, UTRC 11:30-12:00pm

Open Discussion

-Moderator David Hill, Jones Lang LaSalle 12:00-12:30pm

Working Lunch 12:30-1:30pm

The IUB-OCA Building–
a high performance building case study
-Joe Zhou, Iowa Energy Center 1:30-2:00pm

Hierarchical control and planning of high performance buildings

-Mohsen Jafari, Rutgers 2:00-2:30pm

A comparative study of cooling strategy for residential buildings

-Da Yan, Tsinghua University 2:30-3:00pm

Break 3:00-3:15pm

Open Discussion

-Moderator David Hill, Jones Lang LaSalle 3:15-5:00pm

July 18, 2013

Forum on Human Behavior
Location: Building 90, Room 3122

Introduction	9:00-9:15am
An overview of the CERC-BEE Project Human Behavior	
- Tianzhen Hong, LBNL	9:15-9:45am
Introduction to the proposed IEA Annex on occupant behavior	
- Da Yan, Tsinghua University	9:45-10:15am
Behavior is the new green	
- Annika Todd, LBNL	10:15-10:45am
Break	10:45-11:00am
A framework to describe occupant behavior	
- William Turner, LBNL	11:00-11:30am
A software module to simulate occupant movement	
-Xiaohang Feng, Tsinghua University	11:30-12:00pm
Open Discussion	
-Moderator Da Yan, Tsinghua University	12:00-12:30pm
Working Lunch	12:30-1:30pm
Occupant satisfaction and indoor environmental quality: what matter, LEED rating and clothing behavior	
-Stefano Schiavon, UC Berkeley	1:30-2:00pm
Simulating occupancy and occupant behavior	
-Handi Chandra-Putra, Rutgers	2:00-2:30pm
Occupant behavior in Indian commercial buildings	
-Reshma Singh, LBNL	2:30-3:00pm
Action based model for occupant behaviors in buildings	
-Chuang Wang, Tsinghua University	3:00-3:30pm
Break	3:30-3:45pm
Open Discussion	
-Moderator David Hungerford, CEC	3:45-5:00pm
Adjourn	5:00pm

List of Participants

Research Team:

LBNL – Tianzhen Hong (Forum Chair), William Turner, Cheng Li
Tsinghua University, China – Da Yan (Forum Co-chair), Xiaohang Feng, Chuang Wang
UTRC, China office - Jinlei Ding

LBNL:

Nan Zhou	CERC-BEE Director
Brian Heimberg	CERC-BEE Operation Manager
Jessica Granderson	BTUS/EETD, Deputy Department Head
Alecia Ward	EETD Program Office, Program Manager
Annika Todd	Electricity and Markets Group
Reshma Singh	Commercial Building Systems Group
Xiufeng Pang	Simulation Research Group
Caroline Hutchinson	Administrator

Others Invited:

Stefano Schiavon	Center of Built Environment, University of California Berkeley
Tom Webster	Center of Built Environment, University of California Berkeley
David R. Lehrer	Center of Built Environment, University of California Berkeley
Dove Feng	Center of Built Environment, University of California Berkeley
Handi Chandra Putra	Rutgers, The State University of New Jersey
Mohsen Jafari	Rutgers, The State University of New Jersey
Aaron Panzer	Pacific Gas & Electric
David Hungerford	California Energy Commission
Paula David	California Energy Commission
Matthew Fung	California Energy Commission
Xiaohui Zhou	Iowa Energy Center
David Hill	Jones Lang LaSalle
Adam Hinge	Sustainable Energy Partnerships
Sonia Punjabi	U.S. Department of Energy
Amir Roth	U.S. Department of Energy

Visitors from China:

Bin Hao	Ministry of Housing and Urban-Rural Development, China
Shicong Zhang	China Academic of Building Research

Executive Summary

Facing the challenges of global energy and environmental issues especially in the buildings sector, architects, engineers, building owners, operators, and other stakeholders are endeavoring to revolutionize the building design, construction, and operation to achieve high performance buildings. Despite the fast growing number of certified high performance buildings, the actual energy performance of these buildings is far from satisfactory. Since buildings are becoming more and more complex, building design needs to integrate key influencing factors, including technologies, operation, maintenance, occupant behavior, and climate, to deliver the target performance.

As part of the research program under the U.S. - China Clean Energy Research Center for Building Energy Efficiency (CERC-BEE), Lawrence Berkeley National Laboratory (LBNL), USA and Tsinghua University, China have been working together to study human behavior and integrated design to achieve high performance buildings. A forum focusing on these two topics was organized by LBNL and Tsinghua, and hosted at LBNL on July 17 and 18, 2013. Invited speakers and other participants shared their research and experience on these two topics and exchanged the invaluable knowledge on the future of high performance buildings. Here we try to highlight a collection of key points that arose during the presentations, Q&A sessions, and group open discussions. We hope this helps shed some light on new methods, tools, and policies to improve the integrated design and operation of high performance buildings.

Key points are grouped into a few subject areas. Day 1 of the forum focused on Integrated Design of buildings, while Day 2 focused on Human Behavior and the energy impact of building occupants.

Day 1: Integrated Design – Key Points

Research Objective* – The Integrated Design Project *aims to create solutions, including knowledge, tools, case studies, and guidance to achieving integrated design and operations of very low energy, low cost buildings (VLEBs).

Occupants and occupant control

- Give occupants individual control over their environment and the number of complaints to building operators will decrease, e.g.
  - Personalized control of under-floor ventilation systems will help occupants adjust the thermal environment
  - A fae thermostat on a wall might give the illusion of control
- Successful hybrid ventilation strategies (mixing mechanical and natural systems) requires control over openings in the envelope such as windows
- The same occupant can have very different expectations of the indoor environment at home and at work. Contributing factors could be:

    - responsibility for paying the energy bills
    - the different activities undertaken at work and at home
- The behavior of occupants inside buildings such as universities is extremely diverse, in part due to varying cultural expectations of the indoor environment. This can lead to the use of personal heating and cooling devices which can dramatically impact the building's energy performance.

Commissioning, tuning and maintenance

- Fine tuning of an under-floor distribution system (especially around the perimeter) was vital for good energy performance of the CalSTRS building, which was dominated by fan loads
- Cheaper labor costs in China can make high maintenance systems more affordable than in the US
- Automated fault diagnostic systems will be very useful for facilities (such as schools) that cannot afford fulltime maintenance experts
- Reductions in system maintenance due to budgetary cuts can prove more expensive long term when equipment fails
- Users often let systems reach a point of crisis/critical failure before taking action
- Under Proposition 39, the California Energy Commission has committed millions of dollars to retrofitting buildings, but without consideration for maintenance costs
- The US Ministry of Defense is pushing for continuous commissioning systems in its facilities
- Good maintenance practices can be incentivized by use of penalties
- High efficiency systems can be costly in the long run due to higher maintenance costs, e.g.,
    - Fan coil units are more expensive to maintain than VAV systems
- Commissioning of new buildings is essential to maximize energy performance, but:
    - Small buildings without onsite maintenance are at the mercy of contractors
    - Building owners in China do not want to pay for commissioning unless it is to obtain building performance certification/accreditation such as LEED
- Commissioning is necessary regardless of the level of design and construction.

Building performance and metrics

- Should we evaluate a building's energy performance using metrics such as energy per occupant rather than energy per unit of floor area?
- The 'energy value' should be considered i.e., unoccupied space will have a very low energy consumption but does not contribute towards the productivity
- Occupant comfort is the first priority of a building operator, second is energy. Once occupant comfort has been achieved, then energy use can be addressed
- Nations such as India and China should not necessarily try to replicate best practices in Europe and the US – instead they should make decisions based on specific consideration of their climate, e.g.,

- Installation of insulation in India and South China can lead to buildings overheating, particularly residential buildings on hot days after sunset

- The energy performance of US residences will benefit from zoning, rather than conditioning the entire space
- Simulation results of the IUB/OCA building predicted that central heating/cooling would be unable to achieve energy targets, so distributed heat pumps were chosen.

Barriers to good building performance

- A current barrier to low energy buildings is the lack of engagement with building owners who are not responsible for paying the energy bills
- Advantages exist for operators when they have separate control of ventilation and space conditioning systems
- Simulation results based on equipment specifications from manufacturers often don't match real performance after installation
    - Manufacturer specifications can be unreliable and not a good indicator of actual performance
- Energy efficiency measures can have adverse and unintended effects on the performance of the rest of the building, or other building systems, e.g.,
    - Poorly designed solar shading can make window cleaning or maintenance very difficult and even dangerous
    - Light shafts near trees can fill with leaves thus reducing their performance
- Designers of energy efficiency measures need to be made aware of real-world performance and influencing factors
- Building operators can add valuable experience during the design phase of a building
- Energy efficiency measures should not compromise other building systems
- Climate should not be treated as a barrier to achieving good energy performance. In some mild climates the climate itself can be used to improve energy performance, e.g.,
    - Night ventilation for pre-cooling thermal mass.

Building simulation tools

- Even with detailed plans and schematics, it can still take weeks to build an accurate building simulation model – doing so for older buildings without documentation can be extremely difficult
- Building simulation tools need be simpler and require less inputs to speed up the simulation process
- Clients want data to demonstrate that energy efficiency retrofit measures will be worthwhile financially
- There is a lack of skilled design consultants who can create good building simulation models
- Clients often want answers to design related questions in timescales of hours – shorter timescales that is currently feasible with contemporary building simulation tools.

Day 2: Human Behavior – Key Points

Research Objectives – the* Human Behavior Project *aims to:

1. ***Research and develop methodologies and simulation models to characterize human behavior in building design and operations***
2. ***Enhance building simulation tools (EnergyPlus and DeST) and provide realistic simulation inputs related to human behavior in order to improve accuracy of simulated results***
3. ***Simulate and analyze the impacts of human behavior on building energy consumption and performance, and provide guidance on practical engineering designs and retrofits***

Occupants and occupant controls

- Personal comfort devices such as fans and portable heaters are unregulated
  - Although efficiency gains are possible, the focus should be on trying to mitigate their use
  - Researchers showed that is possible to obtain significant efficiency gains regarding fan and portable heater. E.g., personal comfort heaters that are close to the occupant (~30 W) are much more efficient than systems that heat the air around the occupant (~1500-2000 W). In the market there are ceiling fan now that use ~10W compared to traditional fans that use 80 W.
- The location of controls (occupant accessible vs. operator accessible) for fan coil units can have a dramatic impact on the energy performance of a system
- The psychology of occupants needs to be understood in order to successfully model them
- Smart meters will facilitate utilities to target the highest energy users for energy efficiency programs
- Occupant/consumer interest in energy efficiency programs wanes over time so the effectiveness of the programs diminishes (‘persistence’)
- Building level research on occupant movement may be found in the fields of architecture (BOMA) and fire/disaster evacuation
- Actual measurements of building occupancy reveal occupancy rates to be much lower than expected
- Building occupancy can be measure using cell phone data, laptops connecting to building networks, building access cards etc.
- Energy savings can be obtained by providing occupants with personalized controls and then letting the building ‘float’.

Building performance and metrics

- Minimizing complaints in the main metric for building operators
  - Comfort is the priority over energy for operators

- The cost of dedicated operators for VAV systems can be prohibitive in the US, but more affordable in China
- Energy consumption is just a consequence of a building occupant performing a necessary task
- Cultural differences between groups and populations means that behavior is also different, e.g.,
    - Energy efficiency measures that work in Marin County, California won't necessarily work in Texas
- Using smaller zones in buildings will lead to better energy performance
- Behavior can alter the energy performance of a building by up to a factor of two
- There is a strong link between the energy performance of green buildings and occupant behavior due to the high incidence of occupant sensors
- Long term productivity should be considered as a function of indoor conditions

Building simulation tools

- Building simulation tools should move towards providing results as distributions rather than just mean or median values
- HVAC equipment is often oversized in China and the US due to focusing on rare peak loads based on climate weather files
- The common practice in industry is to model building zones in high details
- Generalization of behavior models is very difficult – existing models are based on data from specific buildings, and so model results are usually specific to that building
- The goal of reducing building energy consumption should not be forgotten while developing new behavior models.

Barriers to good building performance

- China and India face similar challenges on building design and energy performance – both countries are experiencing rising levels of income and higher expectations of the indoor environment
- Aspirations for Western-style designs are a barrier to developing and installing climate-appropriate building systems in India and China
    - Building owners are following design trends from North America and Europe without full consideration for the energy implications.

Open Questions

- Who will be the main beneficiary of behavior models?
- What level of simulation detail is really required to give results which can be used for policy decisions?
- What level of detail is practically possible to obtain? Is it high enough to validate behavior models?

Speaker Biographies

Dr. Tianzhen Hong is a Research Scientist with the Simulation Research Group of LBNL. He is also a registered mechanical engineer with the state of California and a LEED accredited professional with USGBC. His research focuses on energy modeling and simulation methods of design, operation, maintenance, and human behavior to achieve low energy buildings and sustainable urban systems. He is a key developer of EnergyPlus, the chief developer of VisualDOE version 4.0, and the founding developer of DeST (former BTP). He is currently leading the research area of Integrated Design and Operation under the U.S. – China Clean Energy Research Center for Building Energy Efficiency. He received his B.Eng., M.Eng. and Ph.D. in HVACR from Tsinghua University, China. Before joining LBNL in December 2007, he worked for Architectural Energy Corporation in San Francisco, Supersymmetry in Singapore, National University of Singapore, and Tsinghua University in Beijing.

Dr. Nan Zhou is a Scientist and the Deputy Group Leader of the China Energy Group of Lawrence Berkeley National Laboratory. In addition, since 2010 Dr. Zhou served as the Deputy Director of the U.S.-China Clean Energy Center-Building Energy Efficiency (CERC-BEE). In October 2012 she assumed the Director position for CERC-BEE. She has driven this program to meet challenging milestones while engaging with a complex joint U.S.-China stakeholder matrix and facilitated creation of a research program portfolio to focus on breakthrough energy efficiency building technologies.

Nan Zhou has also co-initiated and is managing three major programs between LBNL and Chinese organizations: the LBNL-Shenzhen Institute for Buildings Research (IBR) Joint Program on Sustainable Communities, the LBNL Energy Efficiency Training Program for Chinese Industries, and the Tongji University-LBNL-University of California-Berkeley joint PostDoc Program.

Dr. Zhou' s research has focused on modeling and evaluating China's low-carbon development strategies, assessing building energy efficiency policies and technologies, and development and evaluation of China's appliance standards and labeling program. Additional work includes energy efficiency in industry; and assessments of energy efficiency policies.

Dr. Cheng Li is a Postdoctoral Fellow in the Simulation Research Group, EETD. His current work focuses on the development and application of integrated design method for High Performance Buildings. He is a member of the research team on CERC BEE program. In addition to integrated design research, he is also interested in the development of the urban energy model for the ecological urban planning. Prior to joining LBNL, Cheng got Ph.D and bachelor degree in civil engineering from Tsinghua University, China. He has plenty of experiences in collaborating with architects during the design of green buildings and High Performance Buildings.

Dr. Jessica Granderson is a Research Scientist and the Deputy of Research Programs for the Building Technology and Urban Systems Department at the Lawrence Berkeley National Laboratory. She is a member of the Commercial Buildings and the Lighting research groups. Dr. Granderson holds a PhD in Mechanical Engineering from UC Berkeley, and an AB in Mechanical Engineering from Harvard

University. Her research focuses on intelligent lighting controls and building energy performance monitoring and diagnostics.

Dr. Jinlei Ding recently assumed Group Leader, Buildings & Energy, position at UTRC China office in Shanghai. He provides leadership to the buildings and energy group, focusing on developing the capabilities in areas related to integrated buildings including building energy modeling, energy assessment, diagnostics, controls, commissioning, and systems integration. He is also responsible for developing technology and capability roadmaps aligned with UTC BU's technology and product development needs in the buildings and energy area.

He was a principal investigator and individual contributor for a number of projects in the power, energy, and buildings area. Since joining UTRC (China) in 2007 he has been active in external resource development proposals and pursuing collaboration with local universities. He is also the UTRC focal point for the Tsinghua-UTC Institute projects and represents UTRC at the US-China Energy Cooperation Program.

Dr. Ding earned a bachelor's degree in Thermal Energy and Power Engineering in 2002, a bachelor's degree in Applications of Computer Science in 2002, and PhD in Engineering Thermophysics in 2007, all from University of Science and Technology of China."

David Hill works for Jones Lang LaSalle Americas, Inc. as the chief engineer for building operations at the California State Teachers' Retirement System headquarters building in West Sacramento, CA. David consulted during the design and construction phases of the CalSTRS project in 2007 - 2009 and then remained with the project as it progressed into operations. David completed his stationary engineer apprenticeship 1975 – 1979 in San Francisco. Since 1984 he has opened (6) new facilities in San Francisco and Sacramento as chief engineer, providing technical advisory services at the end of construction and then coordinating the transition to operations. In his 38 year career he has worked with private developers as well as state agencies in office building and data center development.

Dr. Xiaohui "Joe" Zhou has been with the Iowa Energy Center since 2002 and currently serves as Energy Efficiency Program Manager. He has over 18 years of work and research experience in commercial building HVAC systems and building controls, and served as a design engineer, application engineer, researcher and team leader. He holds a Bachelor of Science from Zhejiang University (China) and a Master of Science from the University of Connecticut, both in electrical engineering with concentrations in controls and automation. He also received his doctorate in mechanical engineering from Iowa State University. Dr. Zhou is actively involved in ASHRAE at local and national levels, and is member of ASHRAE Technical Committee TC 1.4 Control Theory and Application, TC 7.5 Smart Building Systems, as well as serving as voting member on several Standard Project Committees.

Dr. Mohsen A. Jafari is a full professor of Industrial & Systems Engineering at Rutgers University. He has been with Rutgers U. since 1987. He received his Ph.D. in Systems Engineering and Operation Research and M.S. in Computer Science from Syracuse University. His research areas of interest are in systems optimization & control, intelligent distributed systems, simulations, and data modeling in transportation, energy, manufacturing and healthcare. He has directed or co-directed funding from various government agencies such as the NSF, DOE, ONR, DoD/DLA, FHWA, US/NJ Department of Transportation, NJ Dept. of Health and Senior Services. He has also been consultant to several fortune 500 companies as well as local and state government agencies. He has published over seventy refereed articles and has made many invited and contributed presentations nationally and internationally.

Dr. Da YAN is associate Professor of the School of Architecture at Tsinghua University. His major research topic is building energy performance simulation, occupant behavior simulation and building energy policy research. He has leading developing building simulation tool –DeST (Designer's Simulation Toolkit) for more than 10 years. Act as Operation Agent, a new IEA ANNEX has been approved for occupant behavior simulation. A national building energy model and technical approach of Chinese building energy policy making are also developed by his research group.

Dr. Annika Todd is a Senior Scientific Engineering Associate in the Electricity Markets and Policy Group at Lawrence Berkeley National Laboratory. Annika is an experimental and behavioral economist, and conducts research and analysis on Energy Efficiency, Demand Response, and Smart Grid topics, including Smart Grid Investment Grant (SGIG) Dynamic Pricing Projects, Evaluation, Measurement and Verification of Energy Efficiency Programs, and Technical Assistance to States on Energy Efficiency Programs. Annika's research has included investigating the effect of prices and behavior-based factors on energy consumption through large-scale field experiments, including the effect of dynamic pricing, smart sensor technology, high frequency feedback, competition, micro-raffle incentives, information overload, and social incentives, as well as evaluating the overall impact of behavior-based energy efficiency programs.

Previously, Annika was a postdoctoral researcher at the Precourt Energy Efficiency Center at Stanford, working as part of a team that received a $6 million grant to carry out experimental behavioral research from the U.S. Department of Energy's Advanced Research Projects - Energy (ARPA-E). She was also a co-chair of the Behavior, Energy & Climate Change (BECC) conference in 2010.

Annika has a PhD in Economics from Stanford University, and holds a BA in Molecular and Cell Biology as well as a BA in Economics from the University of California, Berkeley. She has extensive experience in experimental design, behavioral theory and models, statistical analysis and econometric techniques, behavioral financial markets, and game theoretic analysis.

Dr. Will Turner is a postdoctoral researcher at the Lawrence Berkeley National Laboratory. He works with the Simulation Research Group conducting research on occupant behavior. Previous work at the Lab, for the Residential Building Systems Group includes building simulation, development of intelligent HVAC controls and hybrid ventilation systems. Will obtained his PhD in mechanical engineering from the University of Reading, in the UK.

Xiaohang Feng is a PhD student with Department of Building Science and Technology, Tsinghua University, China. He is an exchange student to LBNL.

Dr. Stefano Schiavon is Assistant Professor of Architecture at UC Berkeley. He is focusing on indoor environmental quality parameters and building features that affect occupant productivity and energy consumption. Other research interests include personal environmental control, underfloor air distribution, radiant systems, and thermal comfort.

At the University of Padova, Italy, he received a PhD in Energy in 2008, and a MS in Mechanical Engineering in 2005 with honor. He has been a visiting scholar at Tsinghua University and Technical University of Denmark. He received the REHVA Young Scientist Award and ASHRAE Ralph Nevins Physiology and Human Environment Award."

Handi Chandra Putra, Rutgers University, handi@rutgers.edu. He is a doctoral student in Planning and Public Policy with interests in environmental planning, planning support systems, and behavioral simulation

Chuang Wang is a PhD student with Department of Building Science and Technology, Tsinghua University, China

Reshma Singh is a key member of the core team that has taken LIGTT from concept to reality. She brings experience in managing international partnerships for the Environmental Energy Technologies Division at LBNL. Her experience in development work includes active participation in The Boston Pledge, an organization promoting grassroots entrepreneurship to serve challenged regions around the globe; working with migrant communities at slums in India to design innovative shelter systems; and working with inner-city residents in Massachusetts on urban revitalization solutions. Previously, she has taught graduate seminars on Architecture and Design at the Harvard Graduate School of Design. Apart from her professional life, she teaches dance and recently co-produced an acclaimed children's musical about diversity and tolerance. Reshma holds a Master degree in Landscape Architecture from Harvard University, a Bachelor degree in Architecture from New Delhi, India and is a LEED Accredited Professional.

Brian Heimberg is a program manager in the China Energy Group of Lawrence Berkeley National Laboratory, and the Operations Manager for the U.S.-China Clean Energy Research Center, Building Energy Efficiency Consortium.

Prior to joining LBNL, Brian Heimberg co-founded the Beijing based ecological planning firm Bluepath and was involved in developing large-scale Eco-cities and low-carbon districts. Notable projects include master planning for the Sino-Singapore Tianjin Eco-city and Dongtan Eco-city, development and implementation of first- and second-generation comprehensive sustainable city key performance indicator systems, and multi-lateral technical assistance for green building codes and administration.

Brian Heimberg's recent work includes advising emerging growth clean-technology companies in the United States and China with strategic and private financing needs. Other international entrepreneurial ventures include culinary tourism, green building materials trading, and sustainable agriculture advocacy.

Version: 130510

U.S. – China Clean Energy Research Center Building Energy Efficiency Consortium (CERC BEE)

Program Overview
July, 2013

BERKELEY LAB

Lawrence Berkeley National Laboratory of the United States and MoHURD Science & Technology Committee of China, with:

OAK RIDGE National Laboratory · Massachusetts Institute of Technology · ICF INTERNATIONAL · NRDC

中国建筑科学研究院 China Academy of Building Research

US-China Clean Energy Research Center for Buildings Energy Efficiency (CERC-BEE)

BERKELEY LAB

- Initiated between U.S. President Obama and Chinese President Hu in 2009
- Joint energy efficiency R&D effort between Chinese and U.S. researchers
- ~15 Building Energy Efficiency Projects:
  - Energy-efficient and emissions reduction technologies
  - Analytical tools to assess impacts
  - Policies and programs to promote technology adoption
  - Commercialization and scale-up
  - Data collection for evaluation

Vision: To build a foundation of knowledge, technologies, tools, human capabilities, and relationships to position the United States and China for a future with very low-energy buildings resulting in very low CO_2 emissions.

US-China Clean Energy Research Center for Buildings Energy Efficiency (CERC-BEE)

- U.S. Department of Energy and China's Ministry of Science and Technology
  - U.S. Center Director: Dr. Nan Zhou, China Energy Group, Lawrence Berkeley National Laboratory
  - China Center Director: Dr. Liang Junqiang, Ministry of Housing and Urban and Rural Development's Center of Science and Technology of Construction
- $50M/5 year program funded by U.S. and China:
  - $5M per year from government
  - $5M+ per year from private industry (cash, in-kind)

Fundamental Criteria adopted by U.S. & China:

1. Benefits to both countries
2. Innovative
3. Impact on market
4. Significant reduction of energy demand and carbon dioxide emissions

Lead Research Institutions

United States	China
Lawrence Berkeley National Laboratory	MoHURD Science & Technology Committee
Oak Ridge National Laboratory	Tsinghua University
Natural Resource Defense Council	China Academy of Building Research
ICF International	Chongqing University
Massachusetts Institute of Technology	Tongji University
	Tianjin University
	China Society for Urban Studies

Current Industrial Partners

U.S. Industrial Advisory Board (IAB)

Bill Jackson, *Chair*

Dow	**Roofing Technology, New Insulation**
SAINT-GOBAIN	**Low-e Window Technology & Design**
Bentley	**Integrated Design, Modeling**
CLIMATEMASTER	**Ground Source Heat Pump**
C3	**Energy Systems for Buildings, Behavior**
LUTRON	**Lighting Control Systems**

Chinese Industrial Partners

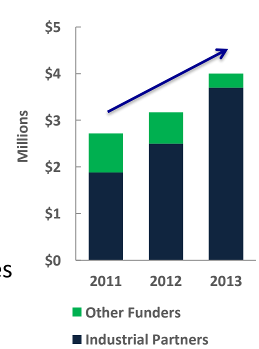
- CONVERTERGY (Shanghai)
- East-West Control Group (Shenyang)
- ENN Group (Tongji)
- Ever Source Technology Development (Tongji)
- Fullshare Energy (Tongji)
- Guangdong Provincial Academy of Building Research (Guangzhou)
- Huaqing Geothermal (Tongji)
- Jiangsu DISMY GSHP (Tongji)
- Lampearl Photoelectric Co., Ltd (Guangzhou)
- LANP Electrical Co. (Zhejiang)
- LatticeLighting (Nanchang)
- Leye Energy Service (Beijing)
- LH Technology Co., Ltd
- Liaoning Solar Energy R&D Co., Ltd (Tongji)
- NARI Technology Development (Nanjing)
- National Center for Quality Supervision Test of Building Energy Efficiency (Beijing)
- Persagy (Tsinghua)
- Shanghai Futian air conditioning equipment Co,. Ltd (Tongji)
- Shenzhen Institute of Building Research (Shenzhen)
- Singyes Solar (Tongji)
- SOLATUBE Daylight Technology, CECEP (Suzhou)
- Telchina (Beijing)
- Tongguang Construction Group (Shanghai)
- Vanke Building Technology (Tianjin)
- Wall Insulation Committee in China Association of Building Energy Efficiency (Beijing)
- Xinjiang Green Messenger (Urumqi)
- Yingli Energy, Beijing (Tongji)

Industrial Partnerships, Intellectual Property

1. **Businesses match up** with joint U.S. – China research teams to accelerate invention and commercial success.
2. **Industry plays a critical roles** in research, development, deployment, and commercialization.
3. **Partners are uniquely empowered by CERC IP protections** to assume central RD&D roles through:
   - Enhanced protection for IP rights with endorsements by both governments
   - Rights to own or license IP for commercial purposes
   - Access to research insights from entire research portfolio
   - Embedding of partners in the innovative process
   - Opportunities to demonstrate and introduce products to large new markets

Industrial Partner Contribution

+40% Annual Average Growth Rate



Strategy to Achieve Cost Effective, Very Low Energy Buildings (VLEBs)

BERKELEY LAB

Building Design

Integrated Design
Protocols and design tools for VLEBs

Behavior
50-70% reduction in energy use

Policy, Market Promotion

Data and Energy Management
Energy use reductions

Policy Analysis and Incentives
New joint policies

Building Envelope

Roofing technologies / Cool Roof Coatings
Long life high solar reflectance

Insulation
New cost effective air sealing technology

Advanced Window and Shading Technologies
Perimeter energy reduction of 15% - 30%

Whole Building

Building technology integration
Optimization and evaluation of energy system and operation

Renewable Energy / Distributed Generation Integration

Integration and Operation in Real Time
Optimized technology selection, real time controls

New Heat Pump Design
System energy use reductions >30%

Building Equipment

Natural Ventilation Design
Optimization of efficiency / comfort

Lighting Controls
New lighting control algorithms

HVAC Systems
Efficiency improvements

Summary of Technical Achievements Through Q2 2013

BERKELEY LAB

Monitoring and Simulation	• On-line comparative energy benchmarking tool • Expanded use of measured data from real-time monitoring • Behavioral impacts integrated into simulation models
Envelope	• Patent filed: liquid flashing to air seal penetrations • Cool Roof provisions for Chinese national BEE standards • New designs for fenestration materials and systems
Equipment	• Integrated control strategies • Advanced algorithms and demonstration programs for lighting • New advanced evaporative cooling systems
Renewables	• Cloud tool for distributed energy technologies based on load and real-time pricing • Evaluation of renewable energy systems • New ground source heat exchanger designs increasing operational efficiency
Whole Buildings	• Real time strategies for cost & peak load reduction • Comparative research on energy use of U.S. and Chinese high efficiency buildings
Policy	• Methodologies for energy cap and trade system in buildings and quota system for public buildings • Policy recommendations to promote EE, renewable energy, and green buildings

Example Project: Advanced Technology for White Roof Coatings in U.S. and China

Objectives

- Quantify the energy and environmental benefits of cool surfaces
- Create white roof coatings with superior reflectance and durability for U.S. and China markets
- Demonstration of cool roofs in China

Funding: \$2M over 5 years

Market Size: 3B m^2 upgradeable by 2025 (U.S. + China)

Commercialization Partner: Dow Chemical

Potential for IP: High

Key milestones:

- China cool-roof simulations (completed)
- China cool-roof demonstrations (ongoing)
- New coating product yields IP (2013)
- Cool roofs in Chinese building energy standards (2015)
- New coating product achieves sales in China and the United States (2016)

Joint Research Team:

BERKELEY LAB · OAK RIDGE National Laboratory · Chongqing University · DOW

Importance of Collaboration

- **Pioneering R&D Consortium**
  - Governments, researchers, and industry
  - Involves key government policy makers
- **Huge Potential Impact**
  - CO_2 emissions reductions ~100 $MtCO_2$/year by 2025
  - Cost savings of \$2B/ year by 2025
- **Long Term Platform**
  - Creating opportunities for sustainable U.S. - China R&D on building energy efficiency

U.S. - China Technical Review Meeting, Site Visit Beijing 10/12

Building integrated renewable energy demonstration sites, U.S on left, China on right.

US CERC-BEE Management Team

Nan Zhou
Director

Mark Levine
Founding Director;
Strategic Adviser

Bill Jackson
Chair, Industrial Advisory Board

Rick Diamond
Chair, Technical Advisory Committee

Brian S. Heimberg
Operations Manager

Yao Yuan
China Liason

CERC Building Energy Efficiency Website:
http://cercbee.lbl.gov

CERC-Building Energy Efficiency

Integrated Design and Operations to Achieve High Performance Buildings: An Overview of the Joint Project

Tianzhen Hong
Lawrence Berkeley National Laboratory, USA
Da Yan
Tsinghua University, China

CERC-BEE Forum
July 17-18, 2013

U.S.–China Clean Energy Research Center
中美清洁能源研究中心

BERKELEY LAB

清華大学 Tsinghua University

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Outline

- Research Background
- Project Overview
  - Research objective
  - Technical tasks
  - Major deliverables
  - Schedules
  - Collaboration
- Recent Process
- Acknowledgement

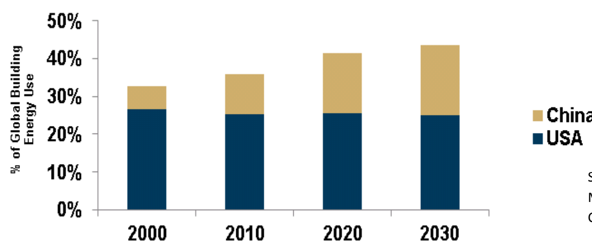
2

Research Background (1)

● US and China, the world's top 2 economics, together consume more than 1/3 of the world's primary energy.

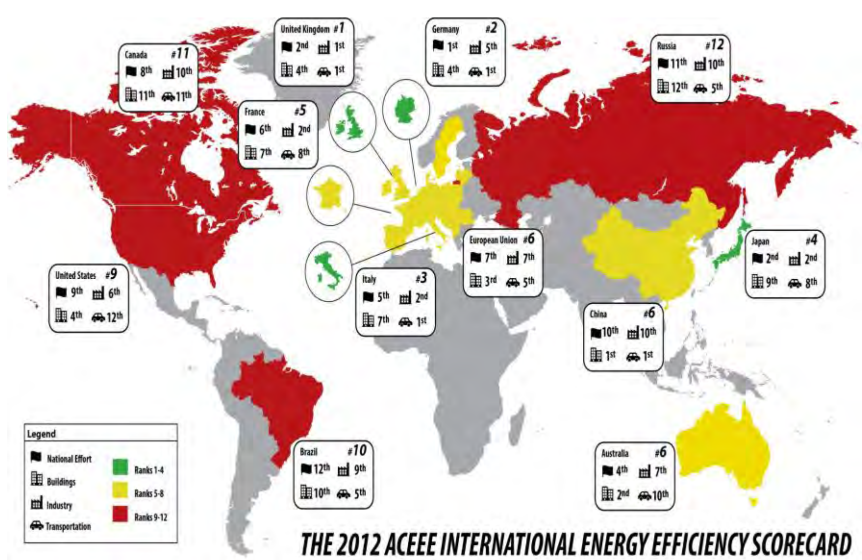
●Primary energy use in the buildings sector in 2011: US 41% (level-off), China 25% (growing quickly)

● Very different energy use styles between the two countries
US: Higher efficiency / Greater demand (full-time full-space)
China: Lower efficiency / Less demand (part-time part-space)
Energy Use = Energy demand / Efficiency



Source: China End-Use Energy Model; Stephane de la Rue du Can and Lynn Price (2008)

3



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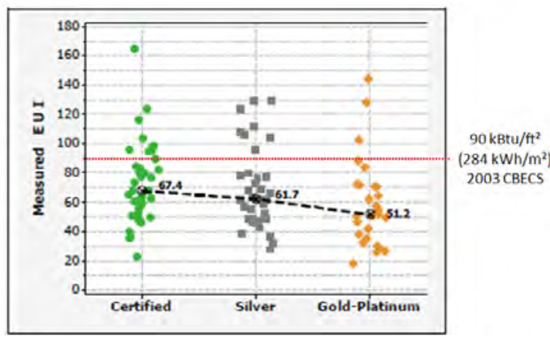
Questions

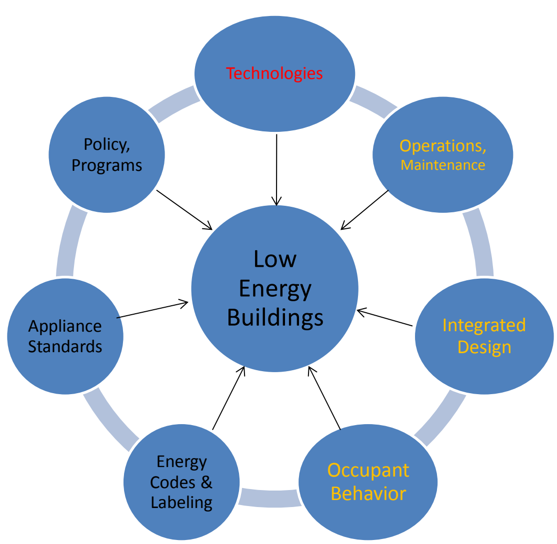
1. Why buildings demonstrate very diverse energy performance?
2. Why Green Buildings could under-perform?
3. What are best Green practices and policies to guarantee building performance?
4. What are methods and tools to support integrated design?



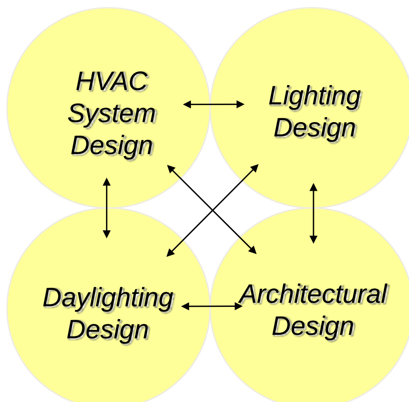
Measured Energy Use Intensities (EUI, kBtu/ft²) of 100 LEED-NC Certified Buildings
Source: Energy Performance of LEED® for New Construction Buildings, NBI, 2008

5

Key elements to achieving low energy buildings



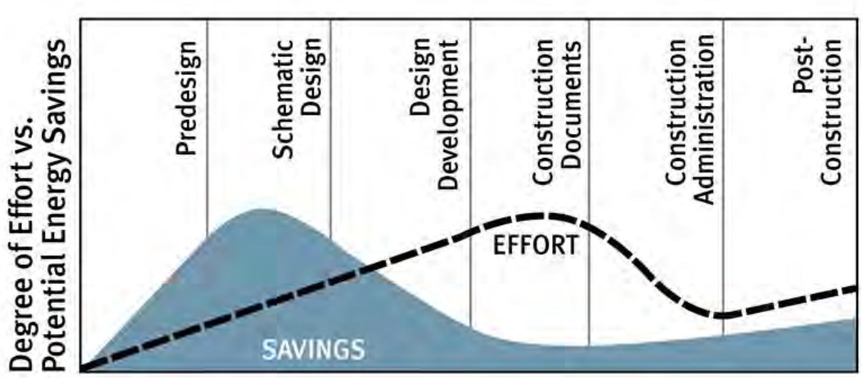
Integrated Design Approach



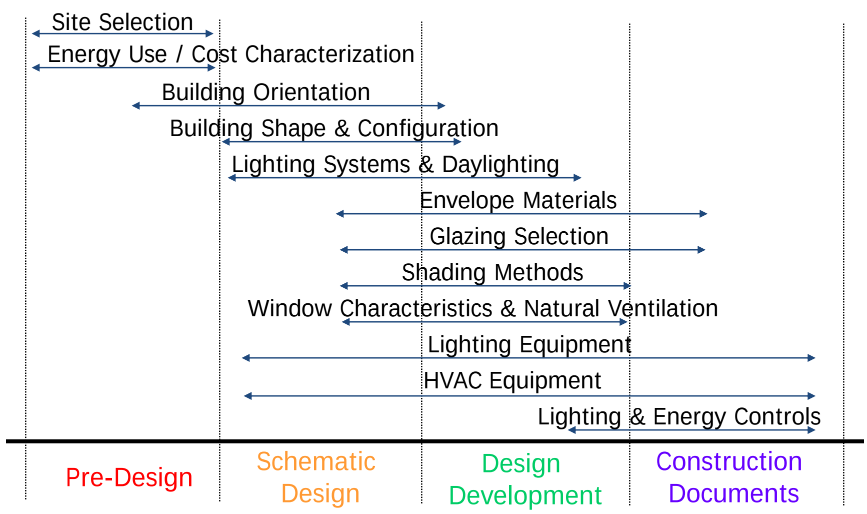
Design for climate, building type, and local available energy resources.

Evaluate the integration and interaction of design disciplines and building systems

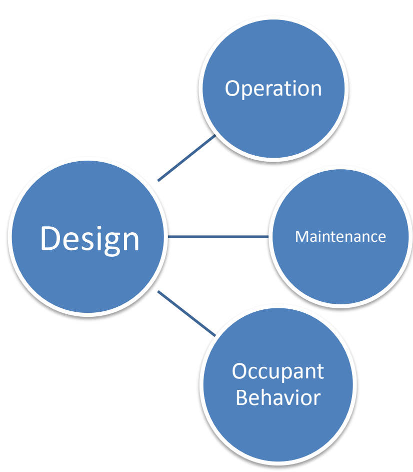
Degree of Effort vs. Potential Energy Savings



Energy Considerations in Design Process



Another meaning of integrated design



Steve Jobs, "Design is not just what it looks like and feels like. Design is how it works."

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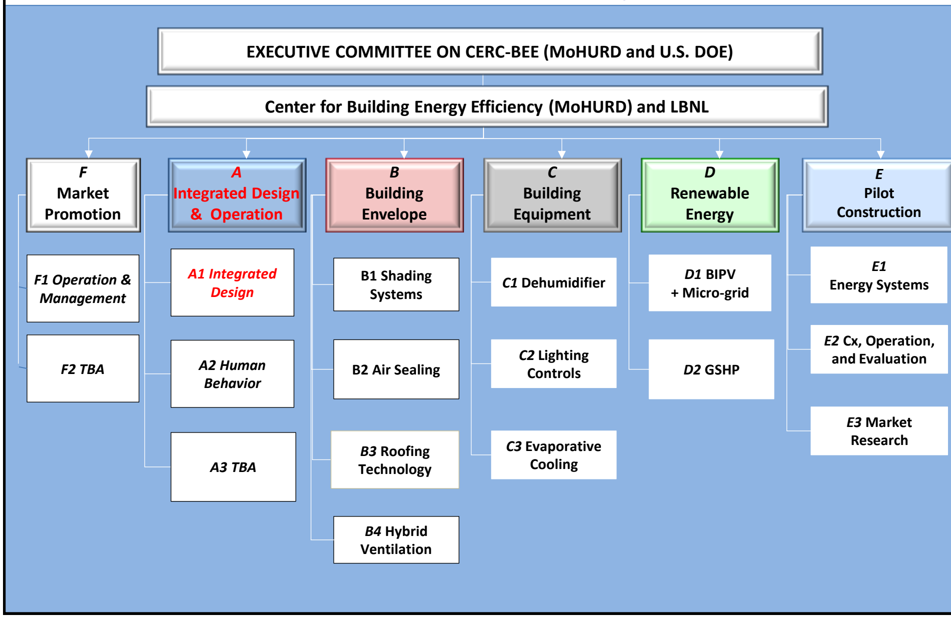
CERC-BEE Phase 2 Research Projects



Research Objective

Develop solutions, including methods, tools, case studies, and guidance to achieving integrated design and operations of low energy buildings

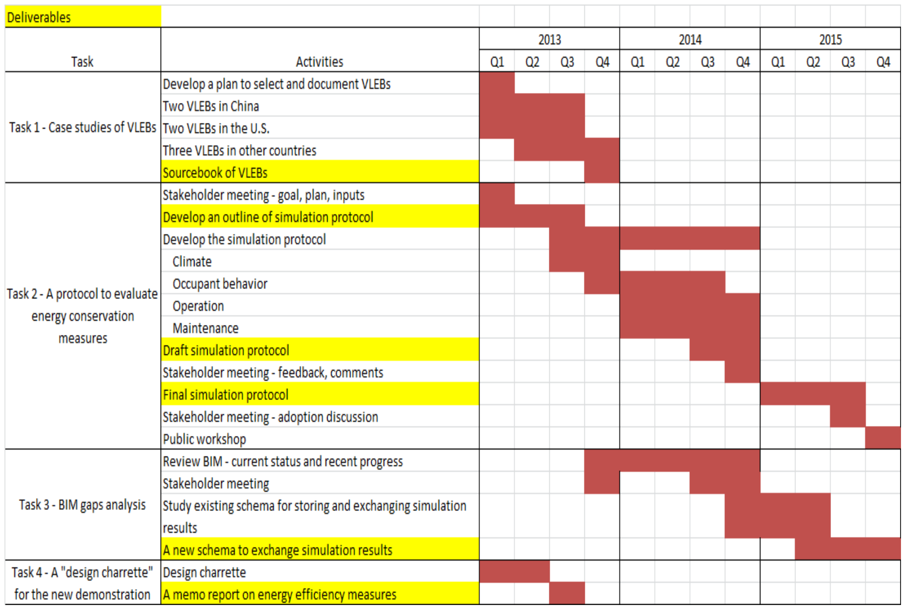
Technical Tasks

1. Portfolio analysis and case studies to identify commonly used technologies and compare energy performance of HPBs
2. Develop a simulation protocol to evaluate energy efficiency measures considering key drivers of performance
3. Research methods and tools to better exchange and share information across multidiscipline during the building life cycle
4. A "design charrette" for the new demonstration buildings in China

Major Deliverables

1. A technical report on technologies and performance of high performance buildings
2. A simulation protocol to evaluate savings of energy efficiency measures
3. A gap analysis report and XML schema on exchanging simulation results using BIM
4. A memo report from the design charrette

Schedules



Research Collaboration

- Strong collaboration between the U.S.-China research teams
  - Bi-weekly conference calls
  - Exchanged students
  - Joint publications
- Industrial partners
  - U.S.: UTRC, Bentley Systems, C3 Energy
  - China: CABR, the CECEP Group, the Vanke Group
- Public workshops & forums
  - Two per year
  - Promote CERC research and seek feedback
  - Engage industry and policy makers
- Synergies with related activities
  - USDOE, California, and ASHRAE asset rating programs
  - ASHRAE SPC 209 Energy Simulation Aided Design for Buildings
  - IEA ECBCS Annex 53 Total Energy Use in Buildings
  - EEB Hub

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Recent Progress

- Two presentations on Task 1
  - Da Yan: a comparative study of cooling strategy for residential buildings
  - Cheng Li: performance and technologies of high performance buildings
- Task 2 in-progress
  - Describe practices of building operation & maintenance and types of occupant behavior as part of the simulation protocol
  - Use the protocol to calculate savings of energy efficiency measures in buildings
- Tasks 3 and 4 to start in Fall

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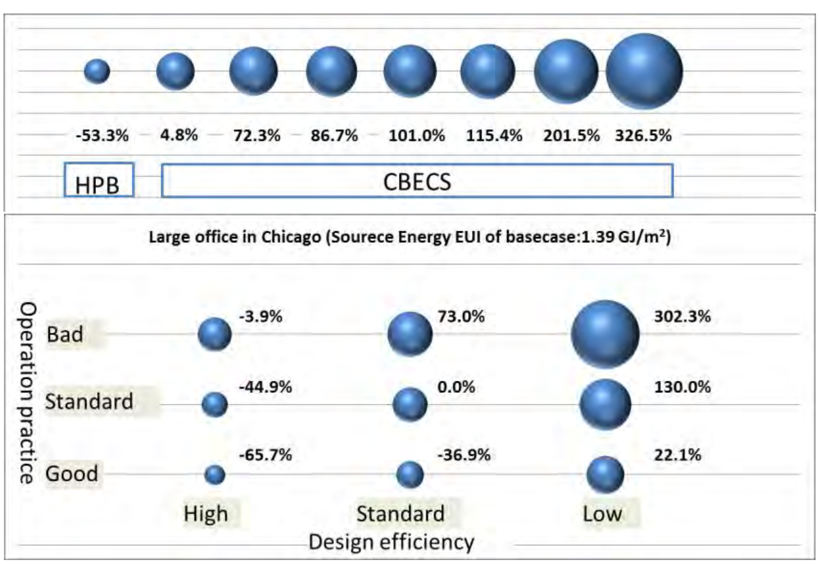
Design vs. Operation



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Acknowledgement

- U.S. DOE for funding U.S. side research
- China MoHURD & MoST for funding China side
- U.S. DOE CERC management
  - Director Robert Marley
  - Senior Advisor Richard Karnay
- U.S. CERC-BEE management team
  - Director Nan Zhou
  - Operation Manager Brian Heimberg
  - Senior Advisor Mark Levine (former director)
  - Technical Advisory Committee
  - Industrial Advisory Board
- China CERC-BEE management

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Questions?

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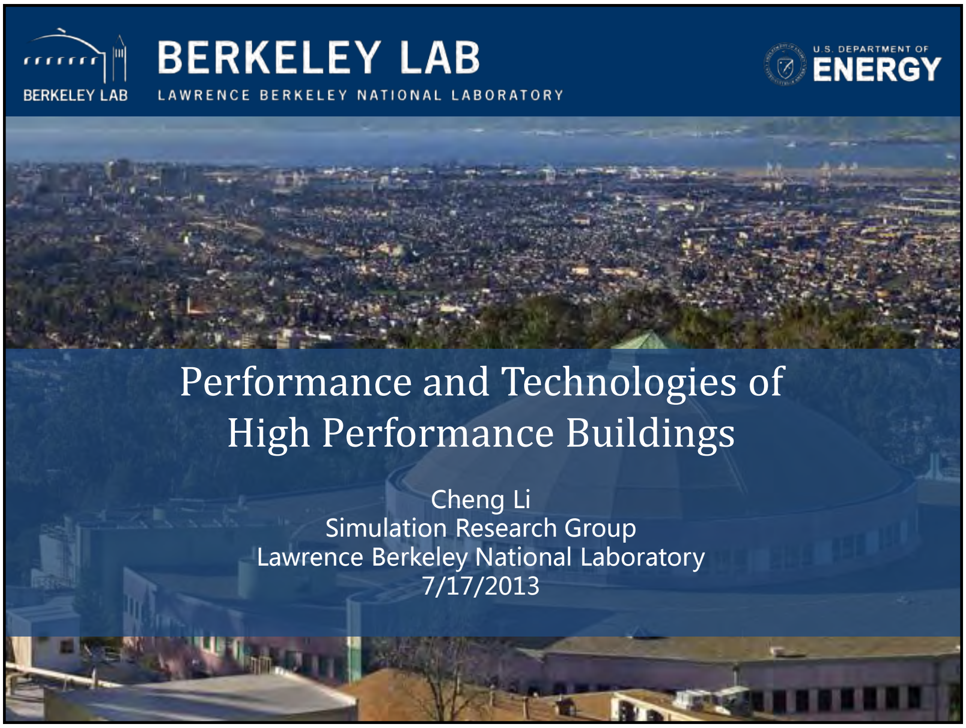

Outline

1. Introduction
2. Technical approach
3. A database of high performance buildings
4. Detailed analysis of technologies and performance
5. Conclusion

Outline

1. **Introduction**
2. Technical approach
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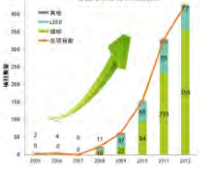
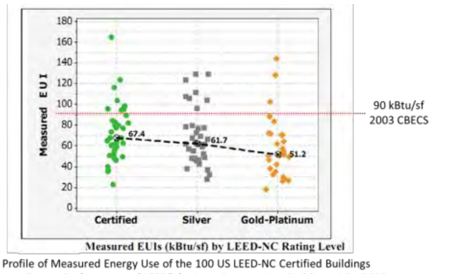
Background

- **Global exponential growth in number of green buildings**



Growth of green buildings in China

- **Some certified buildings failed to deliver the designed performance**



Profile of Measured Energy Use of the 100 US LEED-NC Certified Buildings
Source: Energy Performance of LEED® for New Construction Buildings, NBI, 2008

Questions to Answer

- Globally, what is the status of energy performance of green buildings?
- What are commonly used technologies in high performance buildings?
- What are the driving forces behind energy performance?
- What are good practices to guarantee performance?

Outline

1. Introduction
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5. Conclusion

Technical Approach

- Select and compile a database of High Performance Buildings (HPBs)
- Portfolio analysis of the HPB database
  - Energy Use Intensity
  - Climate
  - Technologies
- Two detailed case studies
  - Buildings with sub-metering and monitoring
  - Design vs. operation & maintenance
  - Occupant behavior

Outline

1. Introduction
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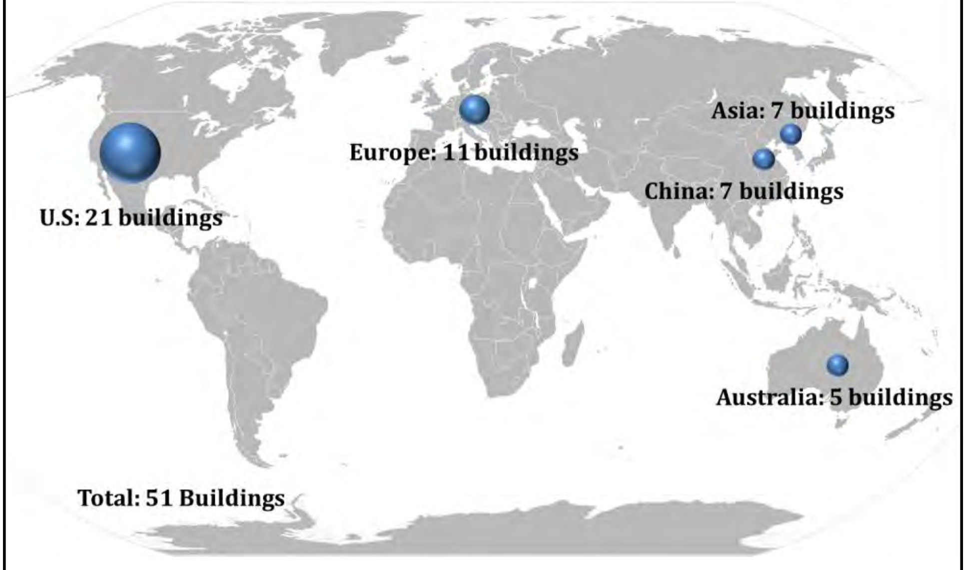
Profile of the Database

- **Target countries and regions**
  - US/ Europe / China / Asia-Pacific
- **Criteria for building selection**
  - **Office Buildings**
  - **Newly Constructed HPBs, occupied after 2004**
  - **US:** LEED NC Gold
  - **Europe:** BREEAM Excellent (UK) / DGNB Gold (Germany) / LEED NC Platinum
  - **Asia-Pacific:** Six-Star Green Star (Australia) / CASBEE "s" (Japan)
  - **China**: Three -Star Certification / LEED Platinum
- **Data collected**
  - Annual site energy consumption
  - Technologies for high performance building
  - Pertinent information on energy consumption
- **Data source**
  - DOE Building Performance Database http://buildingdata.energy.gov/
  - NBI Building Database http://buildings.newbuildings.org/index.cfm
  - Jerry Yudenlson, Ulf Meyer, The world's greenest buildings: promise versus performance in sustainable design, Routledge, 2013
  - From Chinese partner, Tsinghua University Chinese Commercial Building Survey
  - Jones Lang LaSalle Americas, Inc.

Profile of the Database



Outline

1. Introduction
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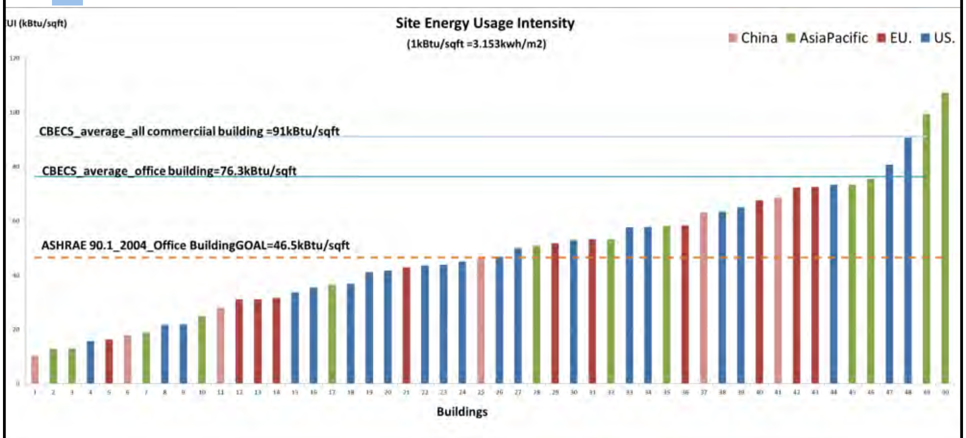
4. **Detailed analysis of technologies and performance**
5. Conclusion

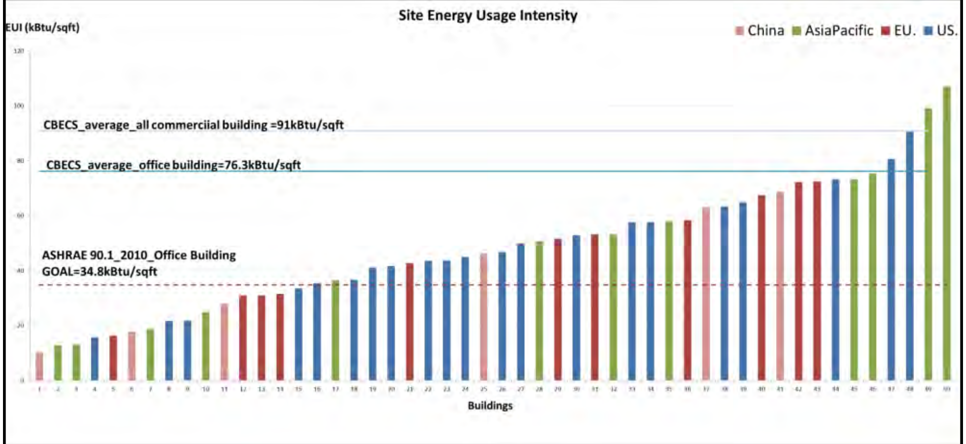
Distribution of Energy Performance



- Median EUI = 46.2 kBtu/sqft
- Average EUI= 47.5 kBtu/sqft

- **50%** reach ASHRAE 90.1_2004 office building goal (46.5 kBtu/sqft)
- Average EUI is higher than ASHRAE 90.1_2004 office building goal

Distribution of Energy Performance



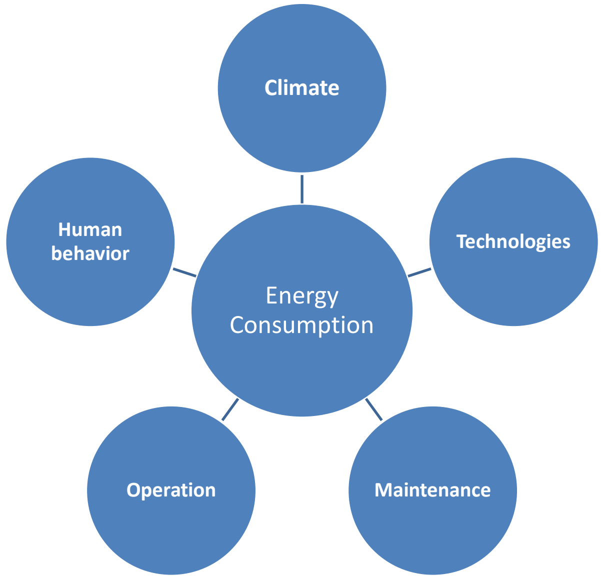
Samples Distribution

	Total number of buildings	Proportion of Buildings (EUI<34.8kBtu/sqft)	Proportion of Buildings (34.8kBtu/sqft<EUI<76.3kBtu/sqft)	Proportion of Buildings (EUI>76.3kBtu/sqft)
US	21	23.8%	66.7%	9.5%
EU	11	36.4%	63.6%	0.0%
Asia	12	33.3%	50.0%	16.7%
China	7	50.0%	50.0%	0.0%

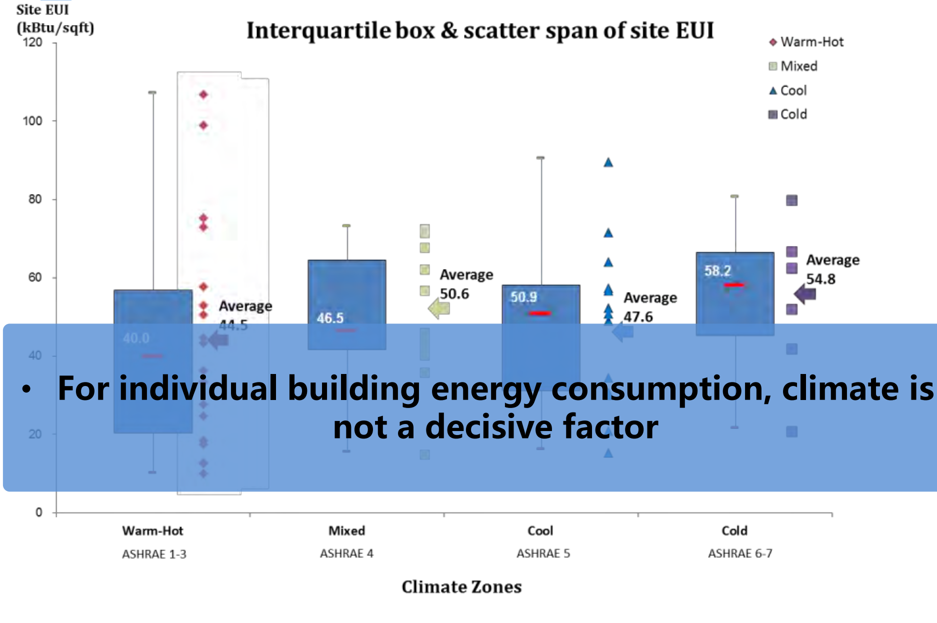
Brief Summary of International Review

- For high performance buildings, scatter of EUI is significant
- More than 50% of HPBs didn’t reach the future energy target
- The high performance certification can not guarantee low energy use in buildings
- What are the influencing factors of the energy usage in these buildings?

Influencing Factors of Energy Consumption

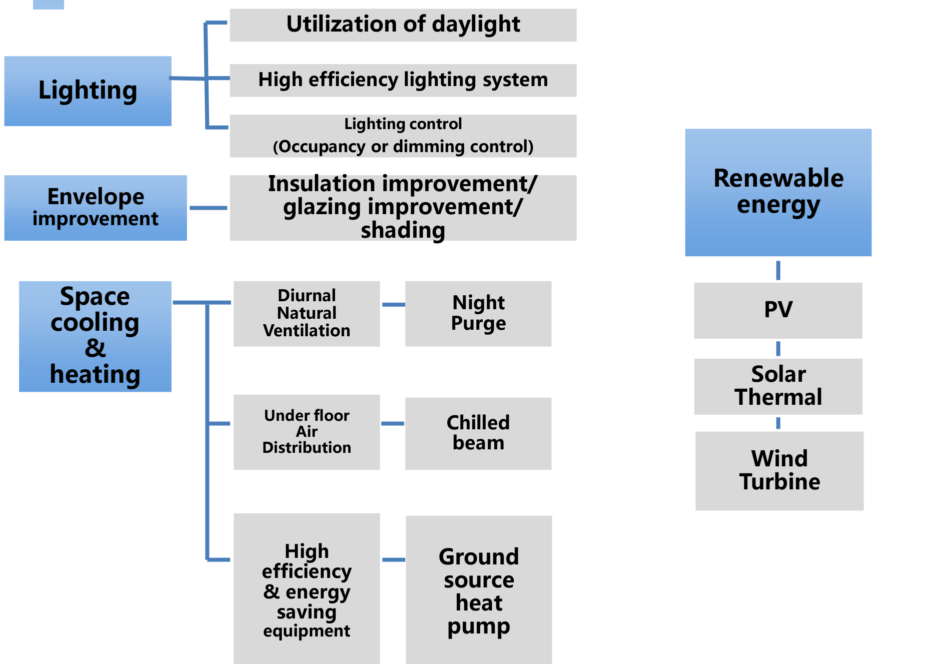


Impact of Climate on EUI



- For individual building energy consumption, climate is not a decisive factor

Technologies in High Performance Building Design



Technologies in HPBs of Warm-hot Zone

		Lighting				HVAC System						Renewable Energy		
Building Num	EUI (kBtu/sqft)	Maximum Utilization of daylighting	High efficient lighting system (low power density)	Lighting control (Occupancy or dimming controlling)	Envelope improvement(Insulation/shading/ glazing improvement)	Daytime Natural Ventilation (System control)	Night Purge (Thermal mass)	Chilled Beam	UnderFlor or Air Distribution	High effeciency& energy saving equipments (chiller/fans/pump/ Air Economizer/ Heat recovery)	Ground Source Heat pump	PV	Solar thermal	Wind turbin
1	10.2	Y			Y	Y		Y				Y	Y	Y
2	12.8				Y	Y				Y		Y		Y
3	13.0	Y		Y	Y	Y						Y		
4	17.8	Y	Y		Y	Y				Y			Y	
5	18.7	Y	Y	Y	Y	Y				Y				Y
6	19.1	Y	Y			Y		Y				Y	Y	Y
7	24.9	Y						Y						
8	27.9	Y				Y				Y			Y	
9	33.6	Y			Y				Y					
10	36.5	Y			Y			Y		Y				
11	43.6		Y	Y	Y					Y		Y		
12	45.0		Y	Y					Y		Y			
13	50.8	Y	Y					Y						
14	53.3	Y		Y	Y	Y				Y	Y	Y	Y	
15	58.1	Y	Y	Y	Y		Y		Y	Y		Y	Y	
16	73.3	Y			Y	Y	Y			Y				
17	75.5	Y	Y		Y	Y		Y		Y				
18	99.3	Y			Y	Y								
19	107.2	Y			Y	Y			Y	Y		Y		
Proportion		84.2%	42.1%	31.6%	73.7%	63.2%	10.5%	31.6%	21.1%	57.9%	10.5%	42.1%	31.6%	21.1%

- Application of daylight strategy , envelope improvement , high efficiency equipment are top 3 measures being used.
- Some technologies appeared in high EUI buildings & low EUI buildings

Technologies in HPBs of Mixed Zone

		Lighting				HVAC System						Renewable Energy		
Building Num	EUI (kBtu/sqft)	Maximum Utilization of daylighting	High efficient lighting system (low power density)	Lighting control (Occupancy or dimming controlling)	Envelope improvement(Insulation/shading/ glazing improvement)	Daytime Natural Ventilation (System control)	Night Purge (Thermal mass)	Chilled Beam	UnderFloor Air Distribution	High effeciency& energy saving equipments (chiller/fans/pump/ Air Economizer/ Heat recovery)	Ground Source Heat pump	PV	Solar thermal	Wind turbin
1	15.7	Y	Y	Y	Y					Y	Y			
2	36.7	Y	Y		Y				Y	Y				
3	41.1	Y		Y		Y								
4	41.7	Y		Y	Y						Y	Y	Y	
5	43.7				Y	Y	Y	Y	Y			Y	Y	Y
6	46.2	Y	Y	Y	Y	Y				Y		Y	Y	
7	46.8									Y		Y	Y	
8	57.6	Y		Y	Y					Y				
9	63.1		Y		Y					Y				
10	68.7	Y		Y	Y	Y		Y		Y				
11	72.3	Y		Y				Y						
12	73.3	Y								Y		Y		
Proportion		75.0%	33.3%	58.3%	66.7%	33.3%	8.3%	25.0%	16.7%	66.7%	16.7%	41.7%	33.3%	8.3%

- Same as that in warm-hot zone, daylight & Envelope improvement &high efficient equipment are top 3 technologies being used
- Some technologies appeared simultaneously in high EUI building & low EUI building

Technologies in HPBs of Cool & Cold Zone

Cool zones

		Lighting				HVAC System						Renewable Energy		
Building Num	EUI (kBtu/sqft)	Maximum Utilization of daylighting	High efficient lighting system (low power density)	Lighting control (Occupancy or dimming controlling)	Envelope improvement(Insulation/shading/ glazing improvement)	Daytime Natural Ventilation (System control)	Night Purge (Thermal mass)	Chilled Beam	UnderFloor Air Distribution	High effeciency& energy saving equipments (chiller/fans/pump/ Air Economizer/ Heat recovery)	Ground Source Heat pump	PV	Solar thermal	Wind turbin
1	16.3	Y			Y		Y			Y	Y	Y	Y	
2	21.8	Y	Y	Y	Y	Y				Y	Y	Y		
3	31.0					Y				Y	Y	Y		
4	31.0	Y				Y	Y			Y	Y	Y		
5	31.6						Y			Y	Y	Y	Y	
6	35.4	Y			Y	Y	Y		Y	Y		Y		
7	50.0													
8	51.7	Y					Y	Y		Y				
9	53.3	Y		Y		Y	Y			Y				
10	57.7		Y	Y										
11	58.4	Y			Y	Y			Y	Y			Y	
12	65.0													
13	72.5	Y			Y							Y		
14	90.6	Y			Y	Y	Y					Y		
Proportion		64.3%	14.3%	21.4%	42.9%	50.0%	50.0%	7.1%	14.3%	64.3%	35.7%	57.1%	21.4%	0.0%

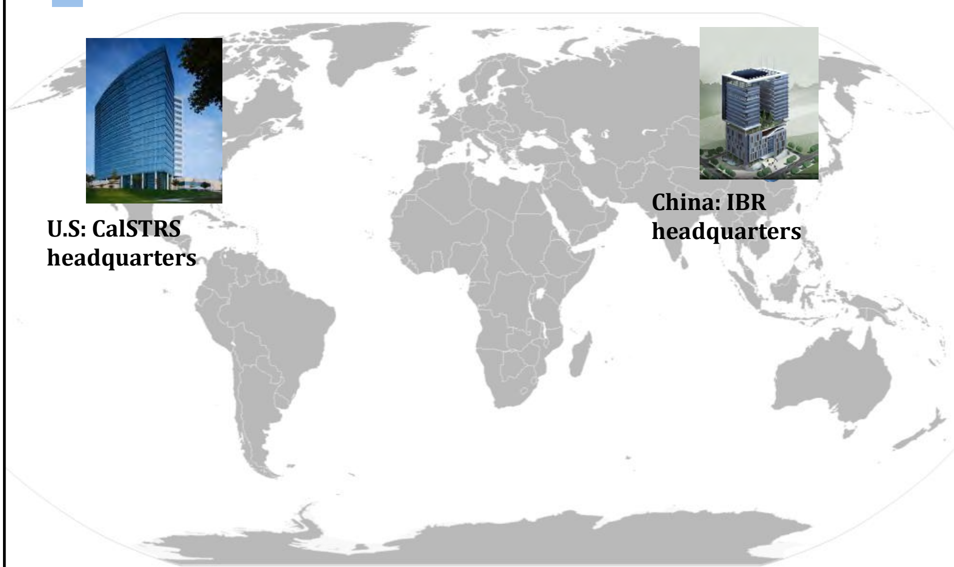
Cold zones

		Lighting				HVAC System						Renewable Energy		
Building Num	EUI (kBtu/sqft)	Maximum Utilization of daylighting	High efficient lighting system (low power density)	Lighting control (Occupancy or dimming controlling)	Envelope improvement(Insulation/shading/ glazing improvement)	Daytime Natural Ventilation (System control)	Night Purge (Thermal mass)	Chilled Beam	UnderFloor Air Distribution	High effeciency& energy saving equipments (chiller/fans/pump/ Air Economizer/ Heat recovery)	Ground Source Heat pump	PV	Solar thermal	Wind turbin
1	21.7	Y		Y	Y	Y	Y	Y		Y	Y	Y	Y	Y
2	42.8	Y			Y	Y				Y				
3	52.9	Y		Y	Y					Y				
4	63.4	Y		Y					Y		Y			
5	67.6				Y	Y		Y		Y				
6	80.7	Y	Y							Y	Y	Y	Y	
Proportion		83.3%	16.7%	50.0%	66.7%	50.0%	16.7%	33.3%	16.7%	83.3%	50.0%	33.3%	33.3%	16.7%

Brief Summary

- Climate is not a decisive factor for energy consumption intensity
- More innovative technologies doesn’t necessarily mean high performance in energy use
- Interaction between design, human behavior, operation and maintenance might be a possible solution for high performance buildings
- Detailed analysis is needed

Two Case Studies

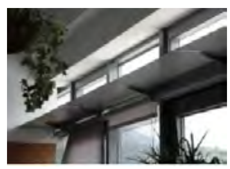


Overview of IBR

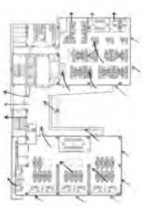
Item name	Descriptions
Name	IBR (Institute of Buiding Research) Headquarters
Location	Shenzhen, Southern China
Year of construction	2009
Type	Office (12 floors), Basement (2 floors)
Floor area (m2)	18,170 m^2 (195,587 ft^2)
Operation hours	M-F 8:00am - 5:00pm

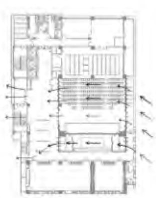
Certification of Green Building- 3 STAR Certification (Highest level)

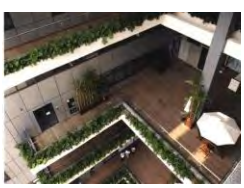
Highlights of Design Features

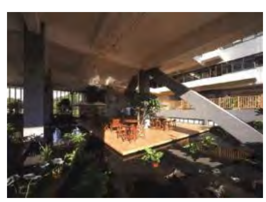


- Application of daylighting
  - Placing the offices at the perimeter area, depth of office is no more than 18.5m
  - Reflecting panel for daylight redirection
- Shading
  - Rooftop shading platform with roof garden
  - Horizontal metallic shading plates (both exterior side & interior side)
- Diurnal Natural Ventilation
  - Operable exterior windows
  - U-shaped layout to capture prevalent wind
  - Apply semi-opened space as common space, improve thermal acceptability, lower the need for HVAC







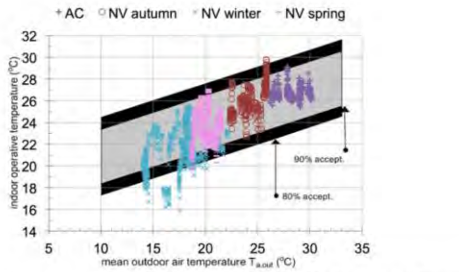


Operation and Human Behavior

- **Diurnal Natural Ventilation**
  - **Exterior windows – manually control by office occupant**
  - **AC system operation is control by property manager**
  - **Property manager should make sure that the windows are closed when AC is on**

Outdoor Conditions under which air conditioning is turned on for the day (T: forecast maximal temperature for the day, RH: forecast maximum relative humidity during the day).

Condition	Action undertaken
T>27°C	Turn on AC
T=27°C, RH>60%	Turn on AC
T=26°C, RH>65%	Turn on AC
T=25°C, RH>71%	Turn on AC
T=24°C, RH>77%	Turn on liquid dessicant dehumidification
T=23°C, RH>84%	Turn on liquid dessicant dehumidification
T=22°C, RH>91%	Turn on liquid dessicant dehumidification

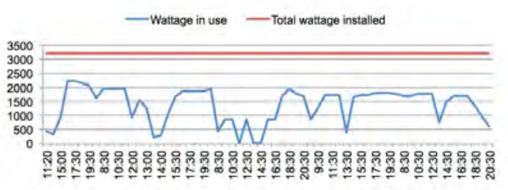


Indoor average temperature during working hours of each of the four time periods, as a function of a 3-weeks average of indoor temperature. Background: ASHRAE 55 standard for natural ventilation

Data & figure source: Jérôme DAMIENS , Using assive design for offices in a subtropical climate: a case study in Shenzhen, Tsinghua University, 2013

Operation and Human Behavior (Continued)

- **Daylight application**
  - **Artificial lighting in working zones**
    - **Manually controlled by office occupants**
    - **Individually controlled in separated working zones**
  - **Common area**
    - **Manually turned on if needed**
  - **Training on lighting control**

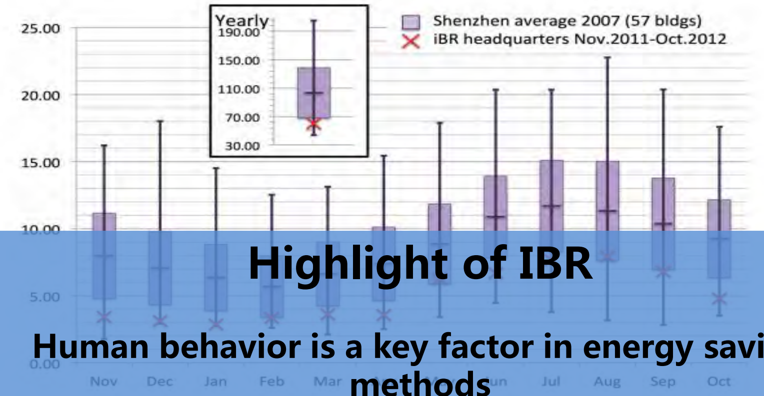


Levels of artificial lighting used in a 720m² office area of iBR during the working hours of a week (five days) in April 2012. The number of measure points obtained is different on each day. The weather during this week was particularly cloudy and rainy, except on the morning of the first day, where less than 500W of artificial lighting was used.

Data & figure source: Jérôme DAMIENS , Using assive design for offices in a subtropical climate: a case study in Shenzhen, Tsinghua University, 2013

Energy Consumption of IBR

EUI_IBR (Nov. 2011~Oct.2012) =60.2kWh/m² ·yr= 19.1kBTU/sqft·yr



Highlight of IBR

Human behavior is a key factor in energy saving methods

Comparison of the electricity consumption of IBR equivalent office building with a sample of 57 Shenzhen offices. The box on the 57 buildings' sample corresponds to the standard deviation band, and the bars to the min and max values. Unit $kWh.m^{-2}$.

Data & figure source: Jérôme DAMIENS , Using assive design for offices in a subtropical climate: a case study in Shenzhen, Tsinghua University, 2013

Overview of CalSTRS

Item name	Descriptions
Name	CalSTRS (California State Teachers Retirement System) Headquarters
Location	West Sacramento, CA
Year of construction	2009
Type	Office (13 floors), Podiums (5 floors)
Number of floor	18 Floors
Floor area (m2)	34,374 m^2 (370,000 ft^2)
Operation hours	M-F 6:00am - 6:00pm (a few floor/rooms are operated from 5:00am in workdays)
Max. Occupancy	1200 people (when full occupied)

LEED NC GOLD (2009)

LEED EBOM Platinum (2011)

Energy Star Scores: 95 (2010)

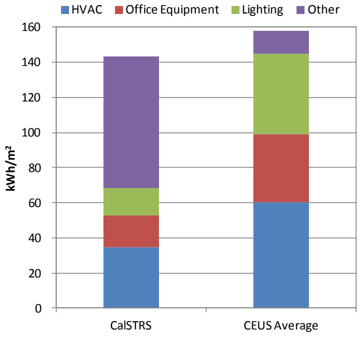
Highlights of Operation & Maintenance

- **Input from a building operation consultant during the design stage**
- **Lighting system**
  - **High efficiency lighting equipment**
  - **Occupant-specific task lighting**
  - **Manually operable exterior lighting**
- **Under Floor Air Distribution (UFAD) system and occupant controllable air diffusers**

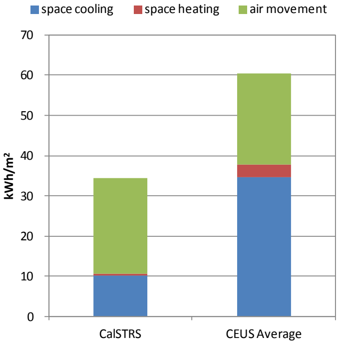
- **Commissioning was completed during early 2011**
- **6 initiatives** to save costs and increase energy efficiency
  - Automation of the west shaft supply air damper to direct the main air supply to load areas;
  - Resetting of the main air handling unit pressure set-point;
  - Resetting of chilled water temperature set-point;
  - Resetting of under floor air damper set-points;
  - Fan terminal unit output set-points to match local load conditions; and
  - Modification of cooling tower operation on cooler days to minimize fan power.

Energy Profiling & Benchmarking

- **Data Period**: 03/2012 - 02/2013
- **Type of data:** Site EUI
- **Site EUI**: 143 kWh/m2/a (**45kBtu/sqft)**
- **Benchmarking**: **12%** less energy use compared to California buildings

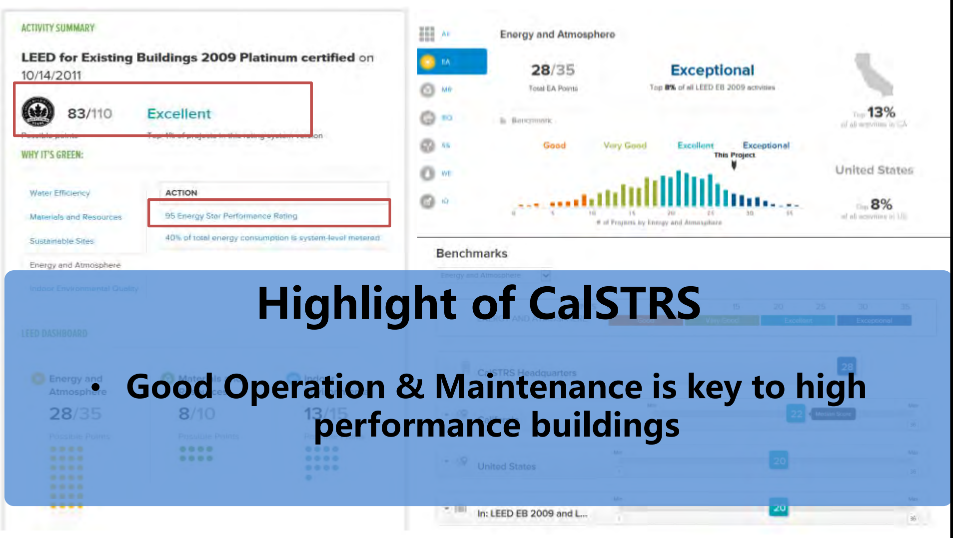


(a) Breakdown of whole building



(b) Breakdown of HVAC

Details of CalSTRS LEED-EBOM Certification



Highlight of CalSTRS

- Good Operation & Maintenance is key to high performance buildings

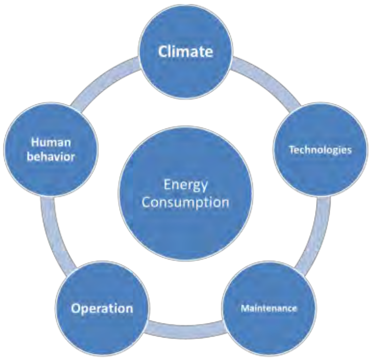
Source: http://www.gbig.org/activities/leed-1000006058#

Outline

1. Introduction
2. Technical approach
3. A database of high performance buildings
4. Detailed analysis of technologies and performance
5. Conclusion

Conclusion

- **Performance of HPBs varies significantly**
- **Current situation of HPBs is challenging**
- **Not a single factor is decisive for energy use in HPBs**
- **Integrated approach considering all 5 factors and their interactions**



BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

BERKELEY LAB

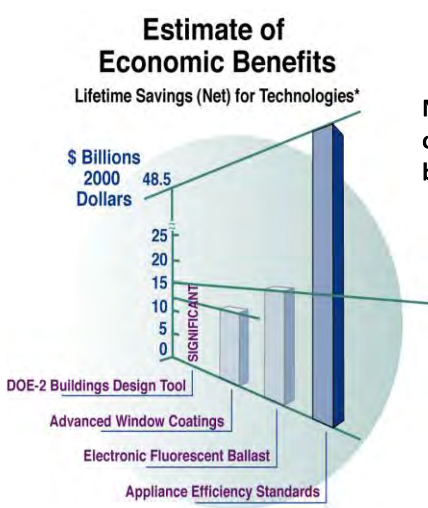
Building Technology and Urban Systems Department

Jessica Granderson

Deputy Department Head
for Research Programs

Lawrence Berkeley National Laboratory

Berkeley Lab buildings RDD&D has a long history saving over $50B in last 30 years



National Academy of Science estimated $23 of the total DOE $30 billion of efficiency benefits of to LBNL technologies

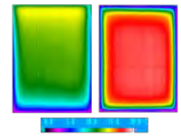
- Primary Energy Savings
  9% of 2025 residential energy use
- Carbon Reductions in 2025
  132 million metric tons CO_2/year

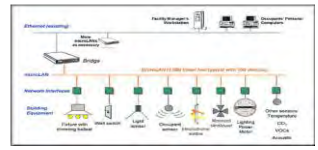
*"Energy Research at DOE: Was it worth it? (Energy Efficiency and Fossil Energy Research 1978-2000)", National Academies Press, 2001. ISBN-10: 0-309-07448-7

2

Technology

Electronics, Lighting, and Networks
Windows and Envelope Materials
Simulation Research





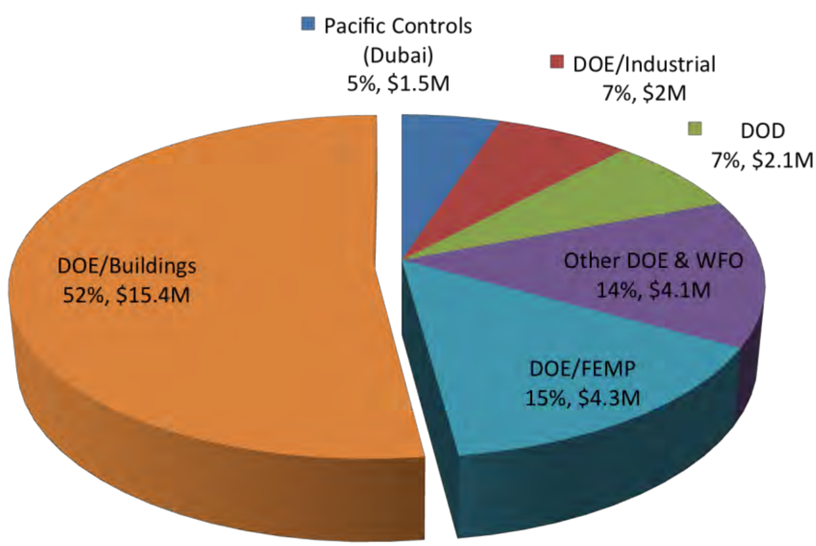
Demand-Side Systems

Commercial Building Systems
Residential Building Systems
High-Tech Buildings and Industrial Systems

Sustainable Federal Operations

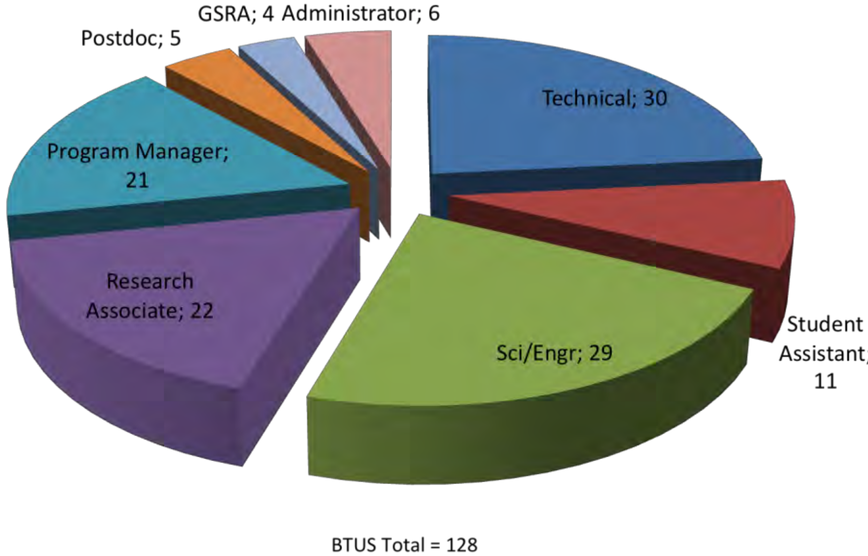
FY12 BTUS Funding Sources

Department Funding Summary



BTUS Department – Staff by Major Job Category

Department Staffing Summary



Top 10 R&D success stories from Berkeley Lab

- Windows and daylighting
- Lighting sources and controls
- Commissioning and diagnostics
- Low standby power
- Energy-efficient data centers
- DOE-2 and EnergyPlus
- Cool roofs
- Aerosol duct sealing
- Healthy homes
- Home Energy Saver
- Automated demand response

- Since 1980 generated U.S. savings> $50B and 5 quads, millions of product ratings, 5 R&D 100 awards

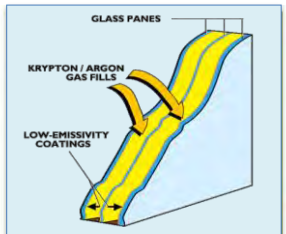
Windows and Daylighting

Commercialized low-emissivity windows, spectrally selective glazings, advanced triple paned gas-filled windows, smart windows, and daylighting

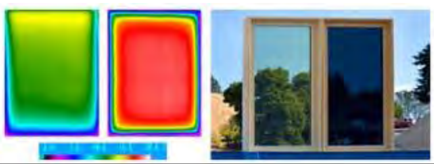
- Low emissivity windows >50% market share, with savings of $17B and 71 million tons CO_2 by 2015

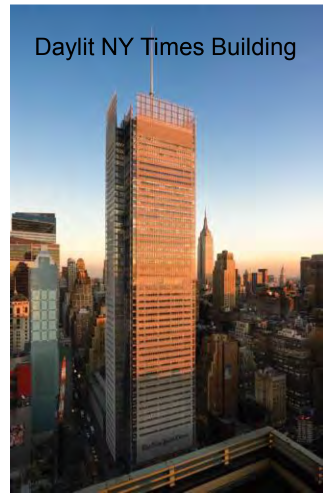
- Nearly all U.S. manufacturers offer low-e windows

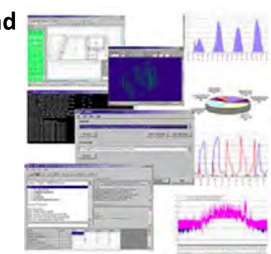
National Fenestration Rating Council



"Superwindow" concept, based on multiple glazing, low-emissivity coatings, and gas fills.



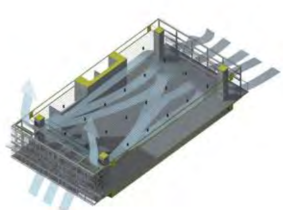




Simulation Tools - DOE-2 and EnergyPlus

Tools for low-energy design optimization, building codes, and retrofit analysis support 10-30% savings per building

- **California code savings: $12B in electricity costs through 2002, and $30B by 2015**
- **R&D 100 Award and Award for Excellence in Technology Transfer**



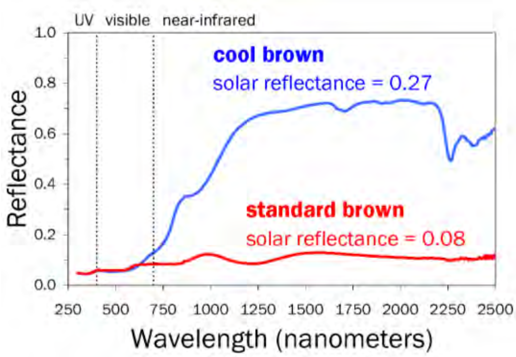
Naturally ventilated
San Francisco Federal Building

EnergyPlus

Cool Roofs

Cool-colored roofs save energy with solar reflective dark-colored products

- **Retrofitting 95% of U.S. homes would generate annual net savings of 0.14 quads, \$1.1B, and 6.1 MT CO_2**
- **Warm-climate AC energy reductions of 5 to 10%**



SR – Solar Reflectance

Healthy Homes

Healthy Homes—high performance, low energy, indoor air quality

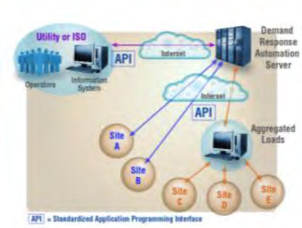
- Program initiated 3 yrs ago, to apply health-based and building science methods
- **30 to 50% of space conditioning** associated with infiltration and ventilation
- **Potential savings ~2 Quads** in moving away from infiltration dominated ventilation
- **Enable performance-based** indoor air quality **standard**
- Incorporation into ASHRAE Standard 62.2
- **Adopters**: Building America, ASHRAE, CA energy code, Energy Star

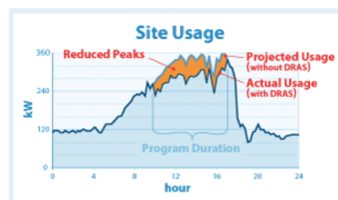
Low Energy Indoor Environmental Quality

10

Energy Storage and Distributed Resources, Building Technology

- Open Automated Demand Response standard and DR deployment
  - **LBNL DR communications model** standard to lower cost, increase participation, enable renewable grid integration
  - **Over 200 MW of DR in California and over 70 companies with products**
  - **Recent adoption as NIST Smart Grid Standard**
  - Testing in Nevada, New York, Florida, China, Japan, Australia, Scotland, Korea and elsewhere
  - **Over 40 companies participate in** development and certification via **OpenADR Alliance**
  - Deployment partners: Honeywell, Siemens, Schneider, Auto-Grid, UISOL/Alstom, GEP/EnerNOC, PG&E, SCE and SDG&E





Collaboration of BTUS within LBNL

With Material Science and Earth Science Divisions, plus Accelerator and Fusion Research Division

- Windows and Envelope Materials

With Computational Research Division

- Commercial Building Systems
- Simulation Research
- High-Tech Buildings and Industrial Systems

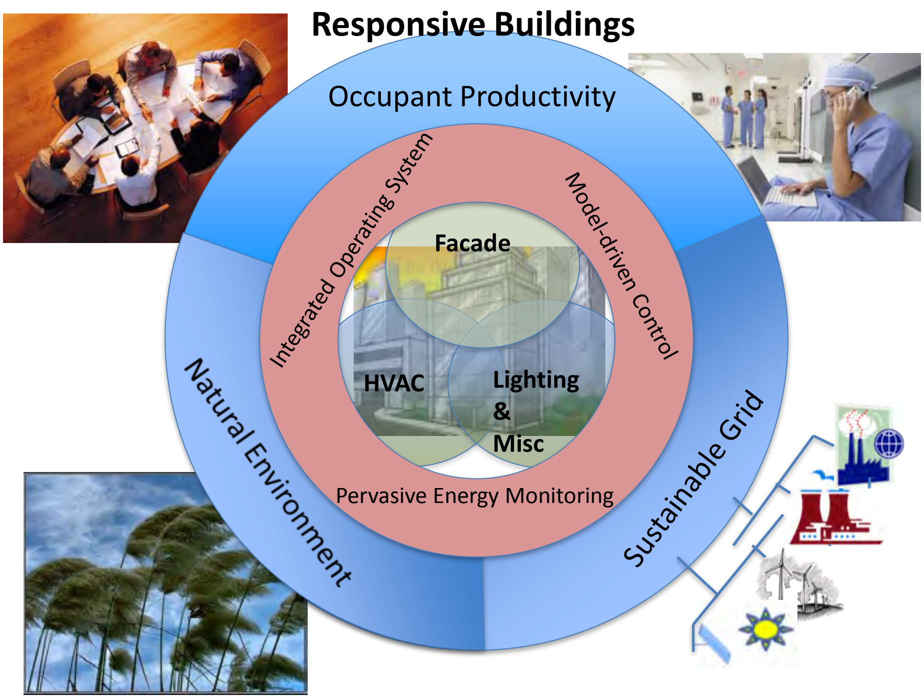
With Lab Facilities and New Campus

- Sustainable Federal Operations
- Electronics, Lighting, and Networks
- High-Tech Buildings and Industrial Systems

12

Today - Information Technology helps make performance visible

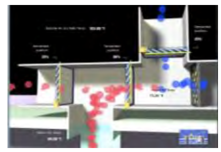
Responsive Buildings

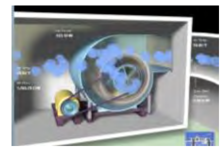


Buildings Need Energy-Aware Controls

Approach

- Use equation-based languages and hardware-in-the-loop real-time simulation to minimize energy use and conduct ongoing fault diagnostics
- Multiple control loops of different time scales for dynamic HVAC, lighting, and façade models to manage operating costs



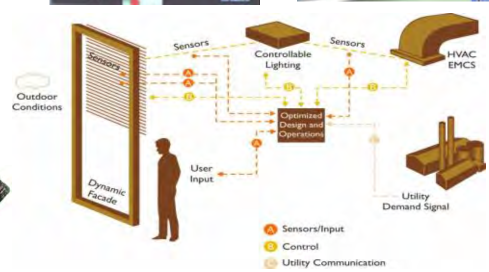


Existing Practice

Control Sequence → Machine Code → (building)

Future Practice

Control Sequence → Model-Based Automated Supervision → Machine Code → (building)



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Goals for Research in Low Energy Buildings

- **Predict Actual Performance**: Fully validated models are used to reliably simulate a wide range of systems and their interactions.
- **Realize and Maintain Performance**: Measured data used with real-time, model-based control to ensure performance meets design intent.
- **Disseminate and Deploy at Scale**: Performance prediction methods mature into scalable techniques that become routine practice.

16

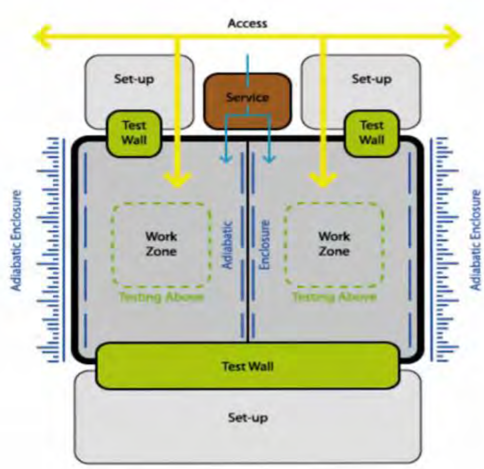
LBNL FLEXLAB

- 2013 opening, 10k sf total: 4 experimental buildings
- Test integration of building systems and components
- Support collaborations between public/private sector
- Accelerate technology market transfer, enhanced control, energy performance

Features and Capabilities

- Interchangeable lighting and façade elements
- Flexible HVAC systems and interior configurations
- Paired cells for comparative studies
- Extensive sensing, instrumentation, monitoring
- Open-source platform for data analysis and visualization

17



Test Bed Diagam

United Technologies Research Center

Integrated Building Design and Tools: Accelerating Innovation and Sustainability

Dr. Jinlei Ding
Group Leader, Buildings & Energy
United Technologies Research Center (China) Ltd.

July 17, 2013

KEY POINTS

Inside-out view from equipment industry perspective

Modeling and simulation as a key driver of energy efficiency and sustainability In building design

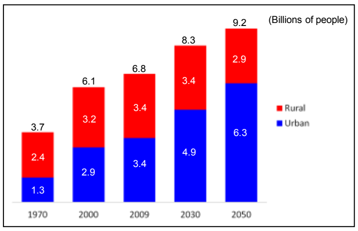
Three-level approach: component, equipment, system

Solid foundation of physics with many research opportunities available in exploring dynamic behavior

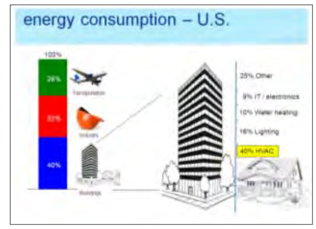
System / building designer has numerous tools available to explore advances in HVAC equipment technology

2

DRIVERS OF ENERGY EFFICIENCY

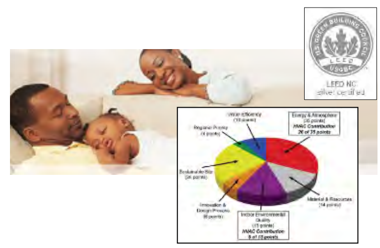


Urbanization



Energy Consumption – U.S.

Company values



Customer expectations

3

MODELING IN EQUIPMENT DESIGN/OPERATION

System

Building Simulation: TRNSYS, EnergyPlus™, DeepRetro

HVAC and Building Design: EnergyPlus™, HAP, eQUEST, TAS

Diagnostics and Prognostics

Steady-state modeling: Fortran, Excel, VB, EES

Equipment

Product Family Design: Universities

Dynamic modeling: Dymola, TransRef

Equipment selection tools: ECAT, TOPSS™

Component

CFD, FEA: Ansys ® Fluent, Ansys® CFX ®, CoilDesigner

Market Needs Early Design → ***Detailed Design*** → ***Operation***

4

BUILDINGS ENERGY AUDIT AND DEEP RETROFIT ANALYSIS

To develop and demonstrate a software tool and methodology to **accelerate level I & II building audit processes** from 2-3 weeks to one day (10x in time and cost).

Current State: 3 levels of audits, defined by ASHRAE

I: Energy baseline (walkthrough and expert judgment) — 1-2 weeks*

II: Detail assessment & retrofit evaluation (expert judgment) — 2-3 weeks

III: Detailed modeling and verification — 3-4 weeks

Desired State:

I-II Combined — 1-2 days

III: Detailed modeling and verification — ~1 week

Differentiators

- Simple inputs, can be defaulted if unknown
- Considers the physics of each building and its environment, provides results that are specific to each building
- Incorporates automatic calibration capability
- Combines energy audit and retrofit assessment
- Economics and environmental analysis integrated
- Building portfolio tracking and comparison is enabled
- Uncertainty is quantified
- ECMs dependences is considered

* Calendar weeks

5

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BUILDINGS ENERGY AUDITS AND DEEP RETROFIT ANALYSIS

To develop and demonstrate a software tool and methodology to **accelerate level I & II building audit processes** from 2-3 weeks to one day (10x in time and cost).

Inputs → **Baseline Evaluation Automatic Calibration** → **ECM Evaluation** → **Sensitivity analysis & uncertainty quantification**

~ 1 hour*

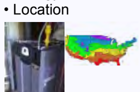
~1-2 min. (w/o calibration)
~4 hrs (automatic calibration)

< 2 hrs all ECM
1 min per package

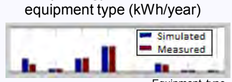
hours

Simplified inputs

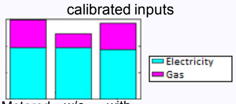
- Building attributes
- HVAC type
- Schedules
- Energy bills
- Location



Baseline energy
by energy source and equipment type (kWh/year)



Total energy with and without calibrated inputs

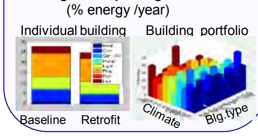


ECMs options
total annual energy (kWh/year) by applying individual ECMs

Savings from package ECMs
(% energy /year)

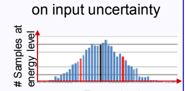
Individual building

Building portfolio

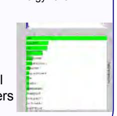


UQ/SA

Results distribution based on input uncertainty



Rank of most influential parameters



* 'man-working hour'

6

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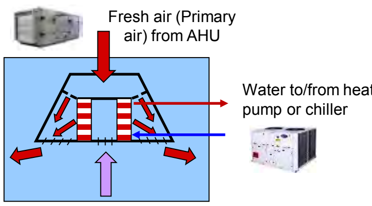
CASE STUDY: CHILLED BEAM VS FAN-COIL

Compared with conventional VAV, systems using chilled beam as terminals are more energy efficient



Typical installation

Requires fresh air to remove latent load only

Handles sensible load with higher temperature water (12 ~ 18 ° C)

Reduced fresh air load; reduced energy consumption for ventilation

Increased chiller efficiency; reduced reheating

Smaller ductwork, more ceiling space, less noisy …

How about chilled beam vs fan coil unit? Still more energy efficient?

7

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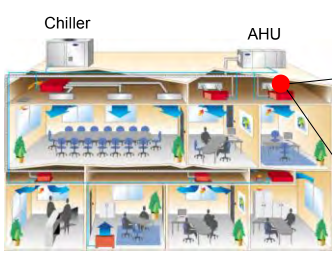
CASE STUDY: CHILLED BEAM VS FAN-COIL

Case study in Shanghai from energy performance perspective



Fan Coil Unit (FCU)

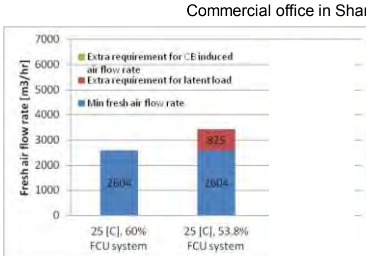
- Entering water: 7 ° C
- Handle sensible/latent load simultaneously, AHU to provide fresh air for ventilation only
- Typical room air: 25 ° C/60%
- Local fan enabled capacity

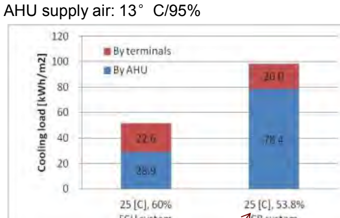
or

Chilled Beam (CB)

- Entering water: 16 ° C
- Handle sensible load only, AHU to provide processed fresh air for ventilation and latent load
- Typical room air: 25 ° C/**53.8% (condensate not allowed on the coil surface)**
- Primary air enabled capacity (4 ~ 6 W/(m^3/hr) primary air flow)

Commercial office in Shanghai (~1900 m^2), AHU supply air: 13° C/95%





If all the primary air comes from processed out door air

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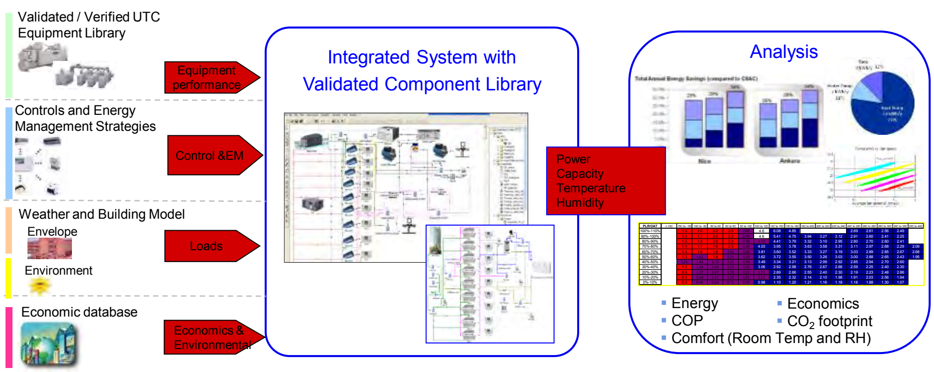
CASE STUDY: CHILLED BEAM VS FAN-COIL

System-level modeling platform



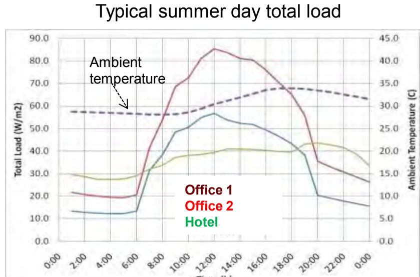
• System integration: Integrated solution and BMS
• Specific unique design: Innovative architectures and optimized efficiency
• Product strategy decision: Component requirements for system optimization

8760 HOUR SIMULATION ANALYSIS

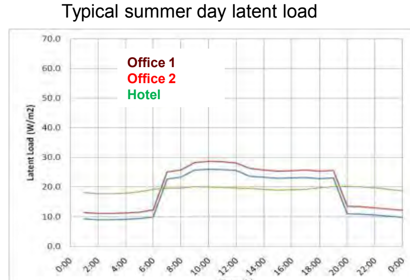
Annual energy performance of CB and FCU systems were compared using three types of buildings with Shanghai weather

Bldg Type	Ext. wall U	Ext. wall total thickness	Ext. window U	Ext. window G value	Infiltration
	[W/m2/K]	[m]	[W/m2/K]		[1/hr]
Office-1: High Performance envelope	0.302	0.17	1.05	0.22	0.01
Office-2: Low Performance envelope	0.496	0.118	1.8	0.429	0.1
Hotel	0.496	0.118	1.8	0.429	0.1

Typical summer day total load

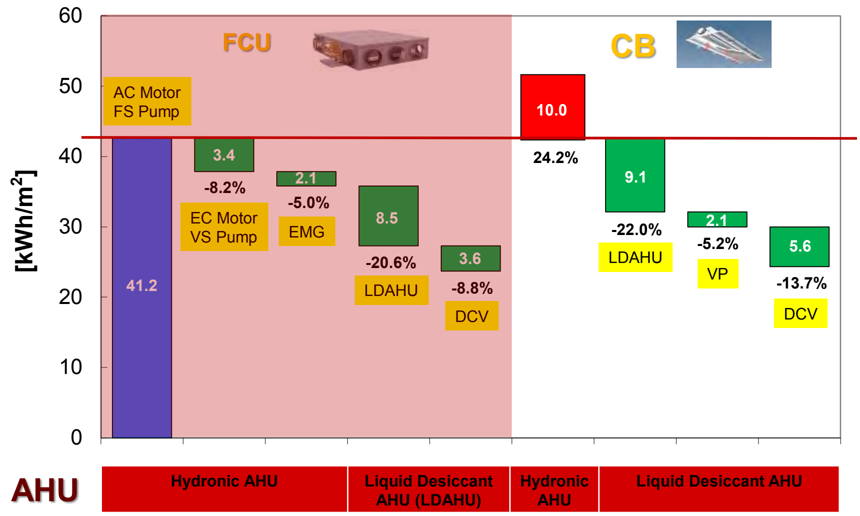


Typical summer day latent load



OFFICE-1 (HIGH PERFORMANCE ENVELOPE)

Annual power consumption per floor area (Shanghai)



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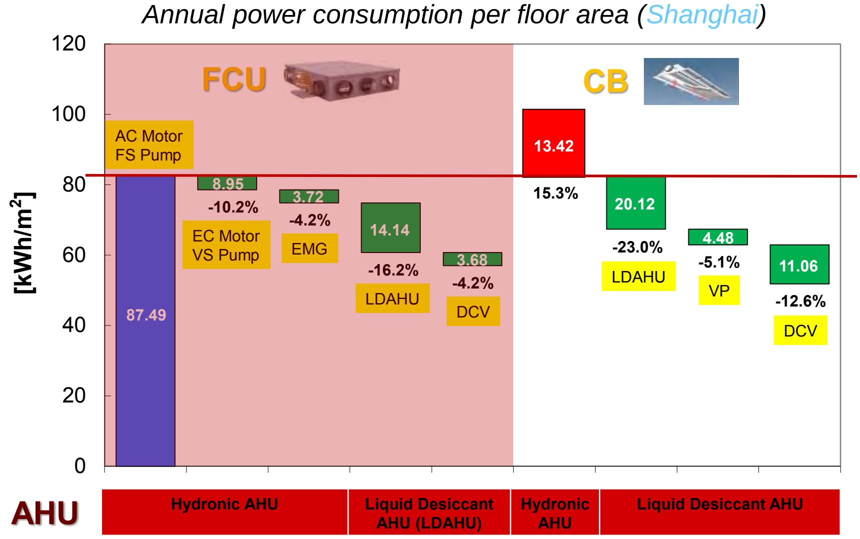
OFFICE 2: LOW PERFORMANCE ENVELOPE

Annual power consumption per floor area (Shanghai)



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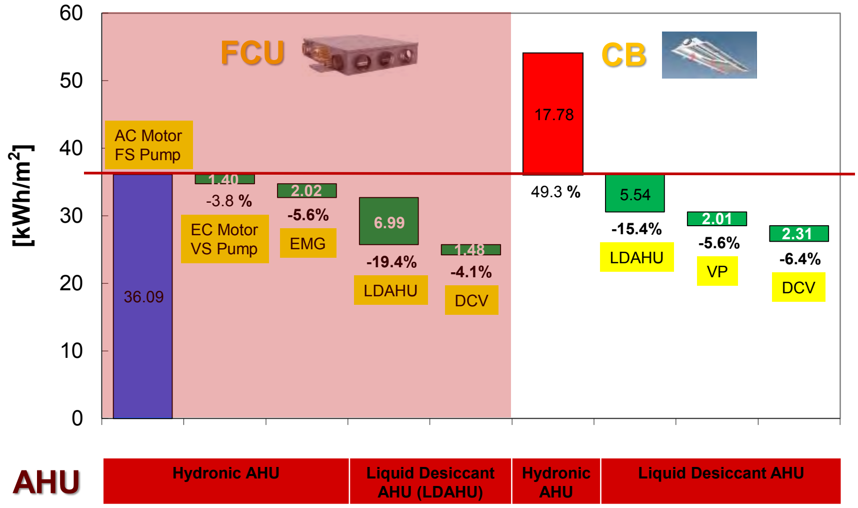
HOTEL (LOW PERFORMANCE ENVELOPE)

Annual power consumption per floor area (Shanghai)



CASE STUDY: CHILLED BEAM VS FAN-COIL

Conclusions and recommendations

In Shanghai climate, office and hotel applications, current chilled beam system is not as energy efficient as Fan Coil Unit system due to

- Increased fresh air requirement to remove latent load (offset heat pump efficiency improvement)
- Low capacity density per primary air flow

Current chilled beam technology may have energy saving potential in Europe where larger ventilation is required

Design improvement needed:

- Increase capacity density per primary air flow (nozzle design, etc.)
- Add capability to hold moisture condensate
- Use return air as part of primary air flow
- Variable primary air flow technology
- Demand control ventilation

WHAT'S NEXT: SOME THOUGHTS

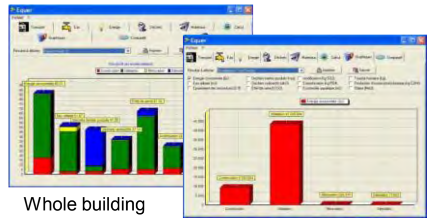
Rigorous implementation of environmental design: beyond energy

Life cycle analysis for buildings (EQUER, GaBi4 softwares...)

Actual integration of diverse equipment at the product design

University degrees on sustainability disciplines

Output: Net-zero energy buildings



Whole building LCA: EQUER

Integration

University Programs

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IUB/OCA Building: A High Performance Building Case Study

Xiaohui "Joe" Zhou, PhD, PE
Iowa Energy Center

2013 LBNL CERC-BEE Forum
Berkeley, CA
July 17, 2013

redefining innovation

Acknowledgement

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  - IUB/OCA Office
  - Iowa Department of Administrative Services Capital Complex Facility Management
  - BNIM Architects
  - KJWW Engineering Consultants
  - The Weidt Group
- Building energy data monitoring, compilation, and analysis by Iowa Energy Center staff & Iowa State University students
  - Dr. Ran Liu
  - Scott Lochhead, PE
  - Robert Milbrandt, PE
  - Mengmeng Liu

All photos courtesy of Dr. Ran Liu, Iowa Energy Center, unless otherwise noted.

Outline

- Introduction of IUB/OCA Building
- Verified Building Energy Performance
- Integrated Building Design Process
- Building Operations and Human Behavior Impact

Introduction

IUB/OCA Office Building

Introduction

Photo courtesy of Google

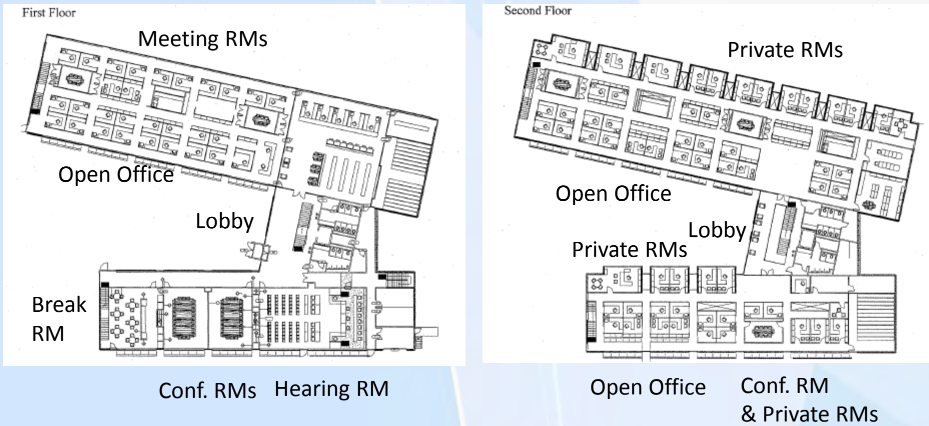
Photo courtesy of IUB

Introduction

- Iowa Utilities Board/Office of Consumer Advocate (IUB/OCA)
- 44,460 sq. ft. office building located in Des Moines, Iowa
- ~90 employees
- Construction cost was approximately $10 million dollars
- Building has been occupied since January 2011
- First LEED Platinum government agency building in Iowa
- Goal: serve as an example of the state's commitment to the development of facilities that are energy and fiscally efficient

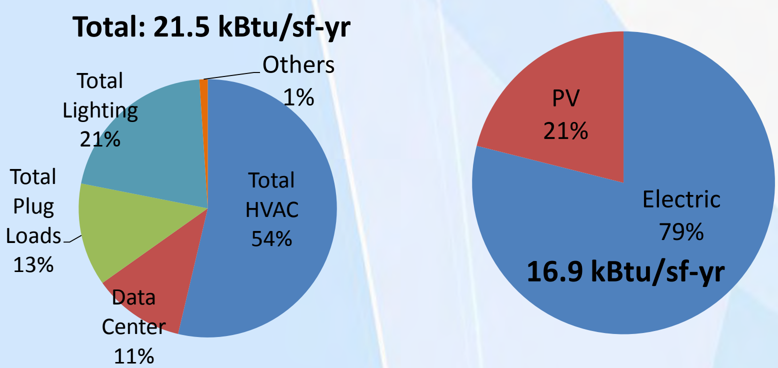
Introduction

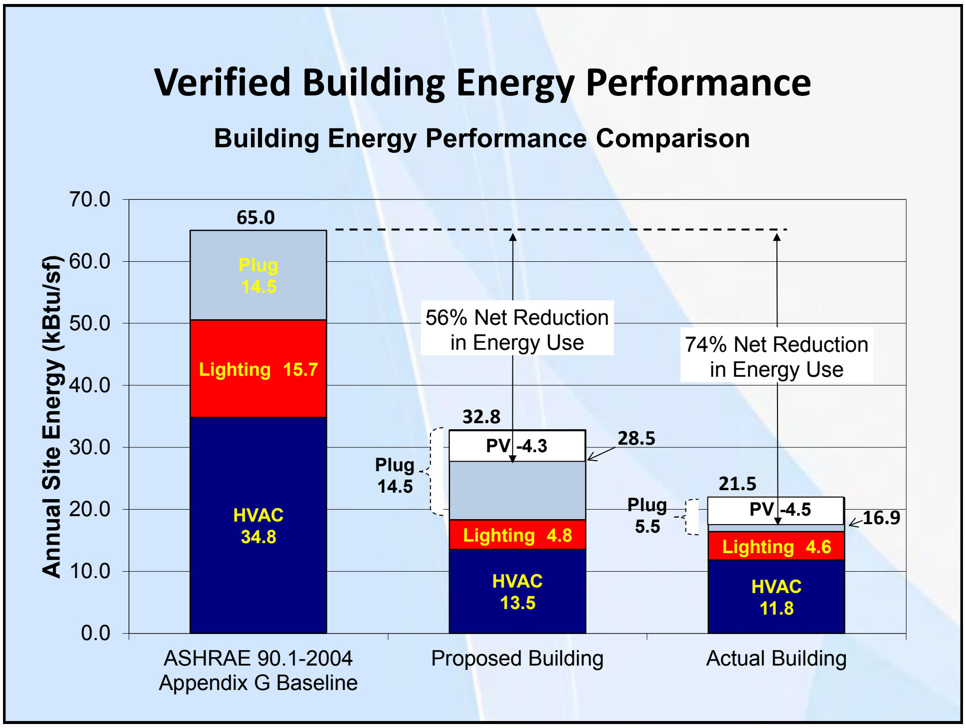
- Building Plans

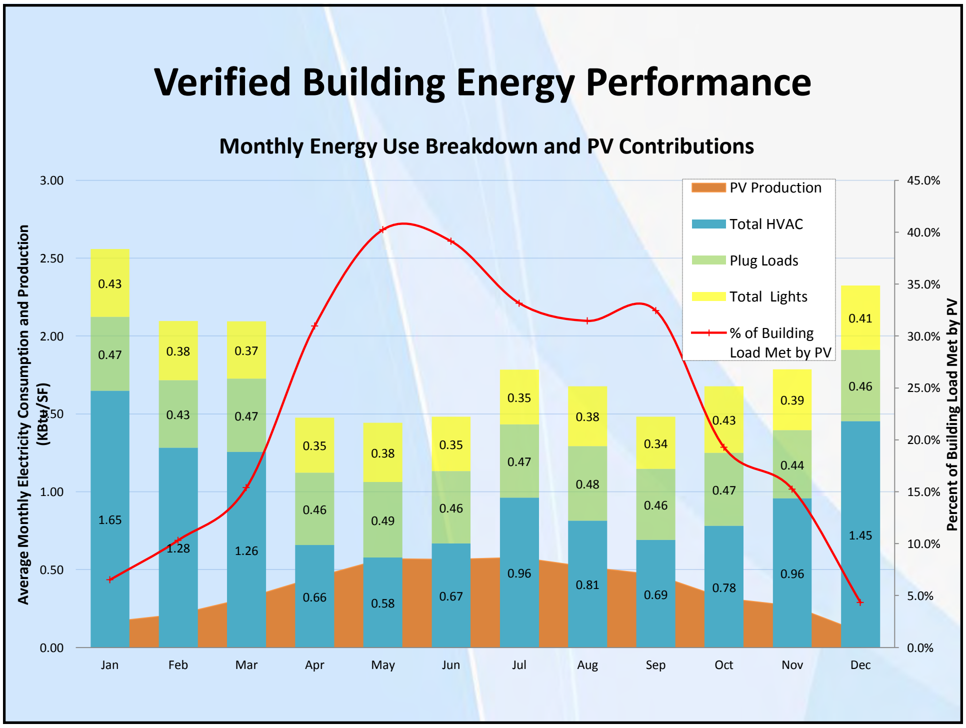


Verified Building Energy Performance

- Iowa Energy Center collected 5 min. and 15 min. building energy data from April 1, 2012 to March 31, 2013. Overall 1000+ points collected daily.
- Energy Star Rating: 98 (out of 100)




Verified Building Energy Performance
Building Energy Performance Comparison
Annual Site Energy (kBtu/sf)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
65.0
Plug 14.5
Lighting 15.7
HVAC 34.8
56% Net Reduction in Energy Use
74% Net Reduction in Energy Use
32.8
PV -4.3
28.5
Plug 14.5
Lighting 4.8
HVAC 13.5
21.5
PV -4.5
16.9
Plug 5.5
Lighting 4.6
HVAC 11.8
ASHRAE 90.1-2004 Appendix G Baseline
Proposed Building
Actual Building


Verified Building Energy Performance
Monthly Energy Use Breakdown and PV Contributions
Average Monthly Electricity Consumption and Production (KBtu/SF)
Percent of Building Load Met by PV
PV Production
Total HVAC
Plug Loads
Total Lights
% of Building Load Met by PV
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Total Lights: 0.43 0.38 0.37 0.35 0.38 0.35 0.35 0.38 0.34 0.43 0.39 0.41
Plug Loads: 0.47 0.43 0.47 0.46 0.49 0.46 0.47 0.48 0.46 0.47 0.44 0.46
Total HVAC: 1.65 1.28 1.26 0.66 0.58 0.67 0.96 0.81 0.69 0.78 0.96 1.45
0.00 0.50 1.00 1.50 2.00 2.50 3.00
0.0% 5.0% 10.0% 15.0% 20.0% 25.0% 30.0% 35.0% 40.0% 45.0%

Integrated Building Design Process

- Key project energy goals:
  - EUI of 28.0 kBtu/SF per year, 60 percent better than ASHRAE 90.1-2004
  - 72 to 74 Deg F zone temperatures and maximum relative humidity of 50%
- Design team and building owner worked together with the project energy goals in mind
- Energy modeling (using DOE-2) was integrated in the design process when selecting best design options to meet the aggressive energy performance goals
- Multitude of strategies integrated together to achieve a building of exemplary energy performance

Integrated Building Design Process

- Energy Efficiency Strategy Options

Strategy ID	Envelope Insulation Strategies	Code / Typical	Strategy Level	Notes
EWC00	Code wall insulation	R-8.1	R-8.1	
EWC01	R-16 wall insulation	R-8.1	R-16	
EWC02	R-20 wall insulation	R-8.1	R-20	
EWC03	R-23 wall insulation	R-8.1	R-23	
EWC04	Pre-cast insulated panel, R-16.3	R-8.1	R-16.3	
EWC05	Pre-cast insulated panel, R-23	R-8.1	R-23	
ERC00	Code roof insulation	R-15.9	R-15.9	
ERC01	R-24 roof insulation	R-15.9	R-24	
ERC02	R-30 roof insulation	R-15.9	R-30	
ERC03	R-40 roof insulation	R-15.9	R-40	
ERC04	R-50 roof insulation	R-15.9	R-50	
EWRF1	White roof	Std roof	White roof	

Strategy ID	Window Glazing Strategies	Unit U-Factor	COG U-Factor	SHGC	Visible Trans.
WGA01	Code: 30 to 40% win/wall ratio	0.57	N/A	0.39	0.39
WGB01	All: Solarban 60 clear	0.42	0.29	0.38	0.70
WGC01	All: Solarban 70 clear	0.42	0.29	0.27	0.62
WGD01	All: Solarban 80 clear	0.42	0.29	0.24	0.47
WGE01	All: VE2-2M	0.42	0.29	0.31	0.60
WGF01	All: Solexia x S500	0.48	0.35	0.45	0.64
WGG01	All: PPG Sungate 500 clear - air fill	0.48	0.35	0.62	0.74
WGH01	All: 3 element Visionwall - clear	0.26	0.20	0.29	0.49
WGI01	All: PPG Sungate 500 clear - argon fill	0.44	0.31	0.62	0.74
WGJ01	North: PPG Sungate 500 clear - air fill	0.48	0.35	0.62	0.74
(contd)	South: Solarban 60 clear	0.42	0.29	0.38	0.70
WGL01	North: Viracon VE1-85	0.44	0.31	0.54	0.76
(contd)	South: Solarban 80 clear	0.42	0.29	0.24	0.47

Strategy ID	Window Design Strategies	Sill / Head Ht.	Notes
WGA17	Exterior shading devices		
WGA16	Reduced sill height for punched opening (4'6" to 4')		

Energy Efficiency Strategy Report courtesy of The Weidt Group

Integrated Building Design Process

- Energy Efficiency Strategy Options

Strategy ID	Daylighting Control Strategies	Region of building	Daylight Control	Notes
DGA01	Open office automatic stepped daylighting		Fluorescent Stepped	
DGA02	Open office automatic dimming daylighting		Fluorescent Dimming	
DGA03	Open office automatic dimming daylighting w/ cutoff		Fluorescent Dimming	
DGA04	Private office automatic stepped daylighting		Fluorescent Stepped	
DGA05	Private office automatic dimming daylighting		Fluorescent Dimming	
DGA06	Private office automatic dimming daylighting w/ cutoff		Fluorescent Dimming	
DGA07	Conference automatic stepped daylighting		Fluorescent Stepped	
DGA08	Conference automatic dimming daylighting		Fluorescent Dimming	
DGA09	Conference automatic dimming daylighting w/ cutoff		Fluorescent Dimming	
DGA10	Lobby / Corridor automatic stepped daylighting		Fluorescent Stepped	
DGA11	Lobby / Corridor automatic dimming daylighting		Fluorescent Dimming	

Strategy ID	Lighting Control Strategies	Peak reduction	Annual hrs reduction	Notes
LCCI1	Corridor occupancy sensor control	5%	20%	
LCST1	Storage / Copy Room occupancy sensor control	25%	40%	
LCRR1	Restroom occupancy sensor control	35%	55%	
LCME1	Mech/ elec occupancy sensor control	40%	60%	
LCOO1	Open office occupancy sensor control	0%	40%	
LCPO1	Private office occupancy sensor control	15%	40%	
LCPO2	Private office dual level occupancy sensor control	20%	45%	
LCPO3	Private office dual level switching	10%	10%	
LCCN1	Conference occupancy sensor control	25%	40%	
LCCN2	Conference dual level switching	15%	15%	
LCCN3	Conference manual dimming	25%	25%	

Strategy ID	Lighting Design Strategies	Old Code W/sf	New Code W/sf	Strategy max W/sf	Lamps/ fixture
L02CG	Building wide at 1 w/sf (including task)	1.30	1.30	1.00	3
L03CG	Building wide at 0.75 w/sf (including task)	1.30	1.30	0.75	2
L04CG	Building wide at 0.5 w/sf (including task)	1.30	1.30	0.50	2

Energy Efficiency Strategy Report courtesy of The Weidt Group

Integrated Building Design Process

- Energy Efficiency Strategy Options

Strategy ID	Lighting Technology Strategies	Base System	Alternate System	Percent Savings	
LTE01	Super T-8 lamps	Std T8	Super T8	15%	
LTE02	Extra efficient ballasts	Std ballast	EE ballast	5%	
LTE03	Efficient fixtures	Std fixture	Eff fixture	TBD	
LTE04	High Kelvin Lamps	Std Kelvin	High Kelvin	TBD	
LTE05	High reflective interior surfaces	Std MH	Ceramic MH	TBD	

Strategy ID	Heat Pump Efficiency Strategies	Code EER/COP	Strategy EER/COP	Reference Size Tons	
MGH01	High efficiency ground heat pump, water to air - stage 1	13.40/3.10	14.30/3.50	0.0 to 11.3	
MGH02	High efficiency ground heat pump, water to air - stage 2	13.40/3.10	17.00/3.50	0.0 to 11.3	
MGH03	Ground heat pump, VFD pumping	const speed	VFD		
MGH05	Ground heat pump, VFD pumping, fans cycle	const speed	VFD		
MHP02	Water to water heat pumps	13.40/3.10	14.30/3.50		

Strategy ID	Fan and Pump Strategies	Code Level	Strategy Level	Notes
MMT03	Premium efficiency supply/return fan motors	EPACT	Premium	
MMT04	Premium efficiency pump motors	EPACT	Premium	

Strategy ID	Conditioning of Outside Air Strategies	Code Level	Strategy Level	Notes
MOA02	CO2 control of outside air	No control	CO2 control	
MOA09	Underfloor air delivery system	Overhead	Underfloor	
MOA04	Heating setpoint 70 , cooling setpoint 74	68 / 78	70 / 74	
MOA05	4 day work week, 10 hour days	5 Day week	4 day week	
MHRT1	Total heat recovery	No recovery	70% Sensible	60% latent

Strategy ID	Plug Load Strategies	Code Level	Strategy Level	Notes
PLG03	Plug load occupancy sensor control of office equipment	Manual	Occup sensor	Green outlet
PLG04	Remove data center	8 kW	1 w/sf	Changed to copy/storage

Energy Efficiency Strategy Report courtesy of The Weidt Group

Integrated Building Design Process

- Selection of EE Strategies:
  - Step 1: Each strategy was simulated *individually* and compared incremental improvement to the ASHRAE 90.1-2004 code compliant model
  - Step 2: Bundle identification
    - Bundle 1 – combination of strategies identified by the design team
    - Bundle 2 – Bundle 1 with the changes from water-to-water heat pump to 2-stage water-to-air heat pump, and remove underfloor air delivery system
    - Bundle 3 – Bundle 2 with the change of removing on-site data center
    - Bundle 4 – Bundle 2 with the change of all glazing to Visionwall glazing
    - Bundle 5 – Bundle 2 with the change of allowing heat pump fans to cycle
  - Step 3: Owner and design team evaluated economic value (including payback with energy construction incentive) and construction cost for 5 bundle options

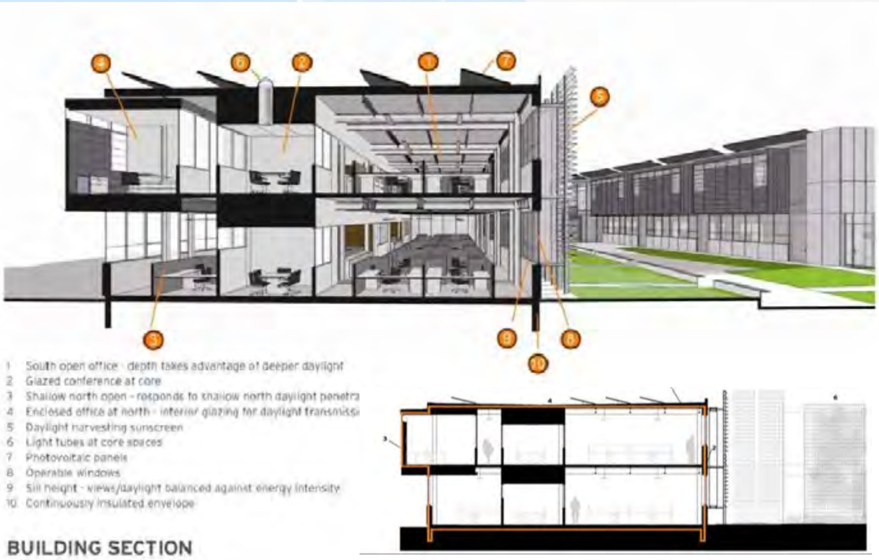
Integrated Building Design Process

- Final Design Key Features:
  - High performance building envelope eliminates thermal bridging
  - High performance glass, tuned to each elevation's exposures
  - Proper solar orientation
  - Skylights at the building core to utilize daylight
  - Daylight-harvesting sunscreens
    - Block summer heat gain while allowing winter passive heating
  - Geothermal field with dual-stage heat pumps
  - Total energy recovery unit
  - Roof-mounted 45 kW photovoltaic array providing on-site renewable energy production and peak demand reduction

Integrated Building Design Process

- Building Envelope:
  - White precast concrete insulated wall panel – total assembly R-32
  - Total roof assembly R-30 – white roof with reflectance of 65%
  - Insulation wrapping uninterrupted from the roof into the thermal layer of the wall panel, down and around the foundation system, and across the underside of the slab on grade
  - Overall wall-to-window ratio 34.5%

Integrated Building Design Process



Graphics courtesy of BNIM

Integrated Building Design Process

- Lighting and Daylighting:
  - East-west orientation, a narrow north-south building configuration provides the most appropriate daylighting and natural ventilation opportunities
  - Daylight-harvesting sunscreens on two south-facing walls block summer heat gain while allowing winter passive heating
  - Skylights at the building core
  - Low furniture panels with translucent upper panels enhanced daylighting utilization - 70 percent of the time light level at work surface met requirements without artificial lights
  - Automatic dimming daylighting control in exterior rooms and open spaces, design lighting level 30~40 Foot Candles
  - Occupancy sensors control electric lighting in interior rooms

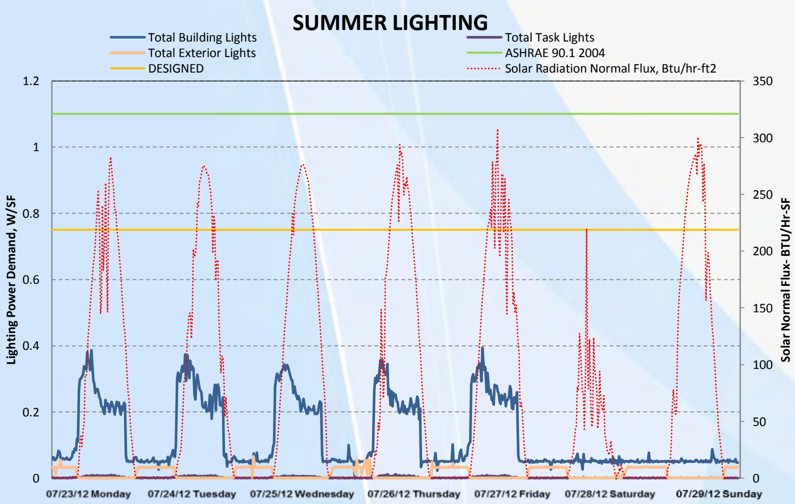
Integrated Building Design Process

Graphics courtesy of BNIM

Integrated Building Design Process

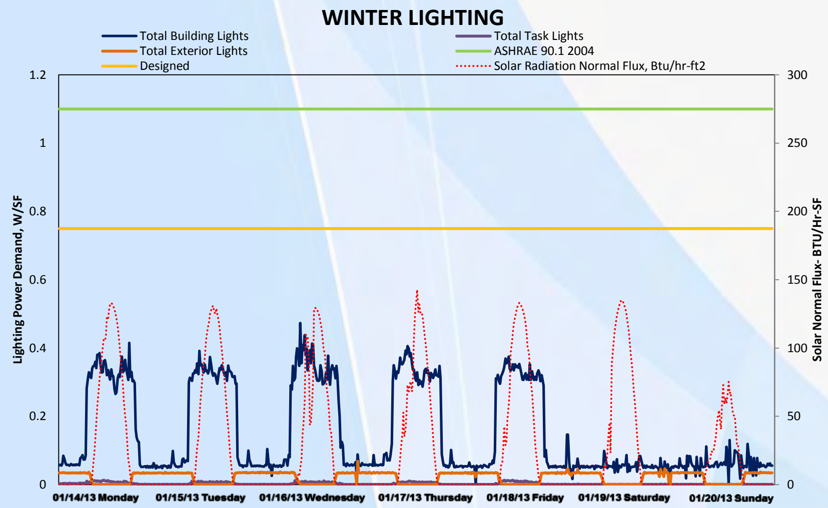
Integrated Building Design Process

- Lighting Power Density:



Integrated Building Design Process

- Lighting Power Density:

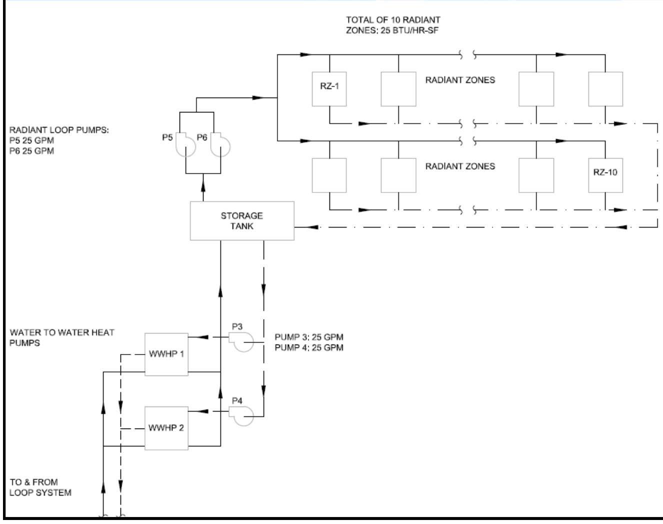


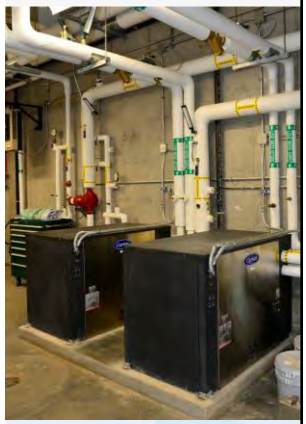
Integrated Building Design Process

- Mechanical System:
  - Space is conditioned with a high efficiency ground source heat pump system with dedicated outside air system using total energy recovery unit
    - Ground loop - single loop, VFD control. 420 gpm, 85' of head.
    - 42 water-to-air heat pumps from 1~4 ton units at 14.5~18.7 EER for cooling, and 3.1~3.8 COP for heating
    - Total ERV 6,025 cfm of supply and exhaust air. 70% sensible and 60% latent heat effectiveness
    - Bypass controls. Summer effectiveness of 62%, winter effectiveness of 68%
  - Premium fan and pumps
  - CO_2 reset control of minimum outside air level by occupancy
  - Occupancy sensor control of plug load office equipment

Integrated Building Design Process

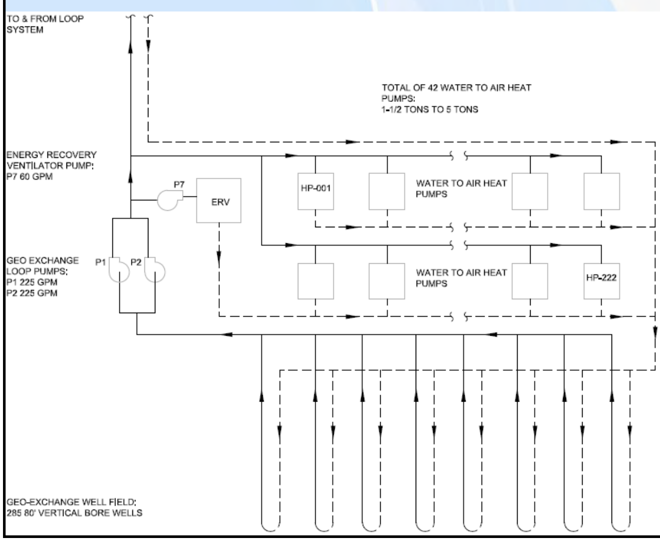
- Mechanical System:





Integrated Building Design Process

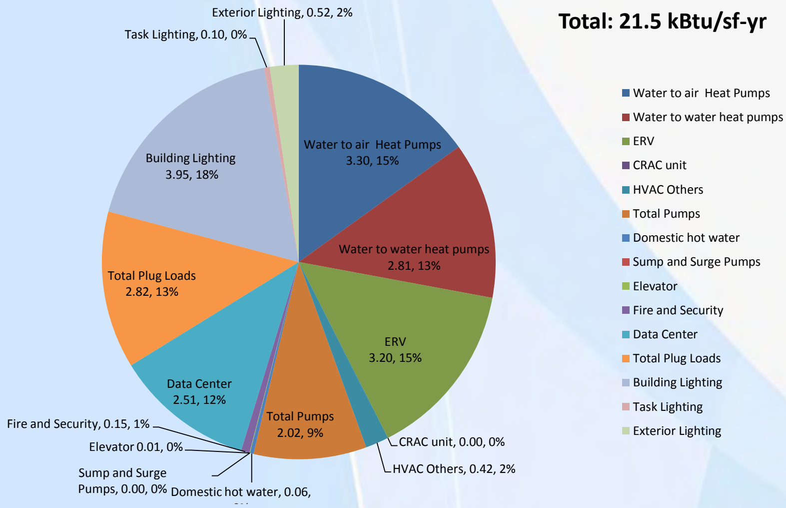
- Mechanical System:



Integrated Building Design Process

➢ Energy Breakdown:

Total: 21.5 kBtu/sf-yr



Building Operations and Human Behavior Impact

Building Operational Parameters	Design Model	Current Building
Number of Occupants (FTE equivalent hours)	90	
Regular Occupants: Hours of Occupancy	6 AM to 5:30 PM, Monday to Friday	
Number of Servers in data center	8 kW peak load	
Number of PC Workstations, this building	90	
Percent of workstations laptops	0%	
Percent of workstations LCD monitors	100%	
PCs, hours per day typical use	11.5 hours	
Percentage of machines used on a typical work day	100%	
Lighting Operational Parameters	**Design Model**	**Current Building**
Monday-Friday, Central Lighting Start Time	6:00 AM	6:30
Monday-Friday, Central Lighting Stop Time	5:30 PM	6:00 PM
Percent of lighting power left ON 24/7	Egress Lighting, 5%	
Saturday, Central Lighting Start Time	Off	OFF
Saturday, Central Lighting Stop Time	Off	OFF
Sunday, Central Lighting Start Time	Off	OFF
Sunday, Central Lighting Stop Time	Off	OFF
Is the Automatic Lighting Control functional in this building?	Yes	Yes
Exterior Lighting start time	dusk	dusk
Exterior lighting stop time	dawn	dawn
System Operational Parameters	**Design Model**	**Current Building**
Zone Heating Thermostat Setpoint, Occupied	68	70
Zone Heating Thermostat Setpoint, Unoccupied	65	68
Zone Cooling Thermostat Setpoint, Occupied	78	76
Zone Cooling Thermostat Setpoint, Unoccupied	85	80
Monday-Friday, Fan Start Time	6:00 AM	6:30
Monday-Friday, Fan Stop Time	5:30 PM	5:30 PM
Saturday, Fan Start Time	cycle on to meet setback	cycle on to meet setback
Saturday, Fan Stop Time	cycle on to meet setback	cycle on to meet setback
Sunday, Fan Start Time	cycle on to meet setback	cycle on to meet setback
Sunday, Fan Stop Time	cycle on to meet setback	cycle on to meet setback
Is the Demand Ventilation Control Reset Control functional?	Yes	Yes

Building Operations and Human Behavior Impact

- Building operations are as designed; no major changes
- Operable windows:
  - Half of the interior space has operable windows within 15 feet of most occupants' work area
  - Operation sequence:
    - Building automation system monitors outside air condition and sends emails to occupants notifying to open/close window when certain conditions are met
    - Occupants open/close windows as instructed
  - People like fresh air and follow instructions closely
  - Some occupants may be reluctant to open window due to environmental smell or allergy
- Demand Controlled Ventilation (DCV) strategy

Building Operations and Human Behavior Impact

- Plug loads control:
  - Occupants buy into energy efficiency concept and don't bring unnecessary energy-consuming items to the office (e.g. space heaters)
- Occupant comfort:
  - Most occupants feel very comfortable working in the building
  - Biggest change is the lighting condition – very bright even on cloudy days; almost never needed to use task lights. Became accustomed to the lighting after one year occupancy
  - Some occupants report glare and prefer individual control of personal environment
  - Conference rooms sometimes feel stuffy due to occupancy sensor controlled heat pumps being on only when people enter room

iowa energy center

Questions and Discussion

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redefining innovation

Hierarchical control and planning of high performance buildings

Mohsen A Jafari

Rutgers University

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Team

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  - Khashayar Mahani
  - J. Zhu
- In collaboration with
  - Dr. Y. Lu, Siemens
  - Dr. J. Brouwer, UC-Irvine

Background (1)

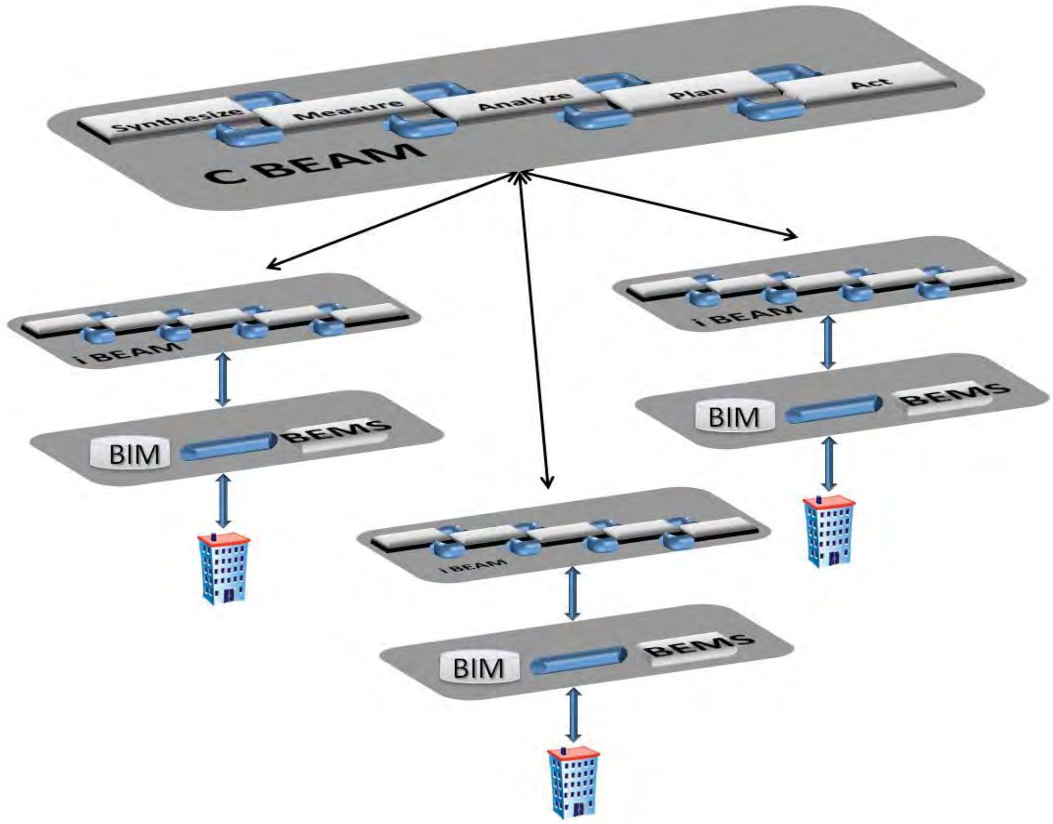
- In typical residential communities, commercial and industrial applications, portfolio of building assets are characterized with varying construction types, age of assets and states of repair.
- The energy efficiency and performance of a building begins to deteriorate as soon as it is placed in service, irrespective of whether it has been designed and commissioned for "optimal performance."
- Performance degradation accelerates over time as the building and the components of its systems age.
- Improved O&M practices can save much of this cost and reduce environmental impacts from building operations.

3

Background (2)

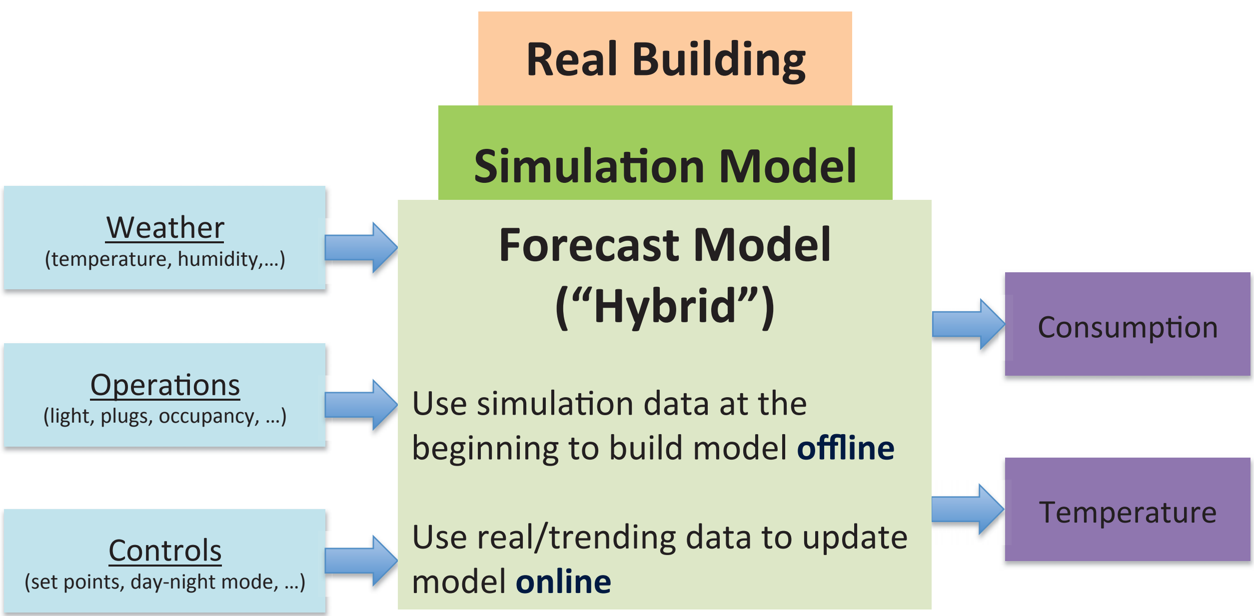
- Buildings are complex stochastic dynamical systems requiring control and planning at different time scales:
  - Real time control, e.g., motor control at HVAC level - deterministic
  - **Short term control, e.g., set point control, lighting control - stochastic due to weather changes, occupancy fluctuations, light industrial load;**
  - **Long term planning and control, e.g., planning of asset maintenance - stochastic due to asset failures and degradation as well as short term factors**

Overall Hierarchical View



5

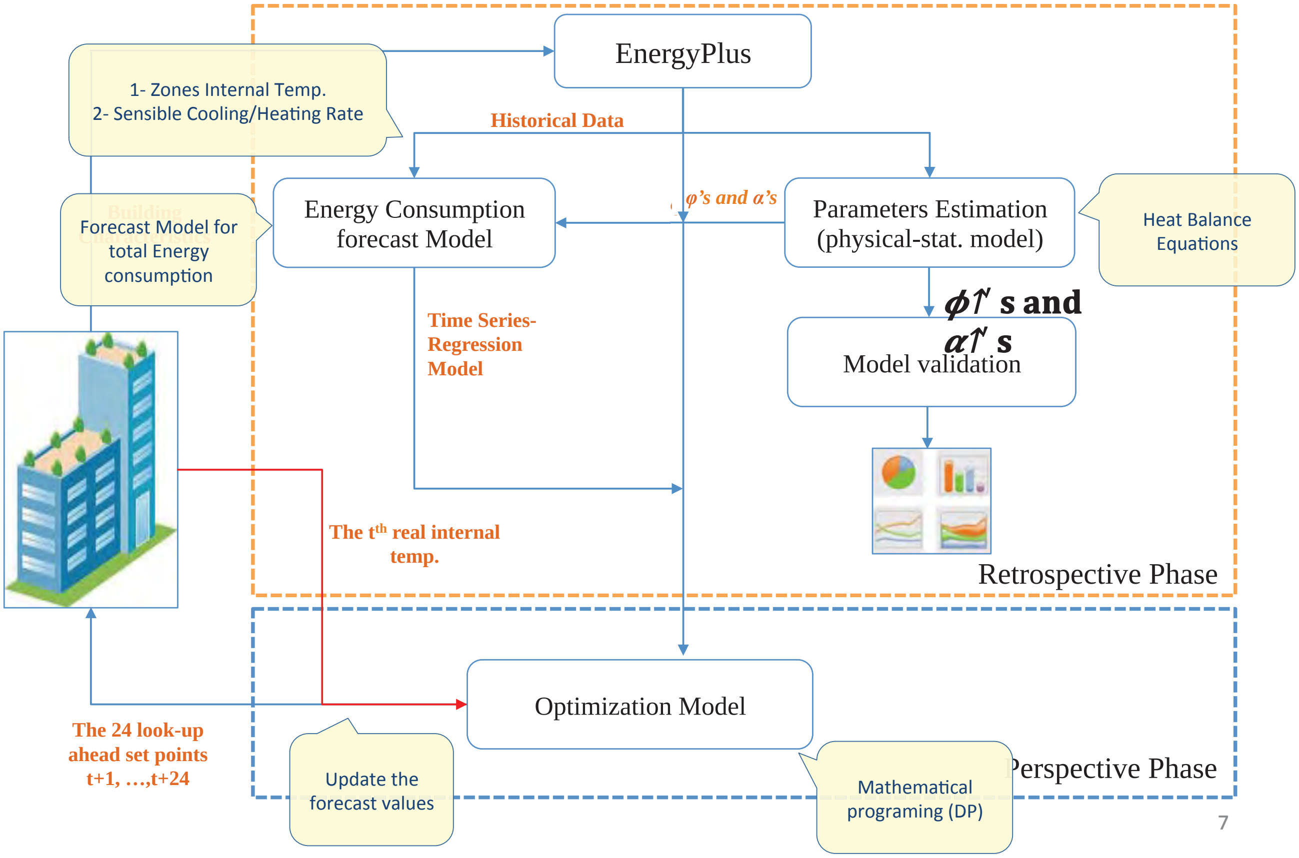
Load forecasting and MPC



- By separating offline and online processes, offline engineering effort and online computational burden are minimized.

6

Physical-Statistical Model – the Big Picture



Physical-Statistical Model – Parameter Estimation

effective power rate

$$T_{in}^{t+1}(i) = T_{in}^{t}(i) + \alpha_i R^t(i) + \varphi_i \left(T_{in}^{t}(i) - T_{ext}^{t}(i)\right) + \varepsilon^t$$

1

i_{th} zone

Estimated Using the Least Square Error Technique

Effect of other parameters + random effect

$$Q_i = \sum_{t=1}^{N} \left(T_{in}^{t+1}(i) - \hat{T}_{in}^{t+1}(i)\right)^2$$

$$\frac{\partial Q_i}{\partial \alpha_i} = 0 \qquad \boxed{\hat{\alpha}_i = \frac{\sum_{i=1}^{N} R^t(i).\Delta T_i^t \sum_{i=1}^{N} (\Delta\tau_i^t)^2 - \sum_{i=1}^{N} \Delta T_i^t.\Delta\tau_i^t \sum_{i=1}^{N} \Delta T_i^t.R^t(i)}{\sum_{i=1}^{N} R^t(i)^2 \sum_{i=1}^{N} (\tau_i^t)^2 - \sum_{i=1}^{N} (R^t(i).\Delta\tau_i^t)^2}}$$

$$\frac{\partial Q_i}{\partial \varphi_i} = 0 \qquad \boxed{\hat{\varphi}_i = \frac{\sum_{i=1}^{N} \Delta T_i^t.\Delta\tau_i^t \sum_{i=1}^{N} R^t(i)^2 - \sum_{i=1}^{N} \Delta T_i^t.R^t(i) \sum_{i=1}^{N} \Delta\tau_i^t.R^t(i)}{\sum_{i=1}^{N} R^t(i)^2 \sum_{i=1}^{N} (\tau_i^t)^2 - \sum_{i=1}^{N} (R^t(i).\tau_i^t)^2}}$$

1) Rogers, A., Maleki, S., Ghosh, S., and Jennings, N. R. Adaptive Home Heating Control Through Gaussian Process Prediction and Mathematical Programming, Agent Technologies for Energy Systems Workshop (ATES) at AAMAS 2011

Physical-Statistical Model – Energy Forecast Model

Time Series Regression Model

1- Weather
2- Zones Sensible Cooling Rate

Total Energy Consumption

$$y_t = \sum_{j=0}^{k} \beta_j x_{tj} + \varepsilon_t$$

Can Explain the effects of nonlinearity, missing variables and …

$$\varepsilon_t = \xi(\varepsilon_{t-1}, \ldots, \varepsilon_{t-q}) + \alpha_t,$$

White noise

Error Terms are assumed to follow ARIMA model

$$\phi_p(B)\Phi_P^s(B)\varepsilon_t = \theta_q(B)\Theta_Q^s(B)\alpha_t,$$

$$y_t = \underbrace{\sum_{j=0}^{k} \beta_j x_{tj}}_{\text{Regression part}} + \underbrace{\varepsilon_t \sum_{i=0}^{p}\sum_{j=0}^{P} (-1)^{i+j-1} \varphi_i \phi_j B^{i+s\times j} + \alpha_t \sum_{i=0}^{q}\sum_{j=0}^{Q} (-1)^{i+j} \theta_i \Theta_j B^{i+s\times j}}_{\text{Time Series part}}$$

How to Estimate Parameters : Cochrane-Orcutt Transformation

A Generalized Load Forecast Model

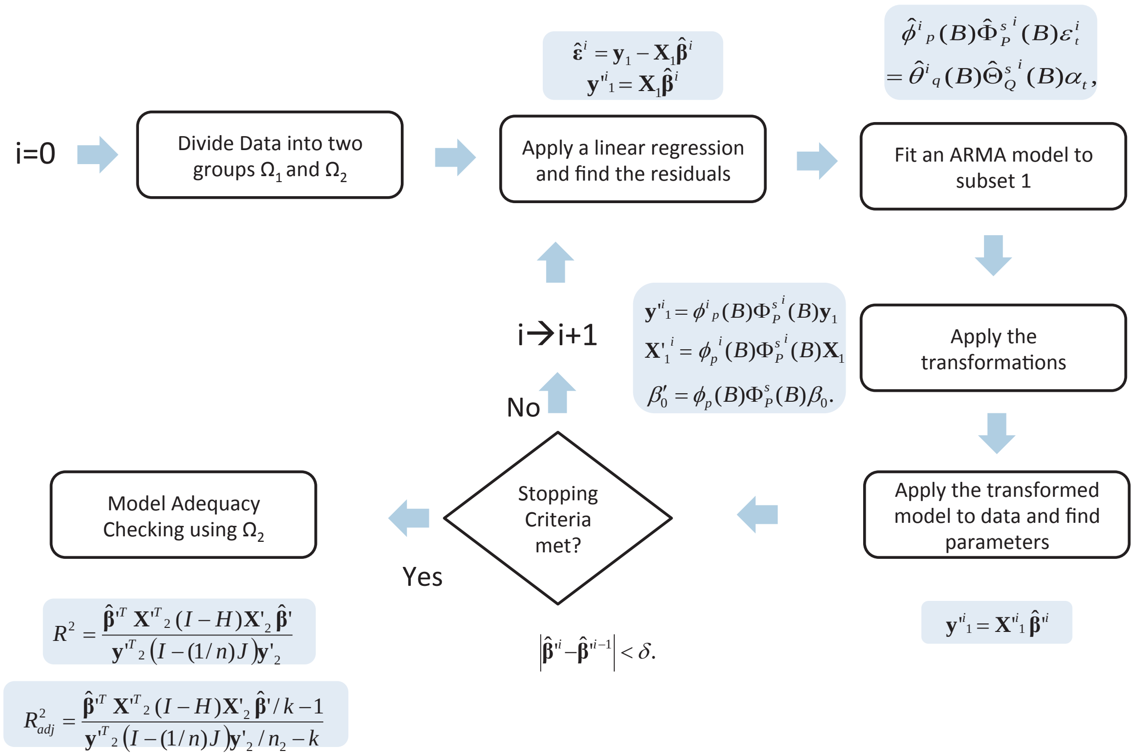
Building Energy Consumption =

$f\{$ Current & past Dry ambient Temperature | Current & past Relative Humidity | Current & past Occupancy | States of Equipment | Current & past Set points $\}$

$$y_t = \underbrace{\sum_{j=0}^{k} \beta_j x_{tj}}_{f(\mathbf{X}_t)} + \underbrace{\varepsilon_t \sum_{i=0}^{p}\sum_{j=0}^{P} (-1)^{i+j-1} \varphi_i \phi_j B^{i+s\times j} + \alpha_t \sum_{i=1}^{q}\sum_{j=1}^{Q} (-1)^{i+j} \theta_i \Theta_j B^{i+s\times j}}_{\varepsilon_t = \xi(\varepsilon_{t-1}, \ldots, \varepsilon_{t-q})} + \underbrace{\alpha_t}_{\text{Error Term}}$$

Model term

Computation Algorithm



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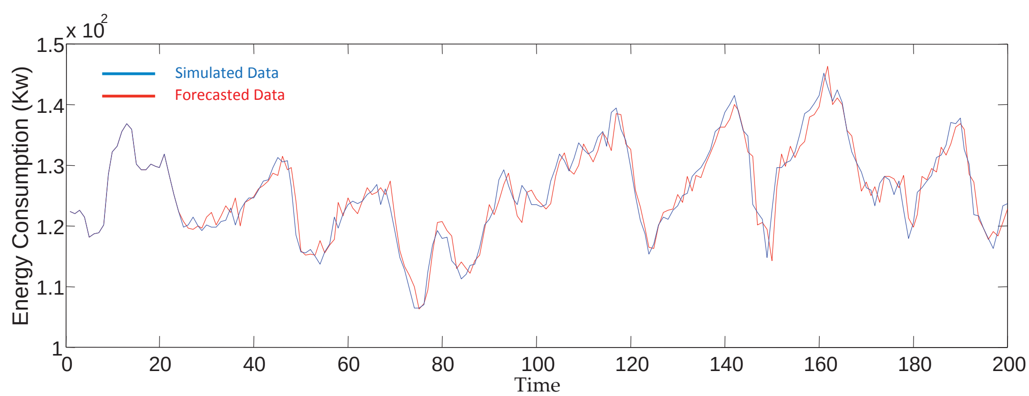
Physical-Statistical Model – Energy Forecast Model

Forecast Model Validation



$$R^2 = \frac{\hat{\boldsymbol{\beta}}^T\mathbf{X}^T{}_2(I-H)\mathbf{X}_2\hat{\boldsymbol{\beta}}}{\mathbf{y}^T{}_2(I-H)\mathbf{y}_2}$$

$R^2 = 95.7\%$

$$R^2_{adj} = \frac{\hat{\boldsymbol{\beta}}^T\mathbf{X}^T{}_2(I-H)\mathbf{X}_2\hat{\boldsymbol{\beta}}/k-1}{\mathbf{y}^T{}_2(I-H)\mathbf{y}_2/n_2-k}$$

$R^2_{adj} = 94.3\%$

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Physical-Statistical Model – Optimization Model

There are two Objective Functions

$$G_1(.) \equiv \underbrace{\sum_{k=1}^{N-1} c_{t+k}\, y_{t+k}\left(R^{t+k+1}, T_{ext}^{t+j}\right).\Delta t}_{\text{Usage Cost}} + \underbrace{\kappa.\max_{k \in t_d}\left\{y_{t+k}\left(R^{t+k+1}, T_{ext}^{t+j}\right)\Delta t\right\}}_{\text{Demand Charge Cost}}$$

$$G_2(.) \equiv \underbrace{\sum_{k=1}^{N}\left(p_1\left|\delta_{t+k}^{u}\right| + p_2\left|\delta_{t+k}^{l}\right|\right)}_{\text{Penalty for Exceeding Thermal Comfort Limits}} \quad 1$$

temperature violation above the upper / lower bound

Obj. Functions is not necessarily additive

1) Ma, Y.; Kelman, A.; Daly, A.; Borrelli, F.; , "Predictive Control for Energy Efficient Buildings with Thermal Storage: Modeling, Stimulation, and Experiments," Control Systems, IEEE , vol.32, no.1, pp.44-64, Feb. 2012

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Physical-Statistical Model – Optimization Model

- **Constraints**

1 Thermal Balance Equations

State Variable(s)

$$\hat{T}_{in}^{t+k+1}(i) = \hat{T}_{in}^{t+k}(i) + \hat{\alpha}_i.R^{t+k}(i) + \hat{\varphi}_i(\hat{T}_{in}^{t+k}(i) - \hat{T}_{ext}^{t+k}(i)),$$

2 Thermal Comfort Bounds

$$T_{min}^{t+k}(i) - \delta_{t+k}^{l} \leq \hat{T}_{in}^{t+k}(i) \leq T_{max}^{t+k}(i) + \delta_{t+k}^{u}, \quad k=1,2,\ldots,N\text{-}1 \text{ and } i=1,2,\ldots,Z$$

thermal comfort lower bound

thermal comfort upper bound

3 HVAC Capacity

$$\sum_{i=1}^{Z} R^{t+k}(i) \leq \theta_{\max}$$

Maximum Capacity

4 Initial Temperature

$$\hat{T}_{in}^{0}(i) = T_0, \quad i=1,2,\ldots,Z$$

$$\mathbf{R}^t \geq \mathbf{0} \quad \delta_{t+k}^{l} \geq 0, \ \delta_{t+k}^{u} \geq 0,$$

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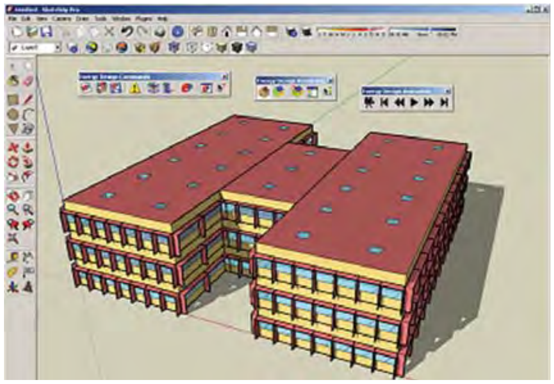
Example

12 zones selected

Phoenix Az
Offline: July 2009
Online: August 2009



The Medium Office Example by USDOE

Standard Model used in many researches

$$\hat{T}_{in}^{t+k}(i) = \hat{T}_{in}^{t+k-1}(i) + \boxed{\hat{\alpha}_i^k} R^{t+k-1}(i) + \boxed{\hat{\varphi}_i^k}\left(\hat{T}_{in}^{t+k-1}(i) - \hat{T}_{ext}^{t+k-1}(i)\right)$$

$$\hat{\alpha}_i^k = \hat{\alpha}_i \qquad \hat{\varphi}_i^k = \hat{\varphi}_i$$

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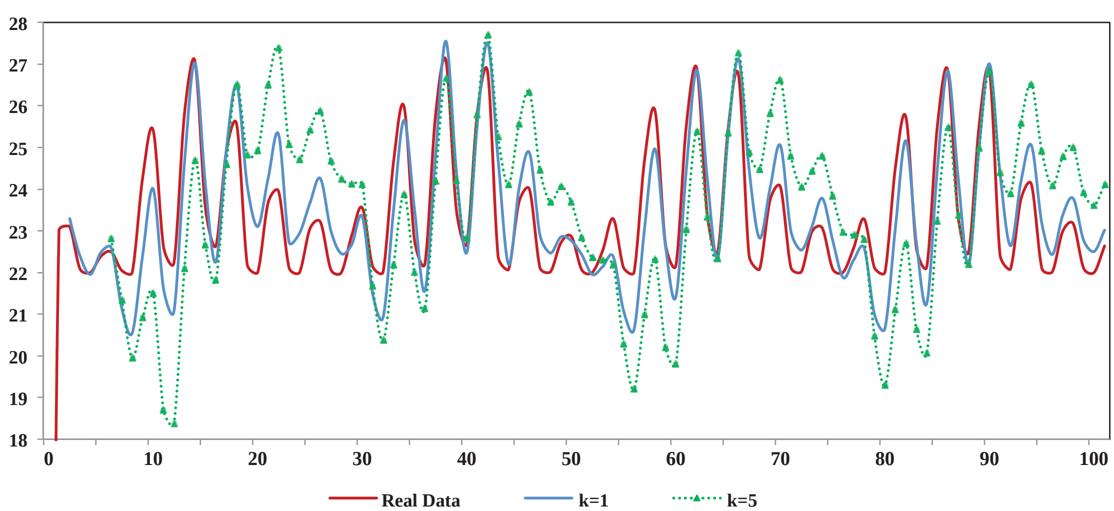
Forecast value vs simulated value for a zone



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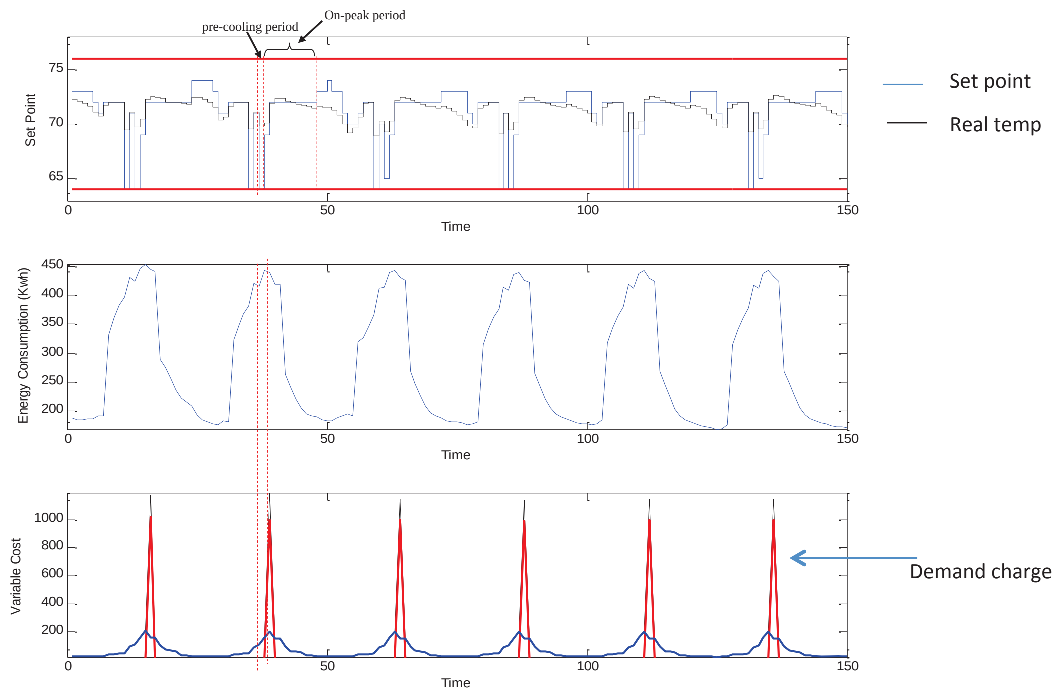
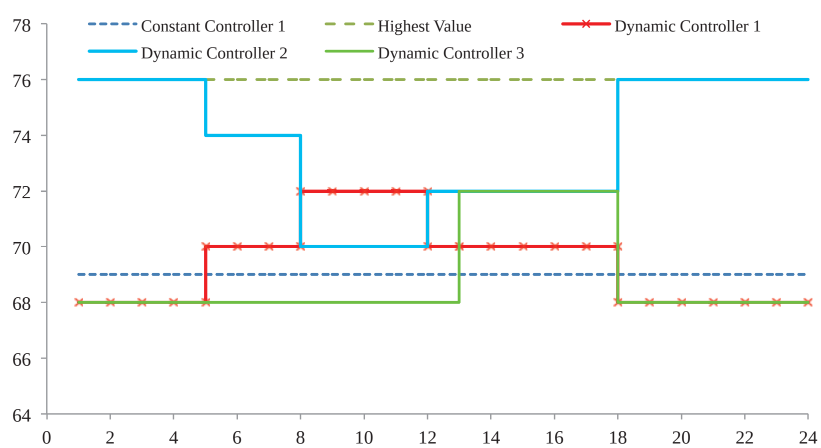
Optimal Control



Alternative Control Schemes



Proposed vs other control strategies

	Control Schemes						
	Proposed Scheme	Constant Controller 1	Constant Controller 2	Highest Value	Dynamic Controller 1	Dynamic Controller 2	Dynamic Controller 3
Daily Energy Consumption Cost	2450.12	2639.72	2508.73	2312.6	2622.52	2410.23	2658.90
Daily Usage Cost	1462.29	1613.27	1517.32	1399.2	1598.66	1457.31	1624.27
Daily Demand Charge	987.83	1026.45	991.41	913.37	1023.86	952.92	1034.63
Normalized Energy Cost, $G_1(.)$	0.20	0.27	0.26	0.25	0.24	0.20	0.24
Violation from Thermal Comfort Bounds, δ	0.06	0.02	0.02	0.81	0.02	0.45	0.02
Normalized Thermal Discomfort Penalty, $G_2(.)$	0.01	0.00	0.00	0.22	0.00	0.08	0.00
Total Combined Metric Value, G(.)	0.08	0.11	0.11	0.17	0.10	0.11	0.10

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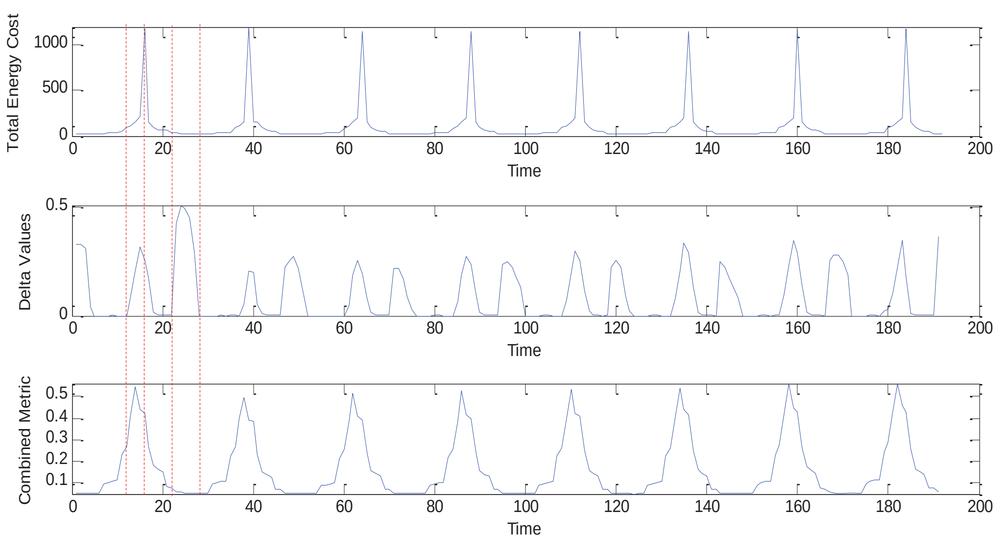
Individual objectives vs combined objective



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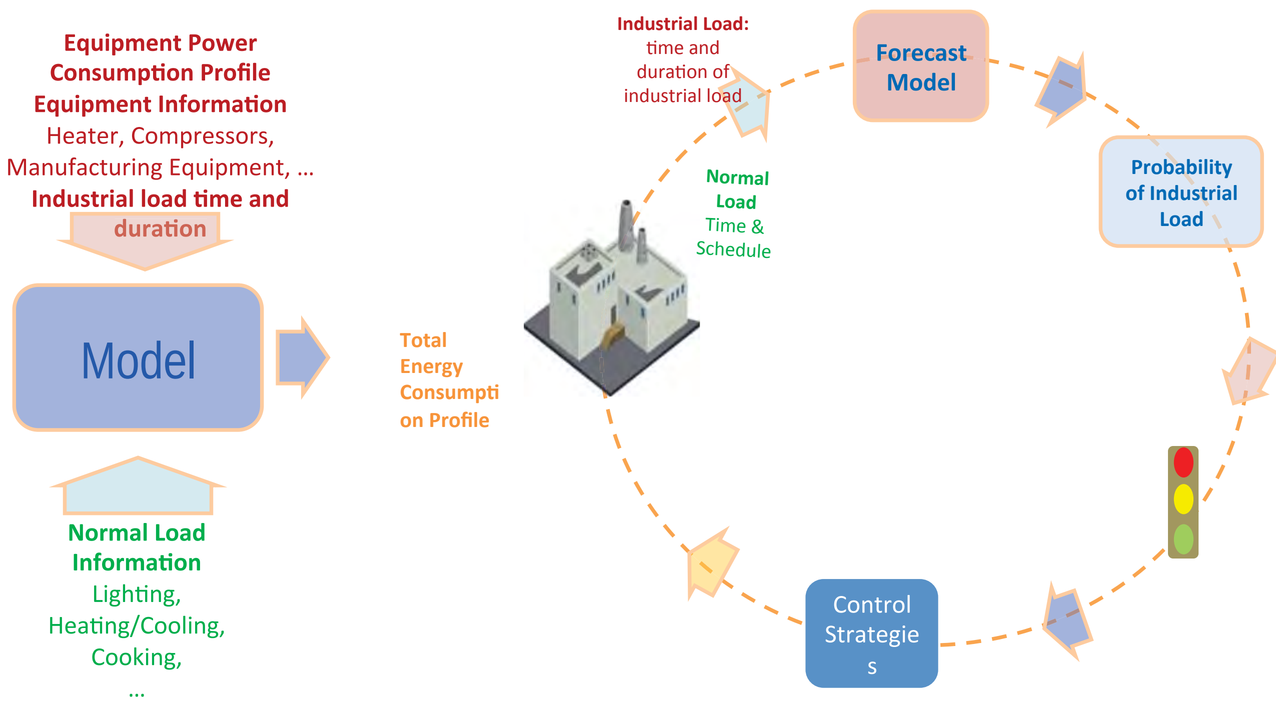
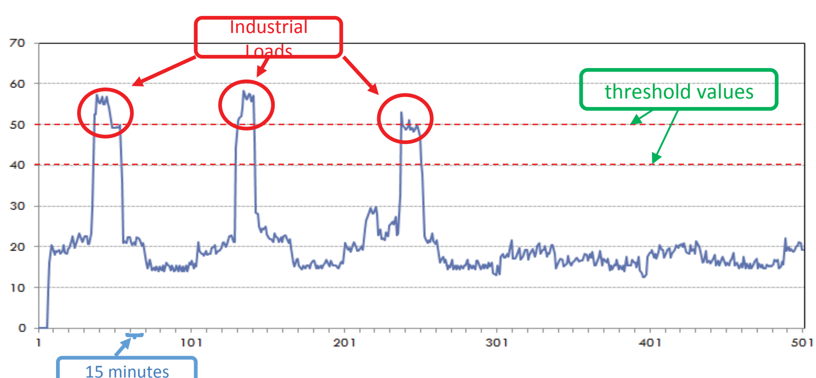
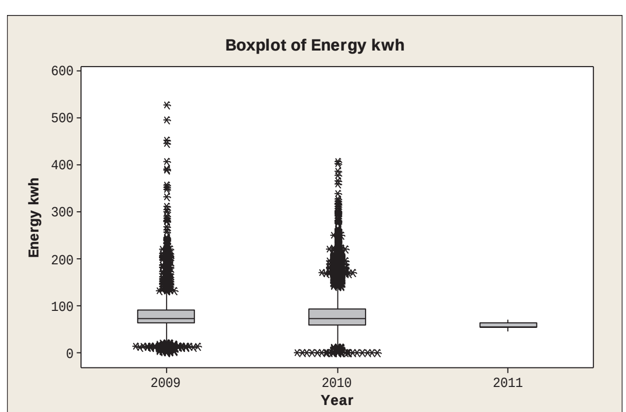
Industrial Load Forecasting & Demand Management

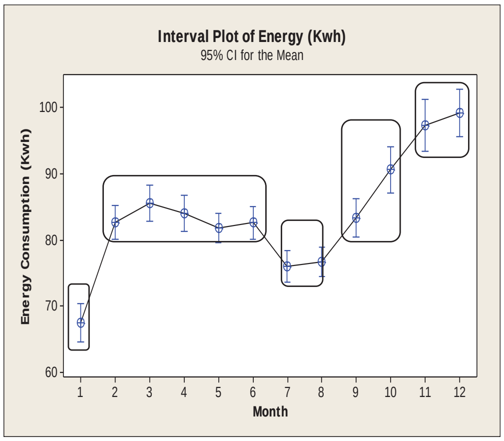


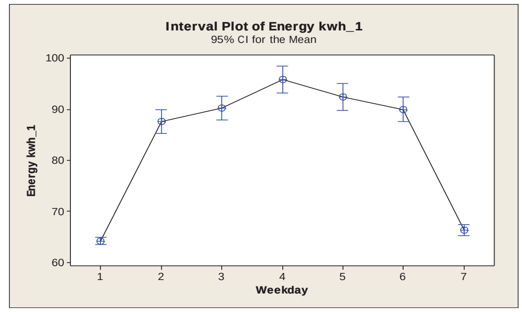
Case Study – XYZ Building

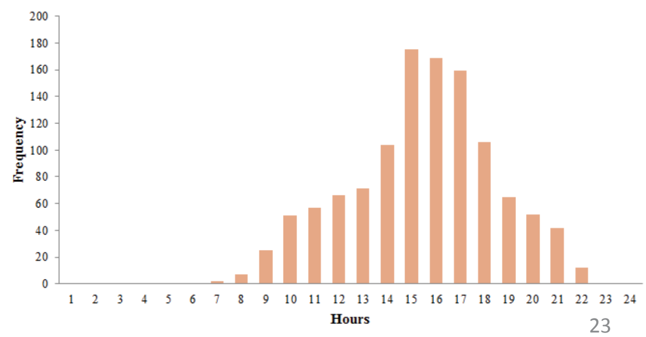




Frequency of Load depends on month, weekdays & hours







Prediction of Industrial Load using Logistic Regression

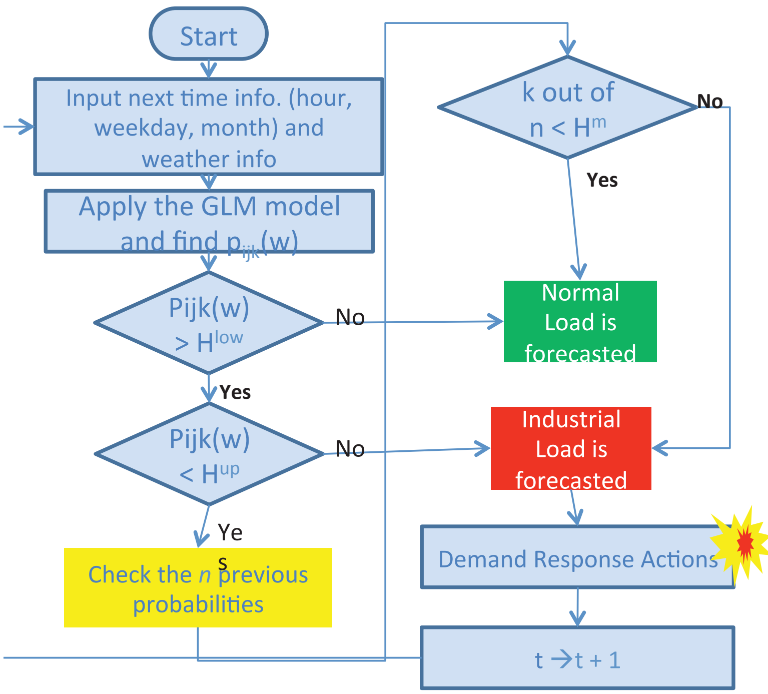
$$X_{ijk}(w) = \begin{cases} 0 & \text{Industrial load} \\ 1 & \text{Normal load} \end{cases}$$

$P_{ijk}(w)$: Probability of Having an Industrial load at the ith hour, jth day and kth Month and under weather condition of w

$$\hat{p}_{ijk}(w) = \frac{\exp(\mathbf{X}'\beta)}{1+\exp(\mathbf{X}'\beta)}$$

Indicator variables showing hour, day, month

A Simple Algorithm



- The Question is that How to determine threshold values: H^{low}, H^{up} and H^{m}.
  - Alternative 1: Maximize Number of true forecast of industrial load and Minimize False forecasts
  - Alternative 2: Minimize total Energy Consumption costs
  - We use the first method
- Demand Response Action items should be defined and categorized Beforehand

Results of Case Study

When Industrial Load is a Load > 40 kW

Value	Count	Percent	
-1	621	1.77% :	Type II Error: (Detecting a normal load while the load is an industrial load)
0	31278	89.26%:	Probability of the Right Decision
1	3141	8.96%:	Type I Error (Detecting an Industrial load while the load is normal)

Model Accuracy **(Signals)**

Value	Count	Percent		
-1	527	1.50%:	Real: Red	Detected: Green
-0.5	616	1.76%	Real: Red	Detected: Yellow
0	26731	76.29%	Right decisions	
0.5	4112	11.74%	Real: Green	Detected: Yellow
1	3054	8.72%	Real: Green	Detected: Red

78% of Industrial loads are flagged: (53% of Industrial load are Red ; 25% are flagged are Yellow)

When Industrial Load is a Load > 50 kW

Value	Count	Percent	
-1	246	0.70%	Type II Error: (Detecting a normal load while the load is an industrial load)
0	30988	88.44%	Percentage of the Right Decision
1	3806	10.86%	Type I Error (Detecting an Industrial load while the load is normal)

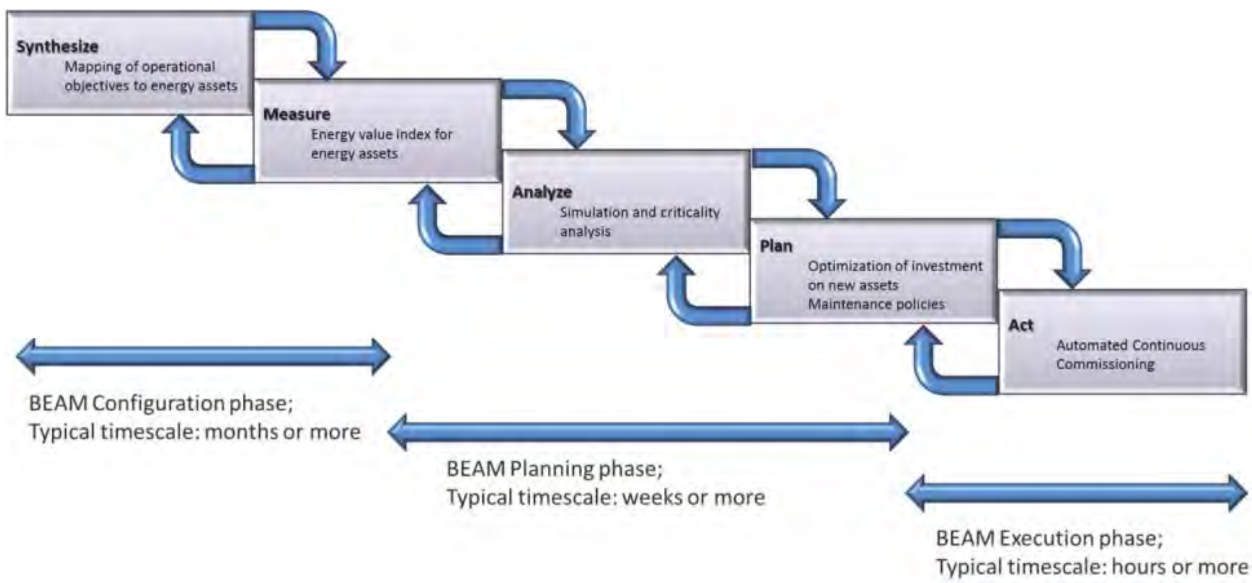
Model Accuracy **(Signals)**

Value	Count	Percent		
-1	143	0.41%	Real: Red	Detected: Green
-0.5	358	1.02%	Real: Red	Detected: Yellow
0	26463	75.52%	Right decisions	
0.5	4358	12.44%	Real: Green	Detected: Yellow
1	3718	10.61%	Real: Green	Detected: Red

85% of Industrial loads were flagged: (56% of Industrial load are Red; 30 % are Yellow)

Building Energy Asset Management (BEAM)

Classical Model of Enterprise Asset Management



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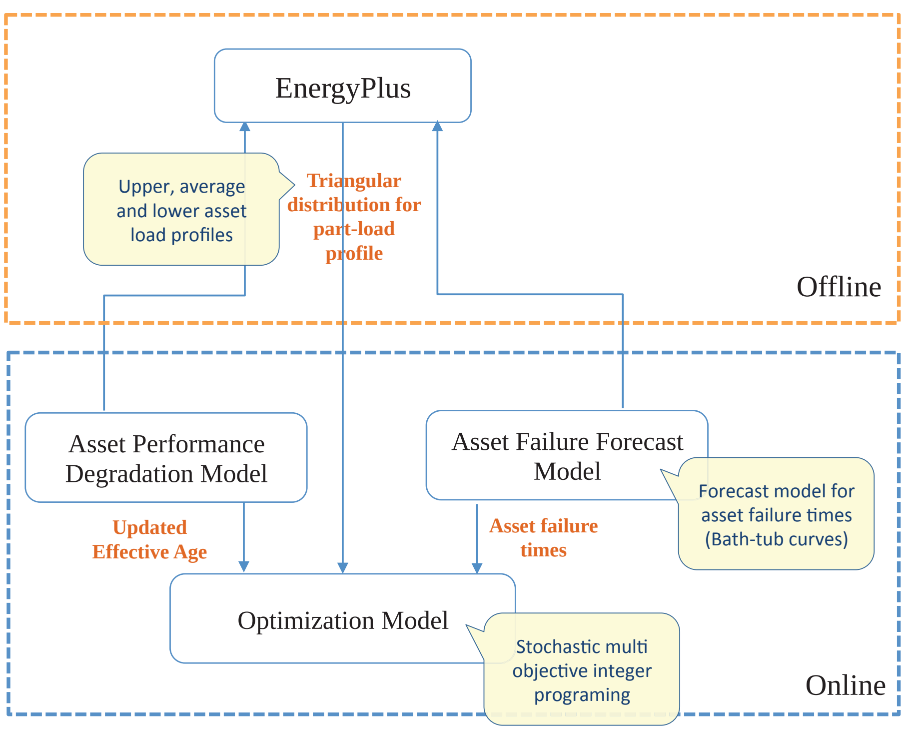
BEAM Methodology



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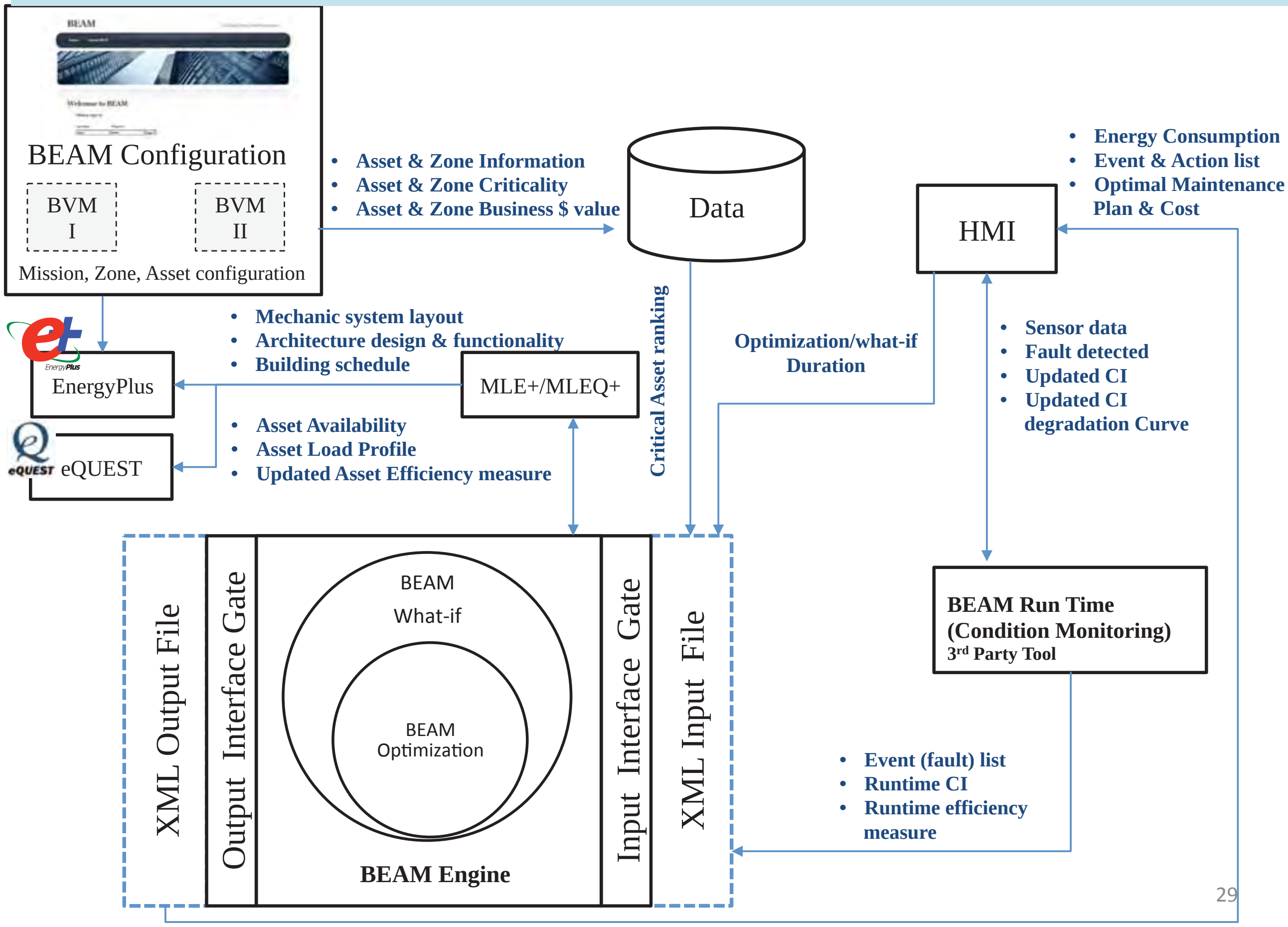
BEAM Overall Architecture



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BEAM Methodology Description – Building Value Model

The Need

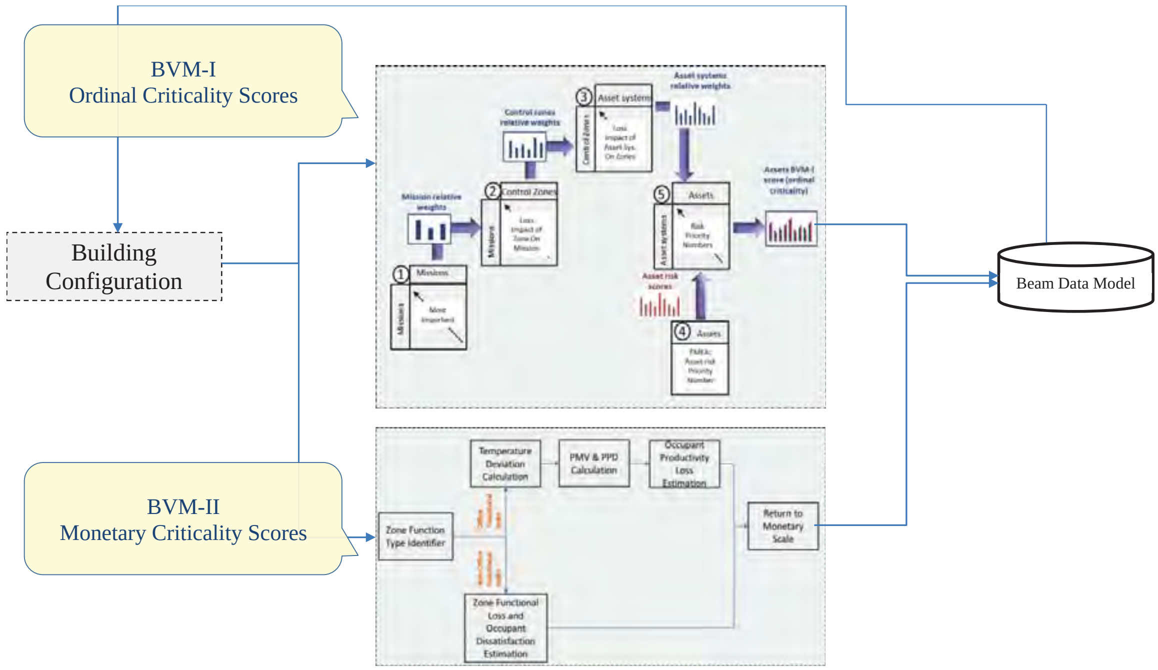
- Asset long term maintenance and operational scheduling need to consider not only energy savings in engineering terms, but also the "value" that the building assets generate.

What does "Building Value Model do"?

- Provide a systematic methodology to compute the building energy assets' value* derived from building missions
- BVM-I and BVM-II measure assets' business value in ordinal terms in [0,1] and ($) terms respectively.

* The term "value" can be defined in economic, social and/or environmental dimensions.

BVM Overall Architecture



BEAM Methodology Description : BVM-I

Our approach: hierarchal mapping of assets criticality to building missions

Relative scores obtained from survey questionnaires

First Pass Model

- Missions Relative Importance
- Impact of Loss of Zone on Missions Accomplishment
- Impact of Loss of Asset Systems to Zone Performance

Define Asset Criticality Score

- Impact of Asset Loss on Overall Mission Accomplishment

Second Pass Model

- FMEA: Impact of Asset Loss on Asset System's Performance

FMEA risk scores obtained from static historical data

BEAM Methodology Description : BVM-II ($ scores)

- Value of building's assets estimated using percentage employees' productivity loss due to asset performance degradation/failure
- Effects of thermal environment on performance and productivity is estimated
- Air temperature is the commonly used indicator of thermal environment
- Economic consequence of energy asset performance degradation/ loss is quantified using occupant productivity loss due to thermal discomfort as a result of elevated air temperature.
- Employees' financial income or income contribution is used to derive criticality score in ($) terms

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BEAM Methodology Description : BVM-II ($ scores)

- PMV (Predicted Mean Vote) is used to express the human perception of thermal comfort. The index includes the combination and interdependencies of the following factors of thermal comfort:
    - Metabolic activity
    - Clothing insulation
    - Air temperature
    - Mean radiant temperature
    - Air movement
    - Humidity
    - Occupant's dissatisfaction due to asset performance degradation/failure
- PPD (Predicted Percentage Dissatisfied) describes the percentage of occupants that are dissatisfied with the given thermal conditions.

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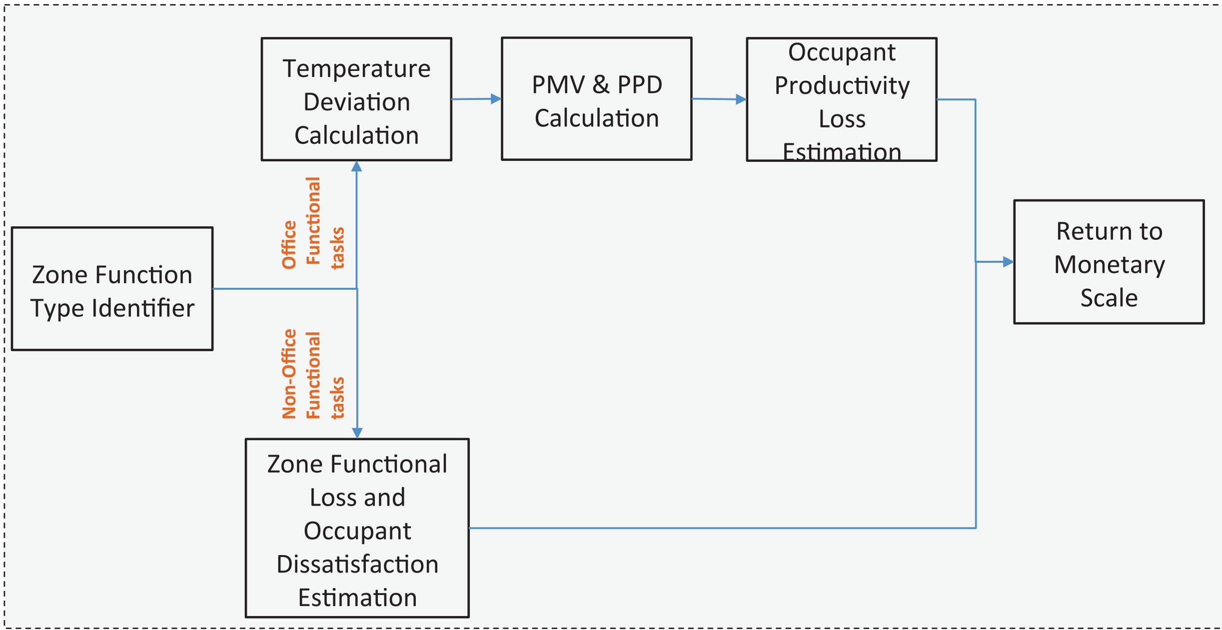
BEAM Methodology Description : BVM-II ($ scores)



BEAM Optimization

Objective #1. Min{Total Building Energy Consumption}
Objective #2. Min{Total Building Cost}
subject to:
Total Building Cost ≤ Total Budget
Mutually Exclusive Maintenance Policy Options

We will assume that:

Asset energy consumption ~ Asset Avg. effective age

Min {Avg. asset effective age} ≡ Max {Total improvement in asset effective age}

BEAM Optimization

Two Types of Optimization for Building O&M

- **O&M Optimization I:**
  - Only direct improvement of O&M policy actions

- **O&M Optimization II:**
  - Both direct & indirect impacts of O&M policy,

    i.e. a maintenance policy put on asset 1, not only improves asset 1's effective age, but it also impacts asset 2's effective age (positive or negative impact).

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BEAM Optimization

Objective # II:

Total Building Cost = Total Preplanned Action Cost + Asset Penalty Cost + Unexpected Reactive Cost

= Total Preplanned Action Cost + Asset Penalty Cost$_{Base}$ - Reduction in Penalty Cost + Unexpected Reactive Cost$_{Base}$ – Reduction in Unexpected Reactive Cost

where,

Reduction in Unexpected Reactive Cost + Reduction in Penalty Cost = Total Reduction in Unexpected Cost

Therefore

Min {Total Building Cost} = Min {Total Preplanned Action Cost – Total Reduction in Unexpected Cost}

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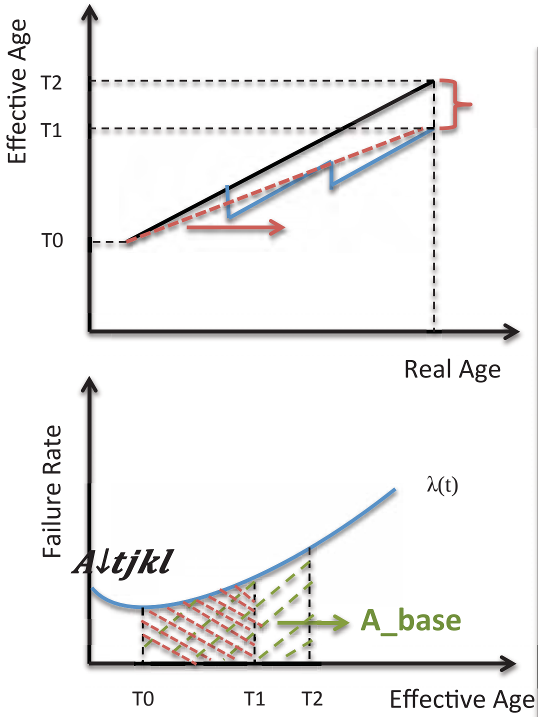
BEAM Optimization

Optimization I, Coefficient Calculation: $\Delta\downarrow tikl$



$\forall(t;k,l)$

for $i=1,\dots,n$ assets

$\delta\downarrow\uparrow(t;k,l) = [\blacksquare\,\delta\downarrow 11\ \&\dots\&\delta\downarrow 1n\ @\delta\downarrow 21\ \&\dots\&\delta\downarrow 2n\ @\ \delta\downarrow n1\ \&\dots\&\delta\downarrow nn\ ]$

$\delta\downarrow ii\uparrow\uparrow(t;k,l)$: *Improvement in asset i as a result of* $(t;k,l)$

$\delta\downarrow ij\uparrow\uparrow(t;k,l)$: *Improvement in asset j as a result of* $(t;k,l)$ *on asset i*

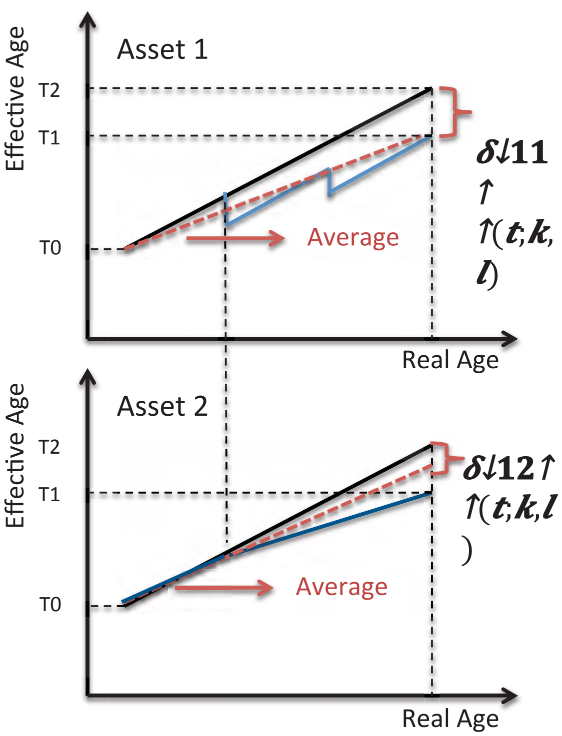
$\boldsymbol{\delta\downarrow ij\uparrow\uparrow(t;k,l)\ \cong 0\quad \forall i\neq j\ (\textit{in optimization I})}$

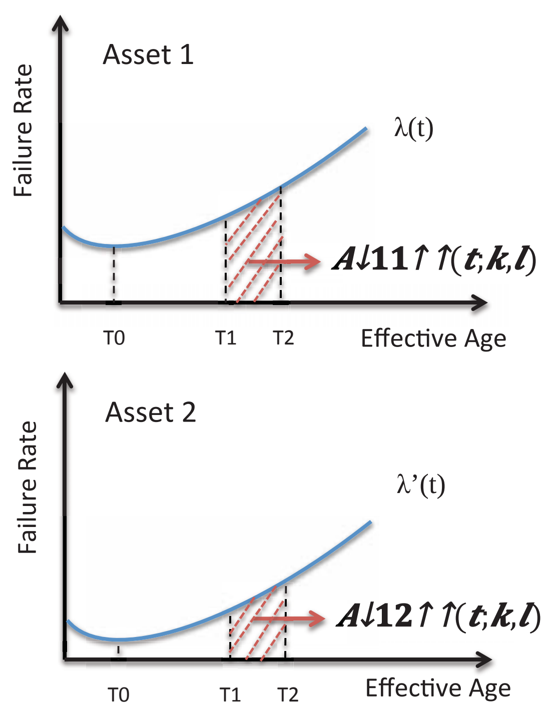
$\Delta\downarrow tikl = \delta\downarrow(i;:)\uparrow\uparrow(t;k,l)\times(EW)\uparrow T\times(\textit{Avg Seasonal Degradation})\downarrow t,i$

EW: *Energy Weight Matrix*

BEAM Optimization

Optimization II, 2 Asset Example Option (t;k,l) on asset 1:

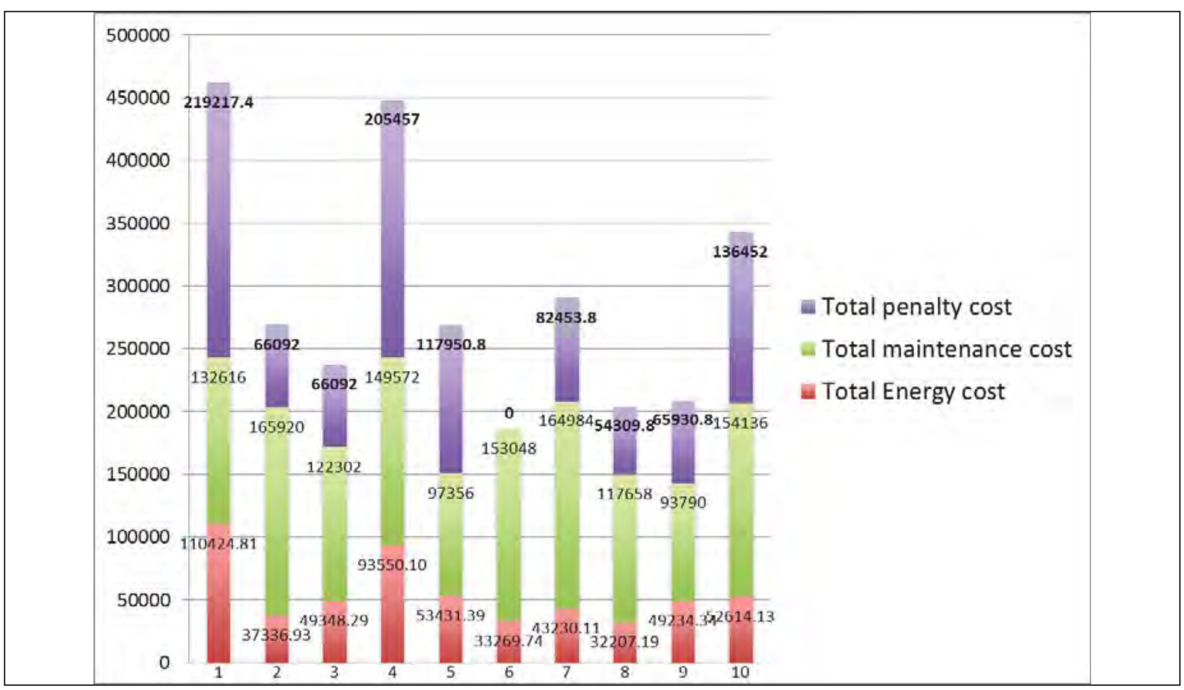




Case Study

Scenario number	"What-if" scenario	
	Asset	Maintenance Option
1	Chiller	Reactive Maintenance
	Boiler	Reactive Maintenance
	Supply fan	Reactive Maintenance
2	Chiller	PM clock, type 3, fr=3
	Boiler	PM clock, type 3, fr=6
	Supply fan	Reactive Maintenance
3	Chiller	PM clock type 3, fr=6
	Boiler	PM clock type 3, fr=3
	Supply fan	Reactive Maintenance
4	Chiller	Reactive Maintenance
	Boiler	PM clock, type 3, fr=3
	Supply fan	PM clock, type 3, fr=3
5	Chiller	PM clock, type 3, fr=6
	Boiler	PM clock, type 3, fr=6
	Supply fan	Reactive Maintenance
6	Chiller	PM clock, type 3, fr=3
	Boiler	PM clock, type 3, fr=3
	Supply fan	PM clock, type 3, fr=3
7	Chiller	PM clock, type 3, fr=6
	Boiler	PM clock, type 3, fr=6
	Supply fan	PM clock, type 3, fr=6
8	Chiller	PM clock, type 3, fr=3
	Boiler	PM clock, type 3, fr=3
	Supply fan	PM clock, type 3, fr=6
9	Chiller	PM clock, type 3, fr=6
	Boiler	PM clock, type 3, fr=6
	Supply fan	PM clock, type 3, fr=3
10	Chiller	PM clock, type 3, fr=6
	Boiler	Reactive Maintenance
	Supply fan	Reactive Maintenance

Case Study



Case Study – Optimization vs Asset Condition

- We run optimization in different condition of assets in the building and the results are compared with the base maintenance option (Reactive Maintenance).
- Three different cases are tested in this optimization model.
    1- Assets are in the first 30% of life cycle.
    2- Assets are in the middle age period (between 30% and 70%)
    3- Assets are in last 30% of their life.

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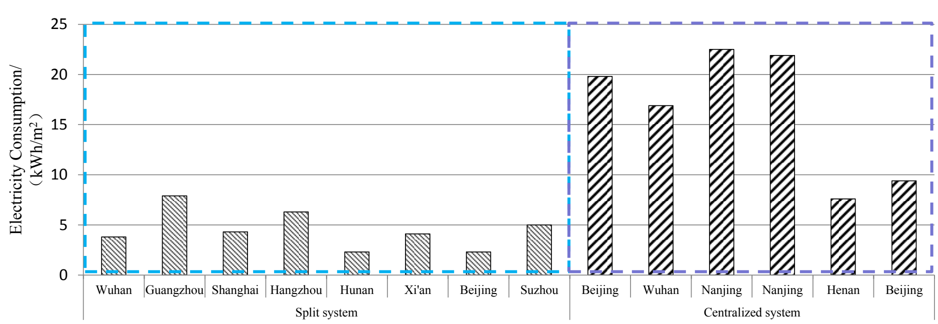
Case Study - Optimization vs Asset Condition

Scenario number	Recommended Policy	Energy Saving (%)	Total Cost Saving (%)
1	Reactive Maintenance for all assets	-	-
2	Chiller: "PM clock, type 3, fr=6" Boiler and Supply Fan: Reactive Maintenance	26%	56%
3	"PM clock, type 3, fr=3" for all assets	69%	59%

Case studies of Centralized and Distributed Cooling system in Residential building

Da Yan
Building Energy Research Center
Tsinghua University
2013.07.17

Cooling Energy consumption in Residential building



Split AC system

Centralized AC system

Case Studies

Case A

Fully Centralized System

Case B

Partial Centralized System

Case C

Cooling Water Centralized System

Page 3

Case A Fully Centralized system

<u>**Location**</u>

Jiangsu Province

<u>**Building information**</u>

10 buildings, 114,000 m^2

<u>**AC system**</u>

Ceiling panel radiation + displacement ventilation systems

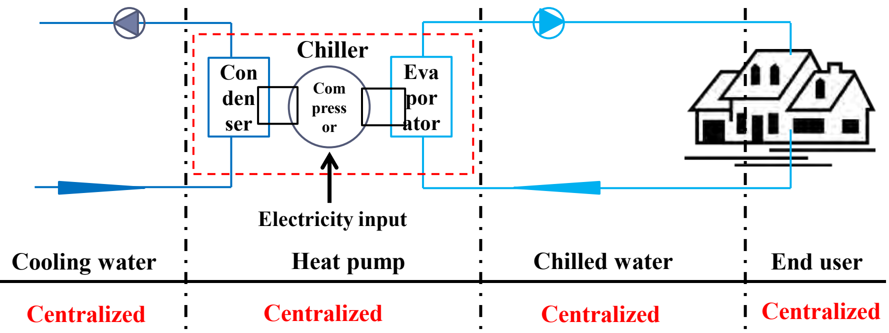
<u>**Chillers**</u>

Two heat pumps for fresh air system

Two heat pumps for ceiling panel radiation

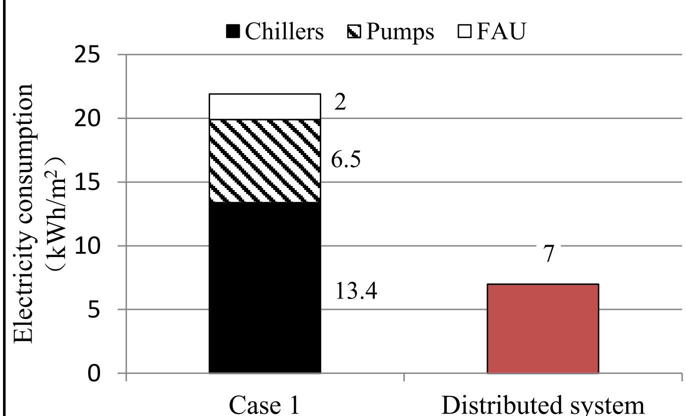
Page 4 4

Case A Fully Centralized system



Page 5

Case A Fully Centralized system



Electricity Consumption Comparison

Higher efficiency

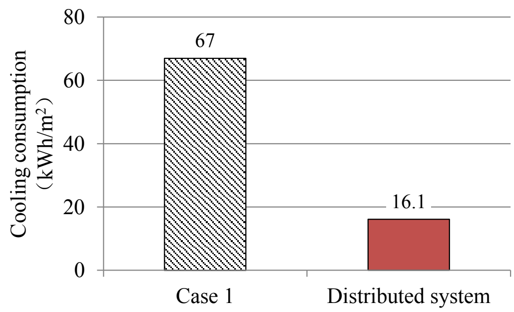
Heat pump's COP is 5

Higher consumption

Fully centralized system's energy consumption is 3 times of distributed system

Page 6

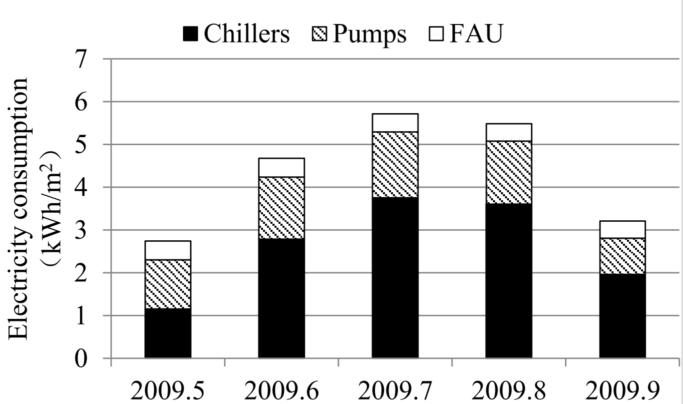
Case A Fully Centralized system



Cooling Consumption Comparison

“Full time Full space” and “Part time Part space”

Case A Fully Centralized system

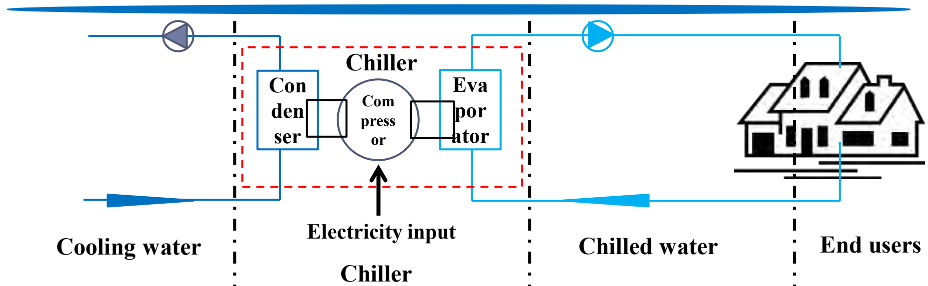


High transmission consumption

The consumption of pumps and fans can take up 30%-60% of total consumption

In some season, the transmission consumption is about 1.4 times of chillers

Case A Fully Centralized system



Case 1	Centralized 2.5kWh/m²	Centralized 13.4kWh/m²	Centralized 4kWh/m²	Centralized 67kWh/m²

1. System EER=[cooling consumption/(chillers + pumps consumption)]= 3.4;
2. Cooling consumption in this system is 4 times of split AC system;
3. AC electricity consumption is about 3 times of split AC system.

Case B Partial Centralized system

Location

Henan Province

Building information

12 buildings, 41,200 m^2

AC system

FCU system without control in chilled water end user side

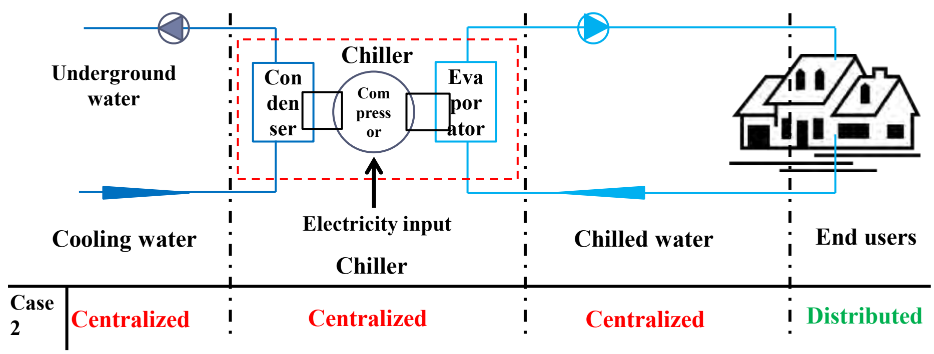
Chillers

Two heat pumps for cooling, with the rated capacity of 1467kW and 542kW

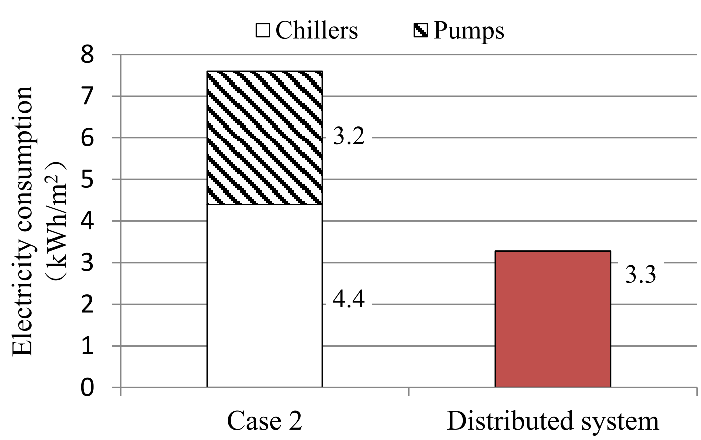
Cooling fee

Charging according to users' cooling consumption

Case B Partial Centralized system



Case B Partial Centralized system

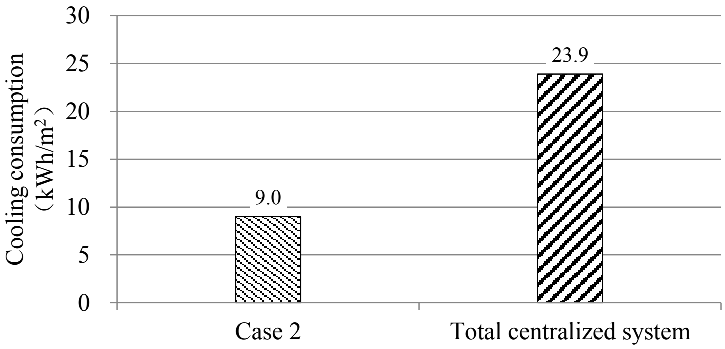


Electricity Consumption Comparison

Energy Consumption

about 2 times of distributed system

Case B Partial Centralized system



Cooling Consumption Comparison

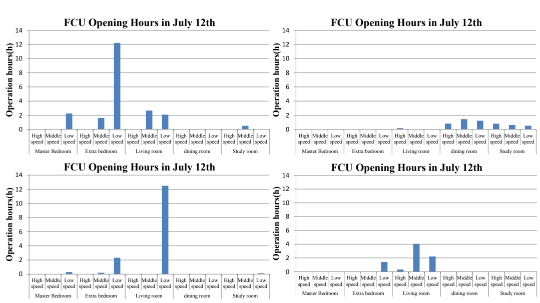
Cooling consumption

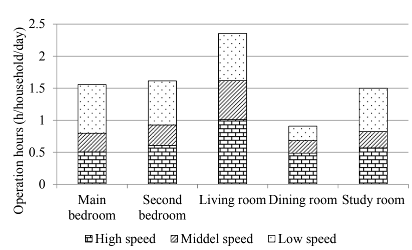
When the users' get the **feasibility** and **motivation** to control, the cooling consumption significantly decreased

Case B Partial Centralized system

Reason for the low cooling consumption

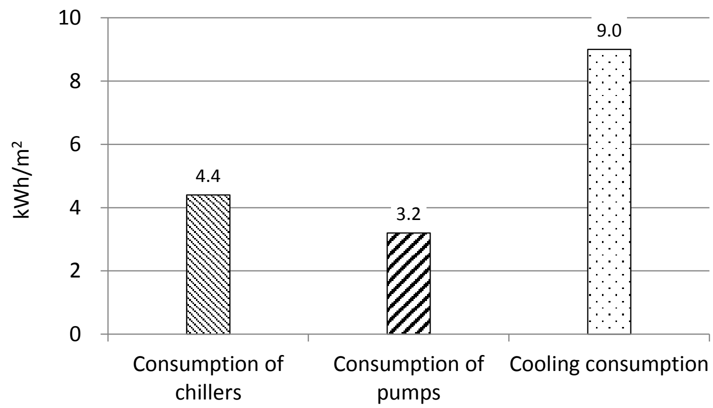
charging method → use mode: "part time, part space"





The average open rate of FCU in the cooling season is only 7%

Case B Partial Centralized system

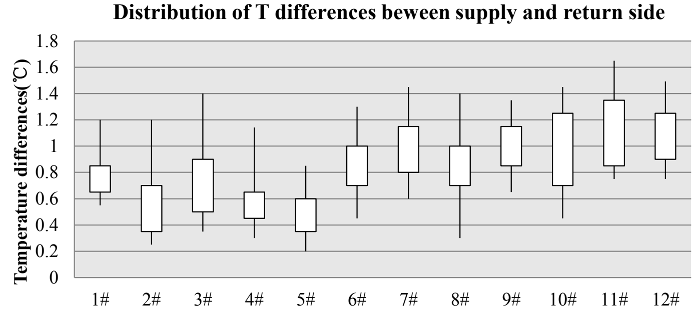


System EER = 1.2

Case B Partial Centralized system

Why very low EER

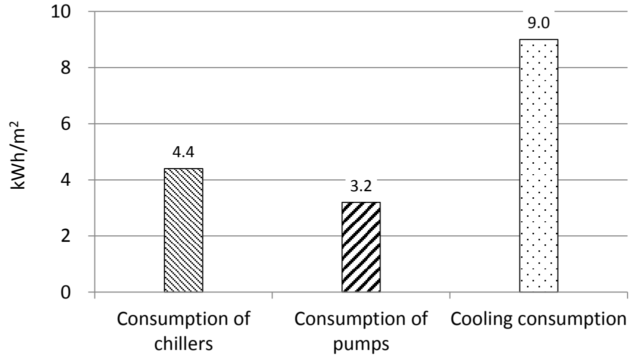
Distribution of T differences beween supply and return side



1. Operation mode: "part time, part space" → low cooling consumption
2. Only few FCU on operation at the same time
3. The electricity consumption of pumps become the main part of total consumption

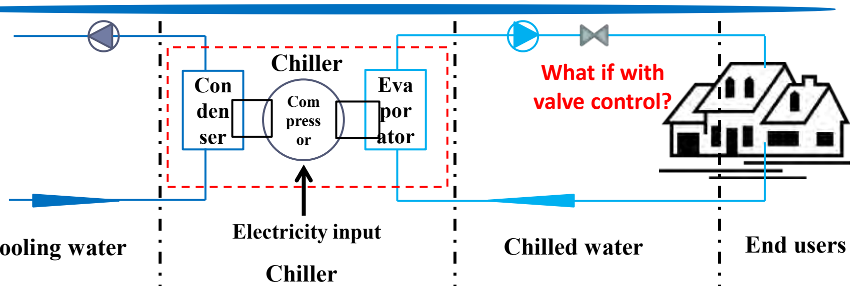
Case B Partial Centralized system

Why very low EER



1. Chillers work under low load ratio during the cooling season. COP of the chiller is far more lower than the rated value
   Average COP=9/4.4=2.0
2. Even the COP of the chiller can reach 6.4, but limited by the consumption of pumps, EER=7.5/(7.5/6.4+3.2）=1.7

Case B Partial Centralized system



Case 1	Centralized 2.5kWh/m²	Centralized 13.4kWh/m²	Centralized 4kWh/m²	Centralized 67kWh/m²
Case 2	Centralized 1.7kWh/m²	Centralized 4.4kWh/m²	Centralized 1.5kWh/m²	Distributed 7.5kWh/m²

When the end users get the **feasibility** and **motivation** to control, the cooling consumption decreases greatly, and the **transmission consumption** become the main consumption part, which greatly decrease of system EER

Case C Cooling Water Centralized system

Location

Beijing

Building information

3 buildings, 70,000 m^2

AC system

distributed water-loop heat pump system, pumps connect in parallel

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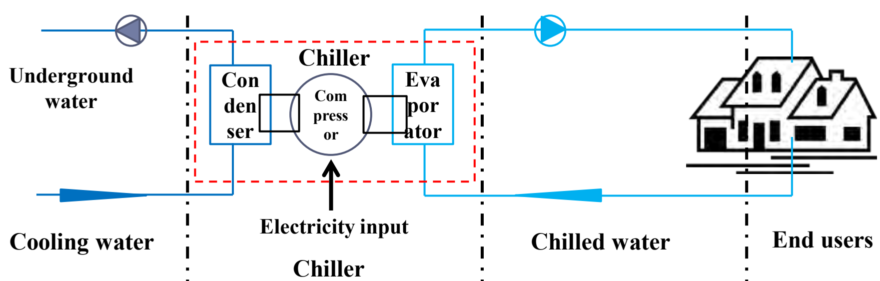
Case C Cooling Water Centralized system



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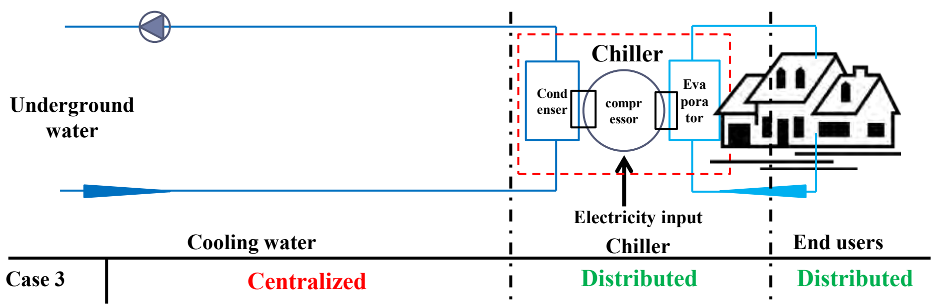
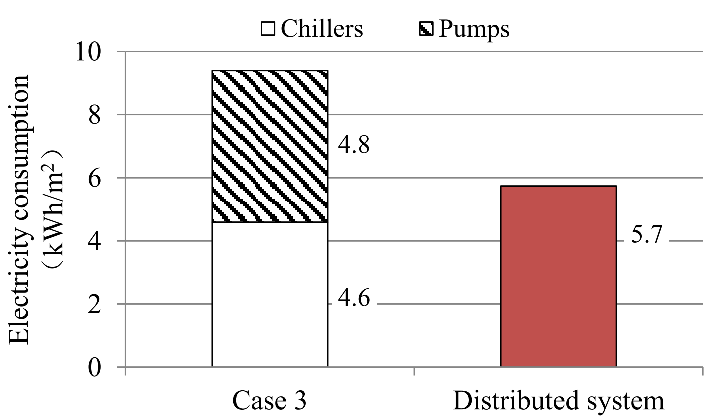
Case C Cooling Water Centralized system



Case C Cooling Water Centralized system

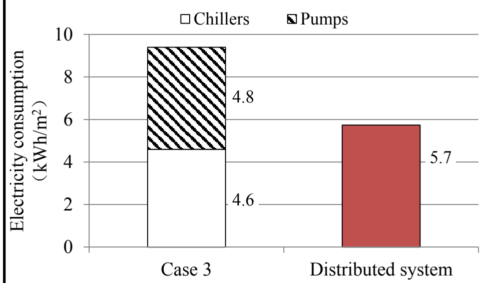


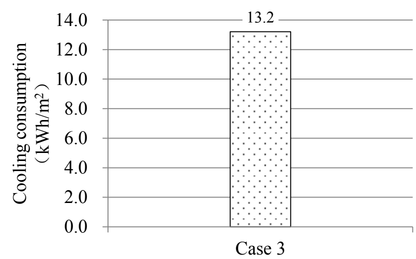
Electricity consumption comparison

Comparison of consumption

about 1.5 times of the distributed system

Case C Cooling Water Centralized system





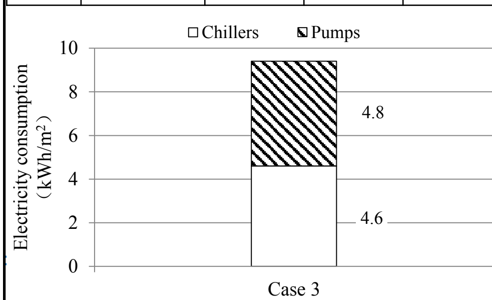
For using distributed terminal type, the cooling consumption is low, and chiller's COP is high. COP = 13.2/4.6 = 2.9

However, the system EER = 13.2/9.4 = 1.4

Case C Cooling Water Centralized system

Reason for high consumption

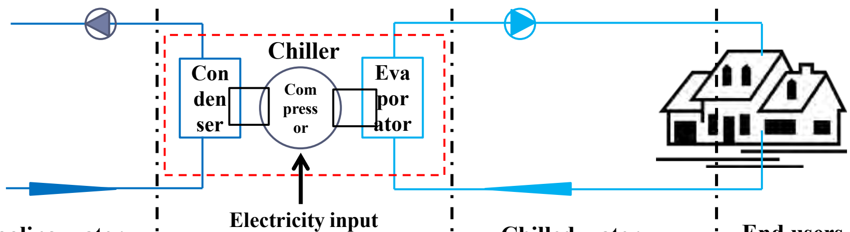
		t_{supply}	t_{return}	T differences
Design value		18	32	14
Measured data	2003	25.8	26.5	0.7
	2004	27.9	28.5	0.6
	2005	27.0	27.8	0.8



1. The cooling water pumps have to work full day. The consumption of cooling water pumps =3.7 kWh/m²

2. In this case, the transmission consumption consume half of the total consumption

Case C Cooling Water Centralized system



	Cooling water	Chiller	Chilled water	End users
Case 1	Centralized 2.5kWh/m²	Centralized 13.4kWh/m²	Centralized 4kWh/m²	Centralized 67kWh/m²
Case 2	Centralized 1.7kWh/m²	Centralized 4.4kWh/m²	Centralized 1.5kWh/m²	Distributed 7.5kWh/m²
Case 3	Centralized 4.8kWh/m²	Distributed 4.6kWh/m²	×	Distributed 13.2kWh/m²

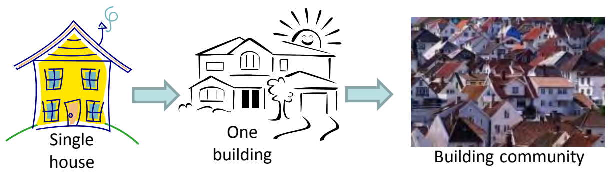
Discussion and Conclusion

	Cooling water	Chiller	Chilled water	End users
Case A	Centralized 2.5kWh/m²	Centralized 13.4kWh/m²	Centralized 4kWh/m²	Centralized 67kWh/m²
Case B	Centralized 1.7kWh/m²	Centralized 4.4kWh/m²	Centralized 1.5kWh/m²	Distributed 7.5kWh/m²
Case C	Centralized 4.8kWh/m²	Distributed 4.6kWh/m²	×	Distributed 13.2kWh/m²

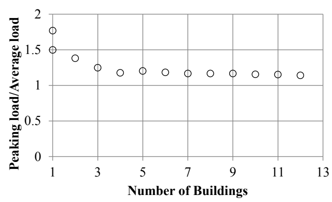
- In cases, the consumption of centralized AC system is usually larger than distributed system
- Wherever is centralized, there appear higher energy consumption

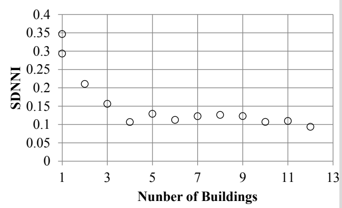
Discussion and Conclusion

- Community Load Profile



As the increase of users and buildings, load features change





Note: SDNNI=Standard deviation/mean

Load feature in community

Part-load:
Part time part space

Mismatch:
Ex: 7% people in use with full load

Distributed load feature:
Main element for Cooling load → Indoor heat gain

Mismatch with centralized system

Discussion and Conclusion

- How to improve the performance of centralized system?
  - End users
    - Provide sufficient feasibility and motivation for control
  - Chillers
    - Significantly improve part load efficiency
  - Distribution system
    - Need effective way to adjust water flowrate
    - Especially for very low load ratio (eg. 7%)

Thank you for your attention!

清華大學

CERC-Building Energy Efficiency

Human Behavior: An Overview of the Joint Project

Tianzhen Hong
Lawrence Berkeley National Laboratory, USA
Da Yan
Tsinghua University, China

CERC-BEE Forum
July 17-18, 2013

U.S.–China Clean Energy Research Center
中美清洁能源研究中心

Berkeley Lab

清華大學
Tsinghua University

1

Outline

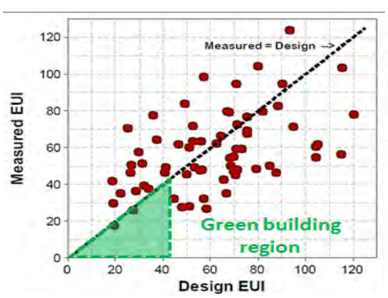
- Research Background
- Project Overview
  - Research objective
  - Technical tasks
  - Major deliverables
  - Schedules
  - Collaboration
- Recent Process
- Acknowledgement

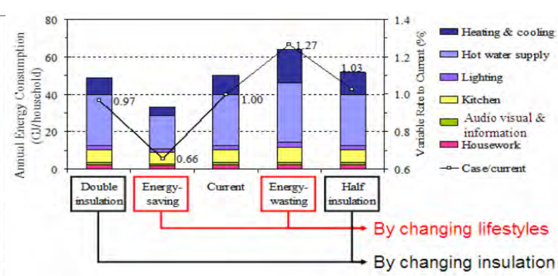
2

Research Background

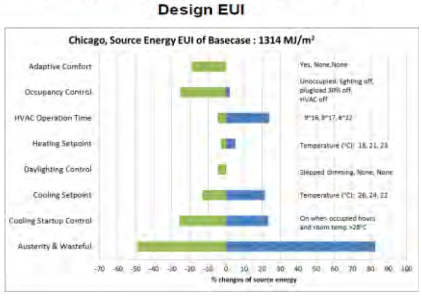
- Technologies alone not necessarily lead to low energy buildings
- Human behavior plays an essential role in building design, operation and maintenance, but it is not well understood and usually over-simplified
- Behavior changes, usually no or low cost, has demonstrated 5 to 30% energy savings in buildings. Potential savings can be > 50%!

Significance of Occupant Behavior

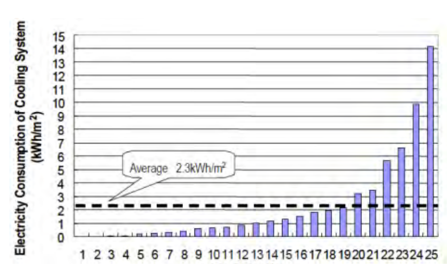




Prof. Yoshino, IEA ECBCS Annex 53, Dec2010



Impact of Occupant Behavior on Energy Use of Private Offices

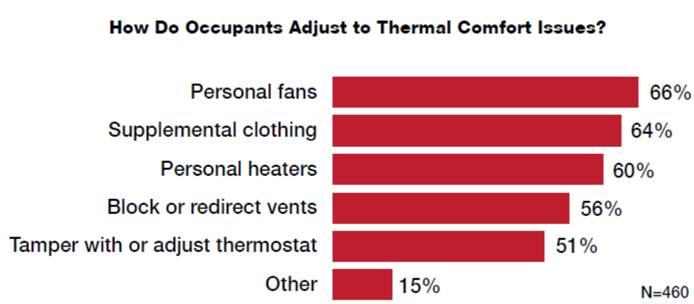


Annual household electricity usage of split type air-conditioners in 2006, Beijing, China. Source: Tsinghua University

Complexity of Human Behavior

- Inherent uncertainty and stochastic
- Multi disciplinary
- Various driving factors:
  - Physical: personal, indoor and outdoor conditions
  - Non-physical: culture, life style, habit
  - Societal: energy & environmental attitude
- Very limited data to help us understand

Occupants Responses to Discomfort



Other responses include: complain, contact facilities department, keep blankets and sweaters within reach, and open windows.

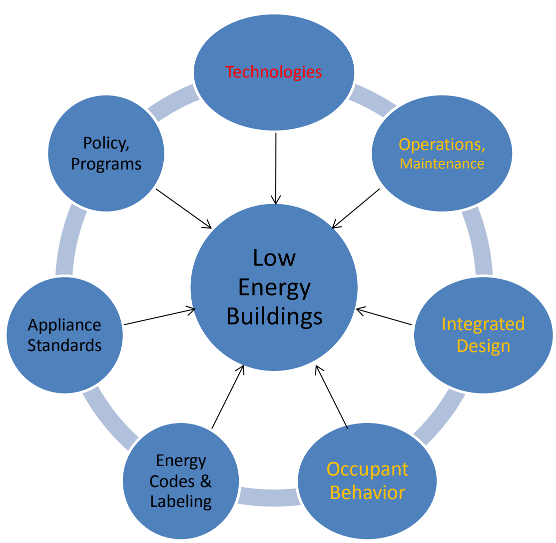
IFMA 2009 HVAC Survey of IFMA members in US and Canada
with 452 responses from 3357 samples

Questions

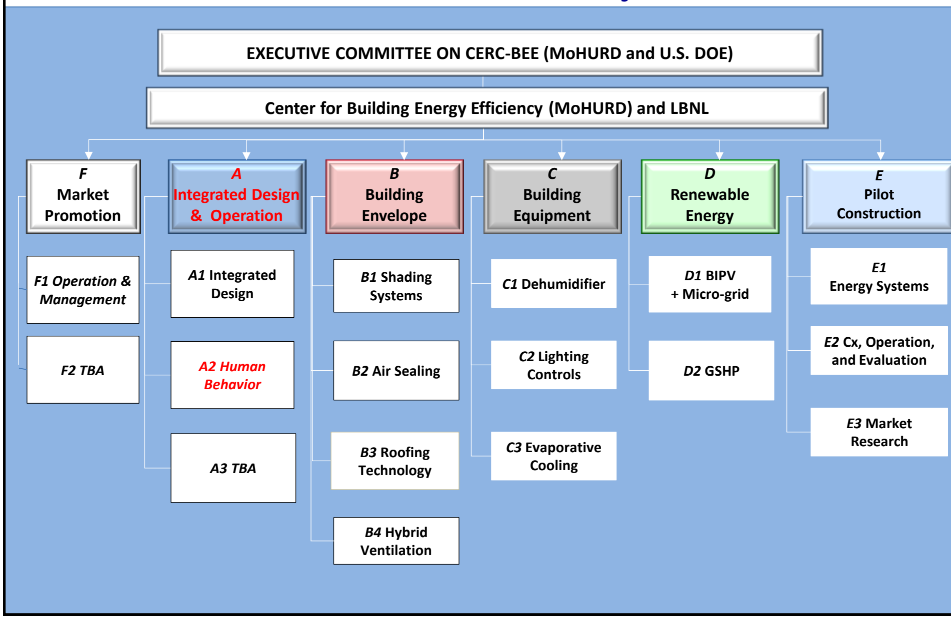
1. What are energy-related occupant behavior in buildings? (Data-driven)
2. How to describe and model these behavior? (Robust modeling)
3. What tools are needed, for designers, operators, owners, manufacturers, and policy makers, to robustly evaluate impact of occupant behavior on building design, operation, and performance? (Provide insights)

7

Key elements to achieving low energy buildings



CERC-BEE Phase 2 Research Projects



Research Objective

1. Develop methods to describe and understand occupant behavior
2. Develop tools to quantify the impact of occupant behavior on energy use in buildings
3. Guide building design and operations for better performance.

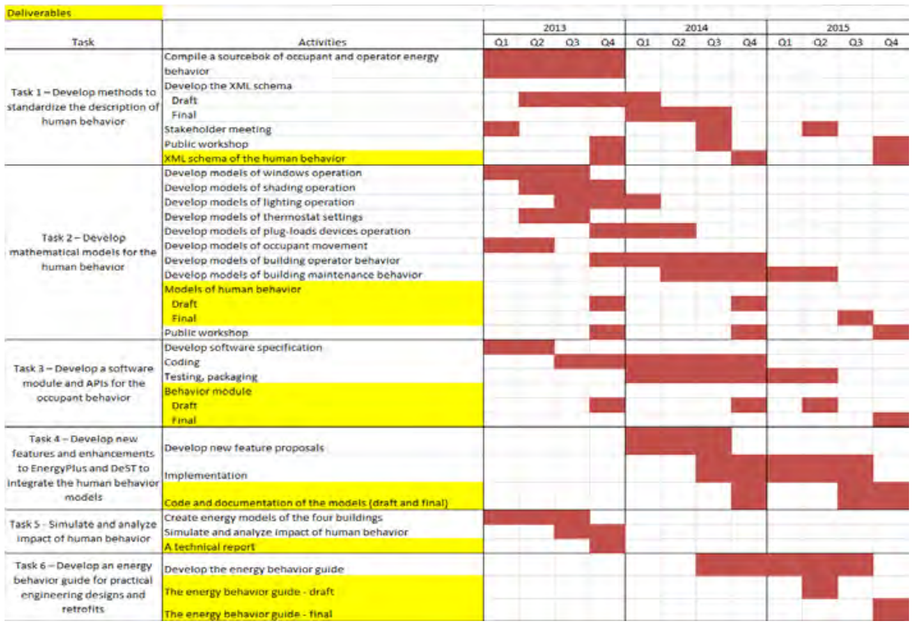
Technical Tasks

1. Develop a framework and data model to describe occupant behavior
2. Develop mathematical models of occupant behavior
3. Develop a software module of behavior models that can be integrated with building energy modeling programs, e.g. EnergyPlus, DeST
4. Develop new features of EnergyPlus and DeST to enable the simulation of occupant behavior
5. Evaluate impact of occupant behavior on energy use in typical office buildings in the U.S. and China
6. Develop an energy behavior guide for building design, operation and retrofits

Major Deliverables

1. A framework and standard data model (XML schema) to describe occupant behavior
2. A suite of mathematical models for occupant behavior
3. A software module of behavior models
4. New features to enable occupant behavior simulation in EnergyPlus and DeST
5. Case studies of occupant behavior in office buildings in the U.S. and China
6. An energy behavior guide for building design, operation and retrofits

Schedules



Research Collaboration

- Strong collaboration between the U.S.-China research teams
  – Bi-weekly conference calls
  – Exchanged students
  – Joint publications
- Industrial partners
  – U.S.: UTRC, Bentley Systems, C3 Energy
  – China: CABR, the CECEP Group, the Vanke Group
- Public workshops & forums
  – Two per year
  – Promote CERC research and seek feedback
  – Engage industry and policy makers
- Synergies with related activities
  – IEA ECBCS Annex 53 Total Energy Use in Buildings
  – New IEA EBC Annex on Occupant Behavior
  – EEB Hub / Rutgers University, ACEEE, ASHRAE, GSA

Recent Progress

- Three presentations on Tasks 1-3
  - Will Turner: A technical framework to describe occupant behavior
  - Chuang Wang: Action-based models of occupant behavior
  - Xiaohang Feng: A software module to model and simulate occupancy in buildings

- Task 5 to start soon

15

Acknowledgement

- U.S. DOE for funding U.S. side research
- China MoHURD & MoST for funding China side
- U.S. DOE CERC management
  - Director Robert Marley
  - Senior Advisor Richard Karnay
- U.S. CERC-BEE management team
  - Director Nan Zhou
  - Operation Manager Brian Heimberg
  - Senior Strategic Advisor Mark Levine
  - Technical Advisory Committee
  - Industrial Advisory Board
- China CERC-BEE management

16

Questions?

17

EBC

Energy in Buildings and Communities Programme

Definition and Simulation of Occupant Behavior in Buildings

A New ANNEX Project Concept Proposal

Da Yan
Tsinghua University, China

July 18 2013

Background

- **Large gaps between simulated and measured building energy use**

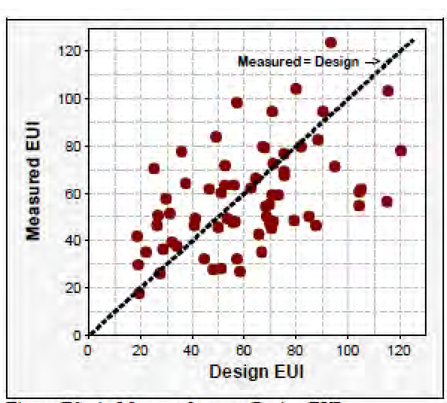
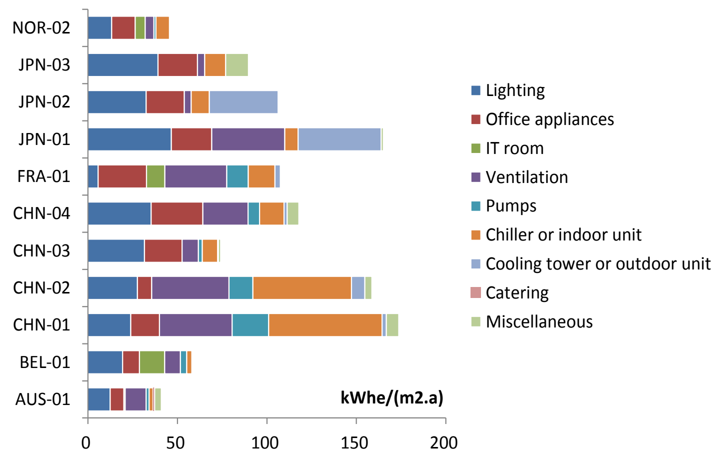


Figure ES- 4: Measured versus Design EUIs
All EUIs in kBtu/sf

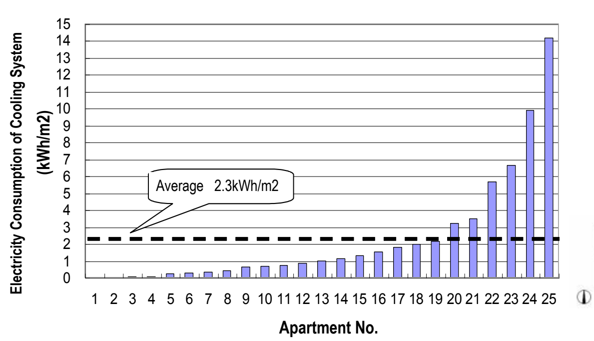
Source: NBI report 2008
Energy Performance of LEED
For New Construction Buildings

Background



Background

- OP has significant influence on building energy use



Significant differences between different apartment units

The cooling energy consumption data in different apartments of one residential building in Beijing,2006

Background

What kind of thermal insulation level would be adapted in Shanghai residential building?

Life Style Mode

	Description
Mode1	Full time full space heating
Mode2	Full time full space heating when Occupied
Mode3	Full time for kids , heating before sleeping for parents
Mode4	heating before sleeping

U Value of building Fabric

W/(m²·K)	Wall	Roof	Window
1990s	2	1.7	4.7
Current	1.5	1.1	3.2
Japan	0.45	0.45	4.65

EBC

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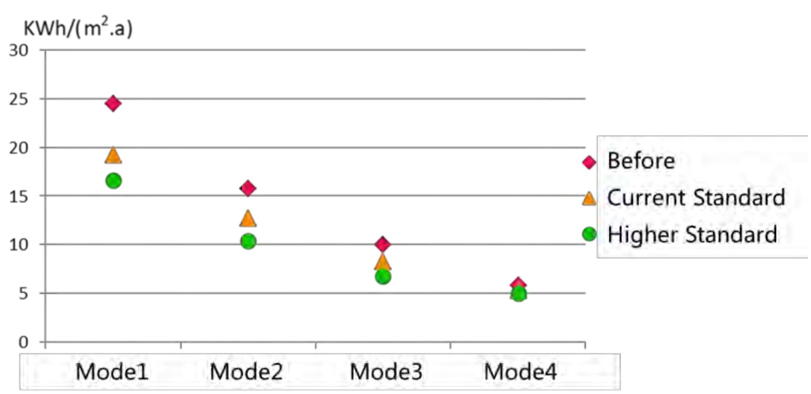
Background



OB is a key factor in the evaluation of building technology

EBC

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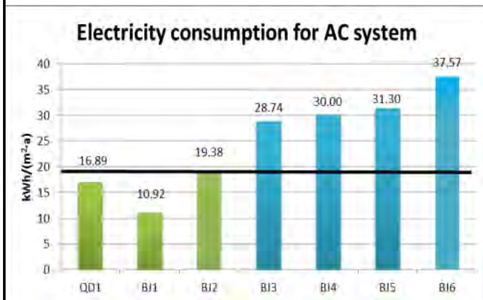
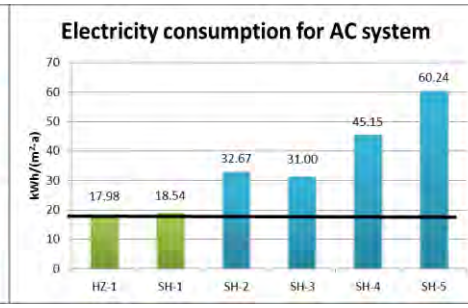
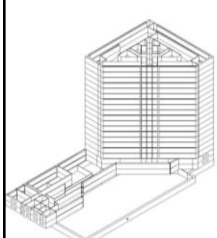
Background

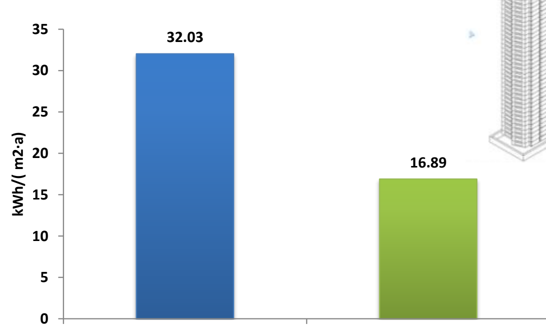


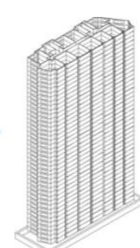


- **VRV system consumes less energy in both Beijing and Shanghai area**
- **But, VRV's COP is at the same level of central cooling system**

Background



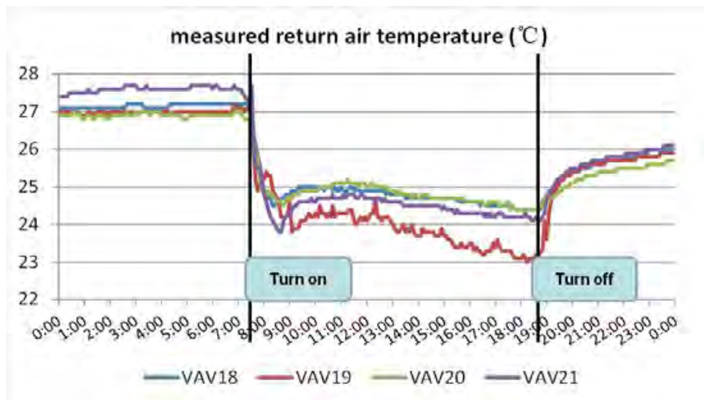




Measured BEC for cooling in two Buildings, 2010

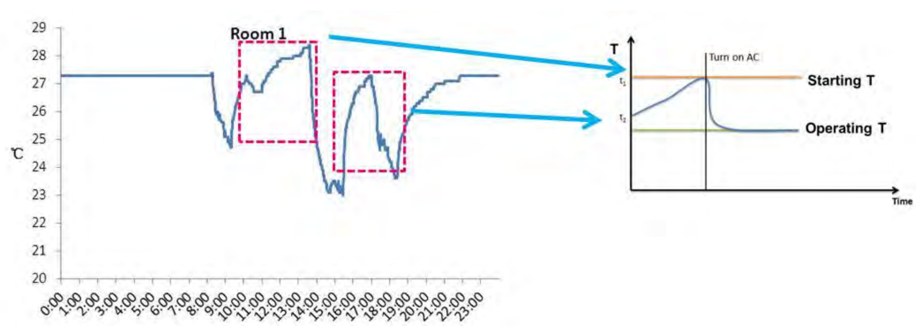
Background

- CWC system: use AC system almost all rooms at the same time



Background

- VRF system: use AC system in a part time part space way



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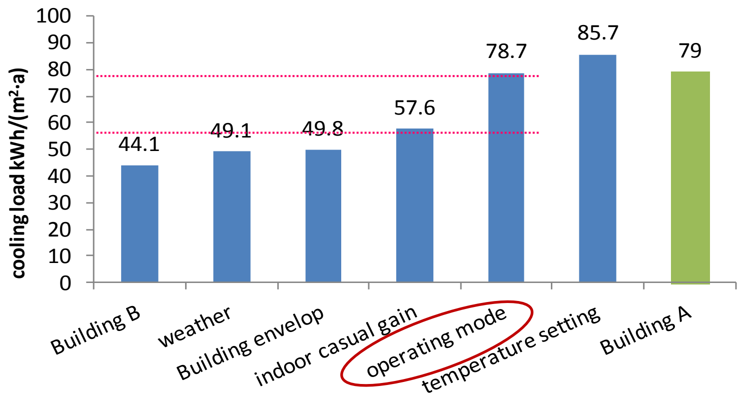
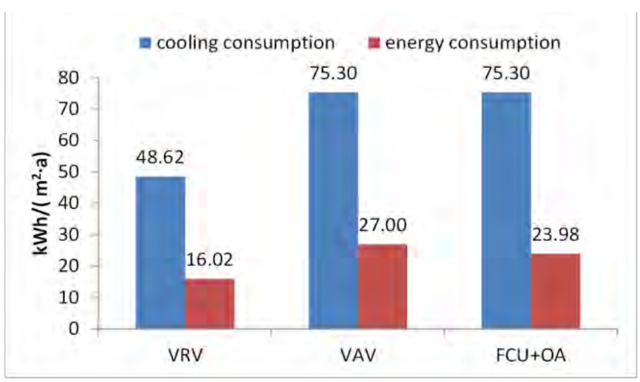


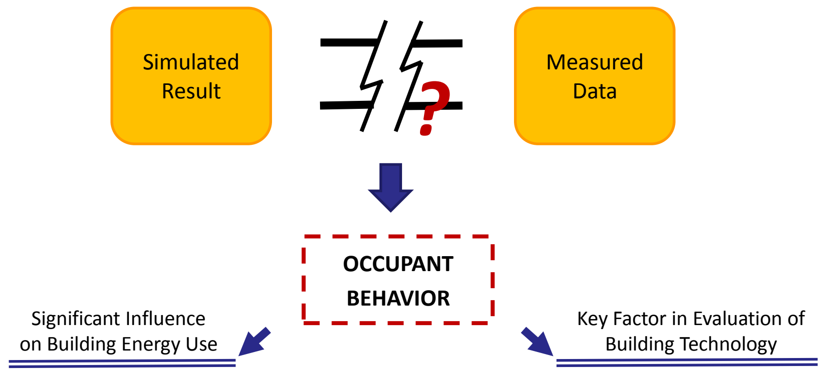
Background



SCOP	3.0	2.8	3.1

- **The VRF system consumes less energy not due to higher COP, but provide the users more authority to control and adjust their rooms.**

Background



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Importance and Urgency

- Key issue for design optimization and energy diagnosis
- Also key issue for building energy simulation
- Limited understanding or inadequate over-simplification on OB;
- In-depth quantitative analysis urgently needed;
- Over 20 groups all over the world studying OB individually
- International cooperation is extremely important for both knowledge gaining and data sharing

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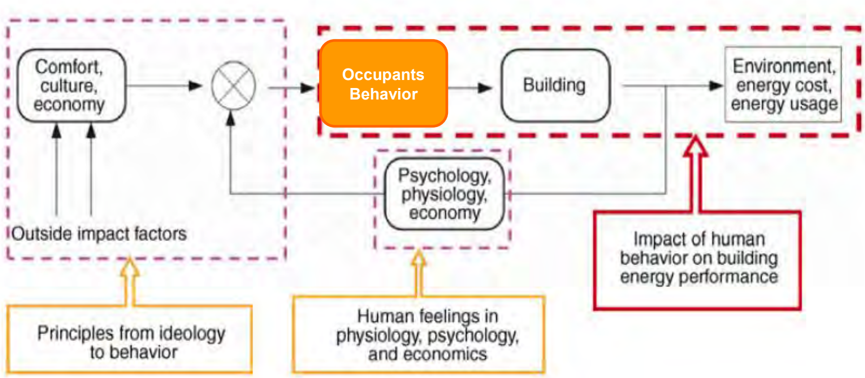
Research Target

- Identify quantitative description and classification of OB
- Develop effective calculation methodologies of OB
- Implement OB models with building energy simulation tools
- Demonstrate the OB models in design and operation optimization by Case Studies

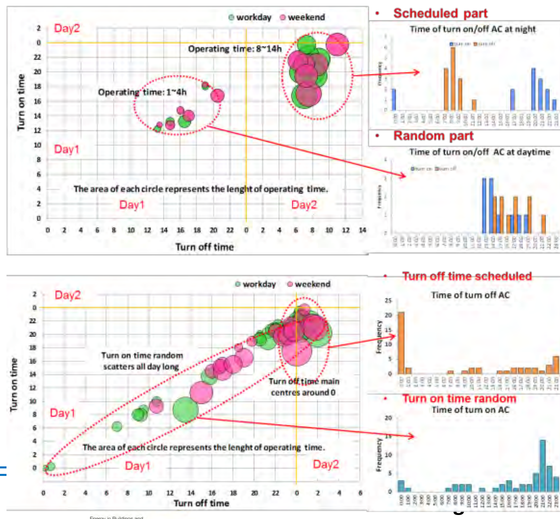
Challenges

- **Relationship between occupants and buildings**



Challenges

- **OB is stochastic and complex**



Family A:
Two kinds of cooling operation behavior

- **Scheduled part**: mostly turn off at 8:00, 12h
- **Random part**: turn on/off during 13:00-19:00, 2h

Family B:
Different pattern for turn on/off point

- Turn off schedule: at 0:00
- Turn on randomly during the whole day, but probability is bigger at 21:00

Challenges

- **Comparison with the Typical Meteorological Year (TMY)**

	Typical Meteorological Year	**Occupant Behaviour**
Common Points	A complex, time serial and stochastic process	
	Both are key issues for building energy simulation	
	Aim to represent the key physical characteristics, not for forecasting	
Study Output	TMY data sorts for different cities globally	**Typical OBs definition and classification for simulation**

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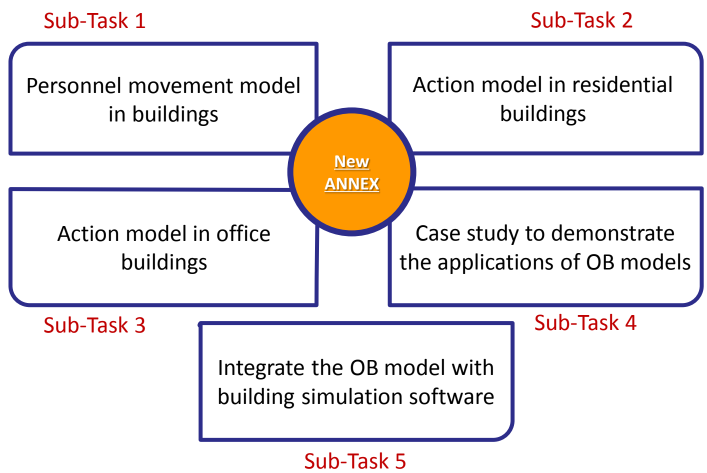
Technical Approach

Targeting Building types:

Residential buildings & Office buildings



Outcomes & Audience

	Outcomes	Target Audience
1	Personnel movement model and calculation method in buildings	**Building Energy Researchers** **Simulation Software Developers**
2	Action model and calculation method in residential and office buildings	
3	Software to simulate OB, integrated with a building thermal and energy model	**Building Designers** **Energy Saving Evaluators** **HVAC Engineers** **System Operators** **Energy Policy Makers**
4	Case studies to demonstrate applications of the new OB definitions and models	

Confirmed Participants

16 Countries

No.	Country	Name	Institute
1	China	Da Yan	Tsinghua University
		Song Pan	Beijing University of Technology
		Ting Shi	China Vanke Co. Ltd
2	USA	Tianzhen Hong	LBNL
		Khee Poh Lam	Carnegie Mellon University
3	Canada	Liam O'Brien	Carleton University
4	Italy	Stefano Corgnati	Politecnico di Torino
5	Norway	Natasa Nord	Norwegian University of Science and Technology
6	Denmark	Bjarne W. Olesen	Technical University of Denmark
		Henrik Madsen	Technical University of Denmark
7	Netherlands	Jan Hensen	Eindhoven University of Technology
		Peter Op 't Veld	Cauberg huygen
		Wouter Van Marken Lichtenbelt	Cauberg huygen
		Ad van der Aa	Cauberg huygen
		Heijnen Piet	Cauberg huygen

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Confirmed Participants

16 Countries

No.	Country	Name	Institute
8	Spain	Stoyan Danov	ICNME
9	UK	Darren Robinson	The University of Nottingham
10	Australia	Astrid Roetzel	Deakin University
		Dong Chen	CSIRO
11	Germany	Marcel Schweiker	Karlsruhe Institute of Technology
		Hanna Soldaty	IGS at Technical University Braunschweig
		Christoph van Treeck	Technische Universität München
12	Denmark	Per Heiselberg	Aalborg University
13	Austria	Ardeshir Mahdavi	Vienna University of Technology
14	France	Francois-Pascal Neirac	MINES Paris Tech
		Bruno Duplessis	MINES Paris Tech
15	Hong Kong	Joseph Lai	BSE
		Ming Yin Chan	BSE
		Sam C. M. Hui	The University of Hong Kong
16	Sweden	Joakim Widen	Uppsala University

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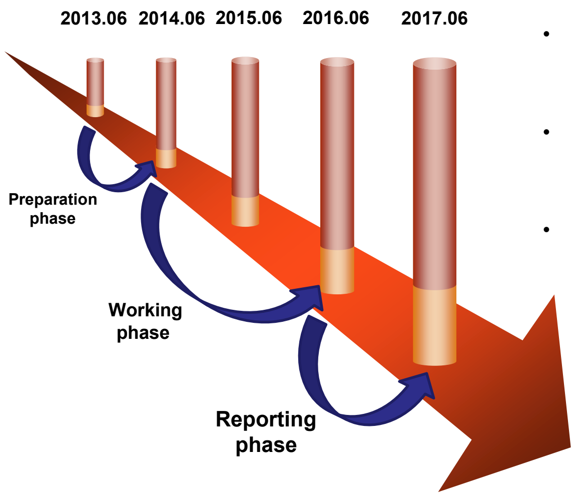
WORK PLAN



- **Preparation phase**
  - One year (2013.6 — 2014.6)
- **Working phase**
  - Two years (2014.6 — 2016.6)
- **Reporting phase**
  - One year (2016.6 — 2017.6)

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Summary

- OB has great influence on building energy usage and also technology evaluation
- There is still lack of quantitative methods for OB description and simulation
- An international cooperation is necessary and urgent for both knowledge and data sharing
- This concept proposal focus on OB description, simulation and applications
- Research deliverables of this research will directly benefit designers, engineers, researchers, simulation software developers, etc.

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Thank you for your attention!

EBC

Energy in Buildings and Communities Programme

Behavior is the New Green

Lawrence Berkeley National Laboratory

CERC-BEE Forum

July 2013

Outline

- Overview: Behavioral Nudges (with examples)
- What is a behavior-based EE program?
- Why is evaluation of these programs hard?
- How can we be confident that the energy savings are valid?
- What are key guidelines on best practice methods (and why are RCTs the gold standard)?

Outline

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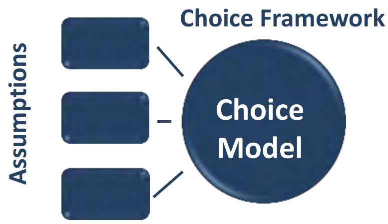
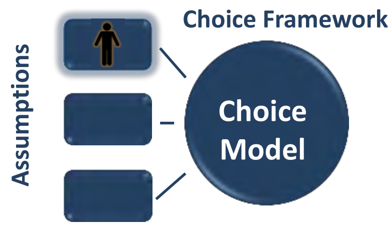
Standard Economics Assumptions



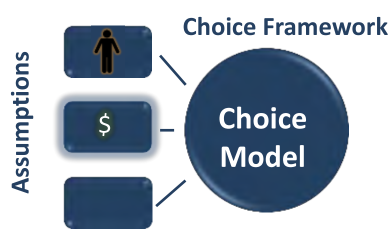
- Standard model assumptions include:

Standard Economics Assumptions



- Standard model assumptions include:
  - People make decisions to optimize their own happiness

Standard Economics Assumptions



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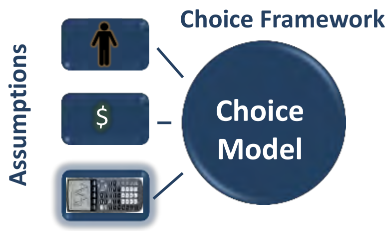
  - Scarcity in the world requires people to make tradeoffs

Standard Economics Assumptions



- Standard model assumptions include:
  - People make decisions to optimize their own happiness
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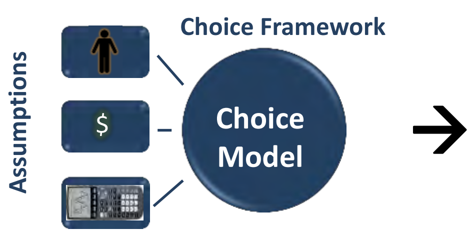
  - People have the cognitive ability to accurately solve this decision

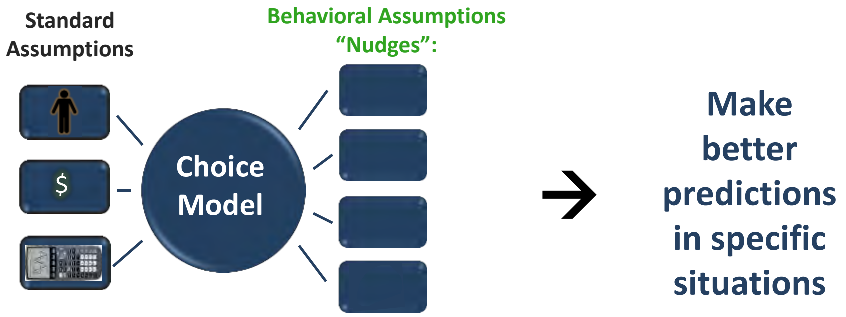
Standard Economics Assumptions



Good at Predicting Behavior (on average, in long run)

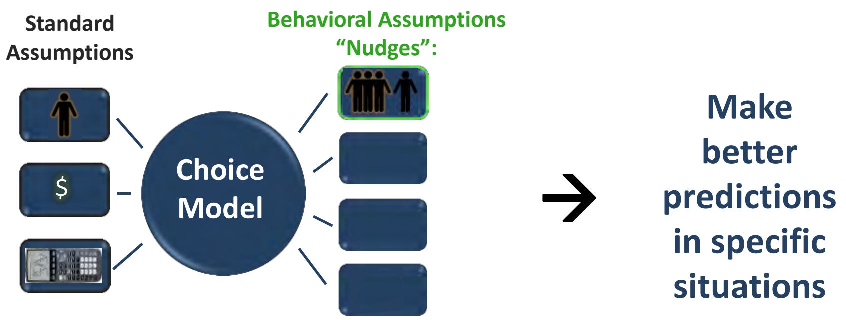
- Standard model assumptions include:
  - People make decisions to optimize their own happiness
  - Scarcity in the world requires people to make tradeoffs
  - People have the cognitive ability to accurately solve this decision
- Result: a simple, generalizable model that is good at predicting people's behavior in many different situations – on average, and in the long run

Behavioral Economics



- Behavioral economics adds some psychological insights, or "Nudges":

Behavioral Economics



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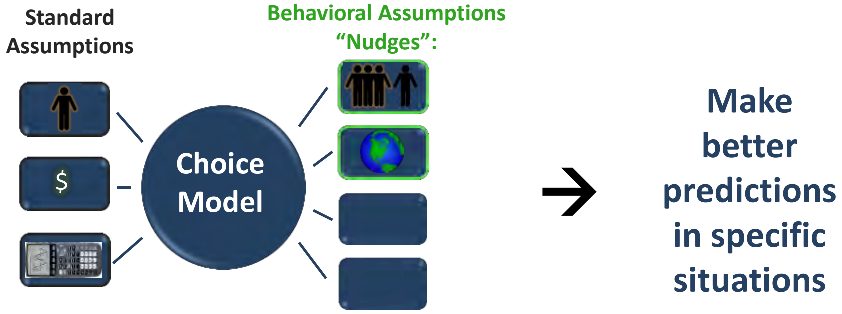
  - Social Preferences – people care about what others are doing

Behavioral Economics



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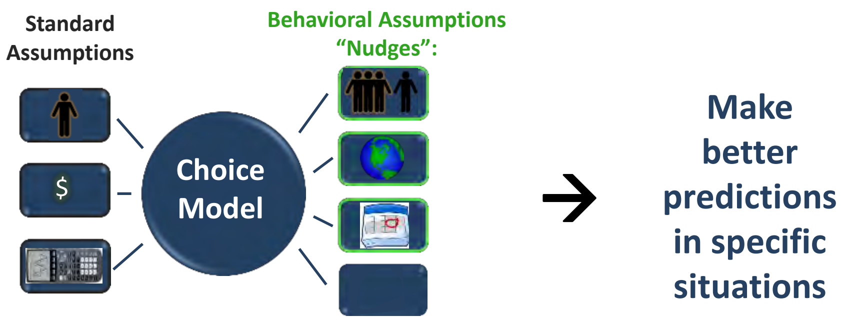
  - Internal Motivation – people actually have non-monetary motivations

Behavioral Economics



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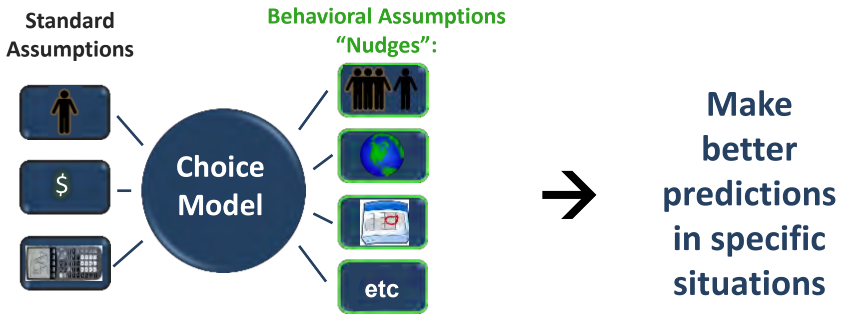
  - Time Discounting – people procrastinate

Behavioral Economics



- Behavioral economics adds some psychological insights, or “Nudges”:
  - Social Preferences – people care about what others are doing
  - Internal Motivation – people actually have non-monetary motivations
  - Time Discounting – people procrastinate
- 6 examples of Nudges

Nudge 1: Internal vs. External Motivation

- **Nudge 1: external vs. internal motivation**
  - Different types of motivation: money, altruistic, fun…..
  - Not additive: small external rewards can “crowd out” internal motivation
  - Offering people a small reward can actually *reduce* their effort
  - Remember to turn off lights….get 1 cent! (Motivating?)

Example: Internal vs. External Motivation

- Home upgrade program – motivate people to get home audits, invest in energy efficient home improvements
- One strategy: pay homeowners to go through the program, and have them sell the program to their neighbors
- This strategy was ***much*** less successful than simply having households who went through voluntarily sell the program
- There are many other examples of this in other fields

Nudge 2: Competition, gaming

- **Nudge 2: competition / bragging rights**
  - Competition is motivating
  - Think about Farmville and other online games
  - If we could harness this motivation to get people to save energy…

Competition Example

- Program that had towns in Connecticut compete against each other for a prize (solar installation)
- Motivate customers to perform several actions…
- Each individual action gets a certain amount of points towards town total.

Competition Example

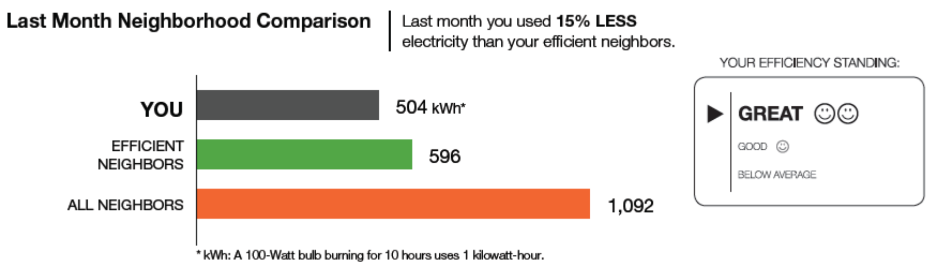
- "Vermontivate" game – Towns are teams, team competition
- Points given for energy efficient activities and engagement
- Teams began helping team members – developed a larger sense of 'team', more motivating than simple educational information

Nudge 3: Social Norms

- **Nudge 3: Social Norms**
  - We care about what other people are doing
  - We want to know what the “right” thing to do is
  - How do you compare to what others are doing?

Social Norms: Real World Example

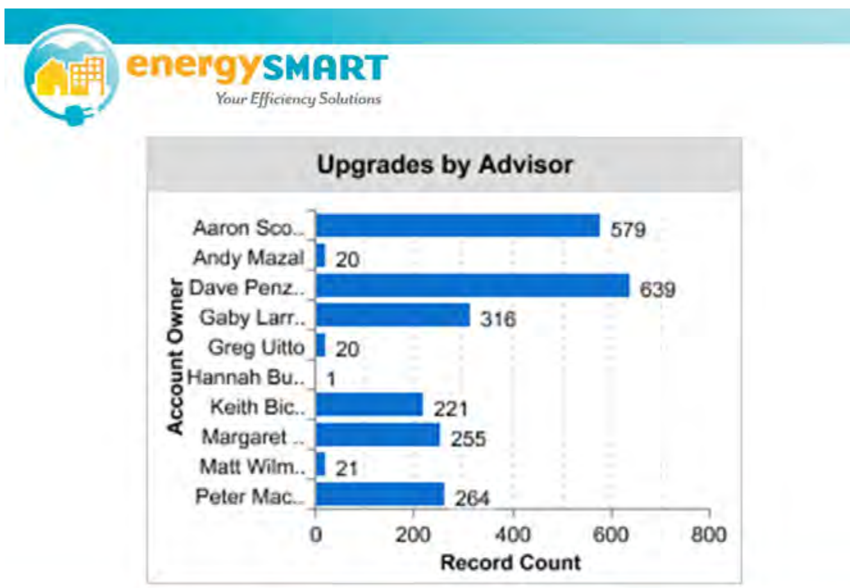
- Energy example – Opower (~1-2% savings):



Nudge 4: Social Approval

- **Nudge 4: Social Approval (or Disapproval)**
  - Last Nudge – what are others doing? This Nudge – what do others think we are doing?
  - Other people's opinions of us matter
  - Publicizing people's actions can be motivating
  - People are much more willing to contribute money or effort if they are publicly recognized (or shamed)

Example: Public leader board for "Energy Advisors"



Nudge 6: Defaults (Opt-in or Opt-out)

- **Nudge 7: Defaults**
  - People are likely to choose the default option
  - Opt-in programs: default is to not join, most people do not join
  - Opt-out: default is to join, most people join (by virtue of not opting out)
  - Seems obvious, but standard econ theory would say people are being given exactly the same choice (join or not join), so "rational" people will make the same decision regardless of whether it's framed as opt-in or opt-out

Opt-in or Opt-out: Real World Example

- LBNL and DOE research is looking to see how customers accept and respond to such rates under these different enrollment approaches using experiments

- Results – (not surprising)
- More people participate in opt-out program (default is to join) than opt-in program (default is to not join)

Nudge 7: Time Discounting

- **Nudge 8: Time discounting**
  - Standard theory: people *should* discount the future at a rate that is comparable to other decisions in their lives
    - If the best interest rate you can get is 10% , you should also prefer $111 in one year over $100 today
  - People *actually* discount the future much more than is “rational”
    - People prefer $100 today over $111 in one year (and over $140 in one year = 40% implicit discount rate)
  - Two selves: current self, future self
  - People procrastinate, people don’t want to pay up front costs, would rather have immediate gratification

Time Discounting: Real World Example

- Example: Regular vs. EE Refrigerator

VS

Up front cost:	**$**	**$$**
Total cost:	**$$$**	**$**

  - People are unwilling to pay more up front for EE refrigerators, even if it would save them money in the future
  - Data: people require an implicit discount of **45% to 130% !!**
  - These people would reject savings account with 44%??

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- **What is a behavior-based EE program?**
- Why is evaluation of these programs hard?
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What is a behavior-based EE program?

Behavior-based energy efficiency programs are those that utilize strategies intended to affect consumer energy use behaviors in order to achieve energy and/or peak demand savings. Programs typically include outreach, education, competition, rewards, benchmarking and/or feedback elements.

- Programs that affect the way that consumers use energy (without using traditional methods, such as rebates or time-based tariffs)
- Instead, use simple psychological levers (Nudges) or information to change behavior

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What are the potential benefits and concerns of behavior-based programs?

Potential Benefits

- In theory, potentially cheap to implement and result in significant energy savings → **cost effective**
- Currently, some **examples** of well designed, rigorously evaluated programs that show savings
- As a result, increasingly being **adopted nationwide**

Potential Concerns

- These programs are **relatively new**
- Don't have a lot of evidence of energy savings in different types of programs, different situations, and program persistence is unclear
- Potential for unsubstantiated claims (anecdotal evidence)

Why is rigorous evaluation crucially important?

→ It is very important to accurately evaluate the effectiveness of these programs

- For planning purposes - gain information about how well different types of programs work in different situations
- For validly claiming energy savings

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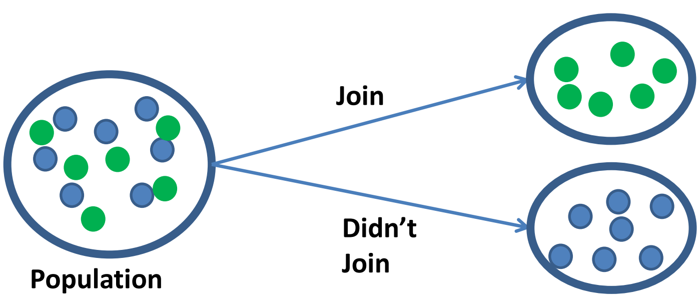
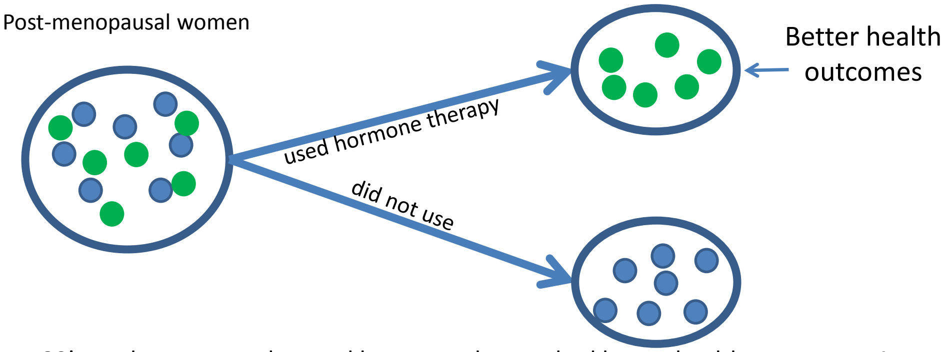
Why is evaluation of these programs hard?

- Strong problem of **"Selection Bias"**: households that join (e.g., opt-in, screened) are fundamentally different



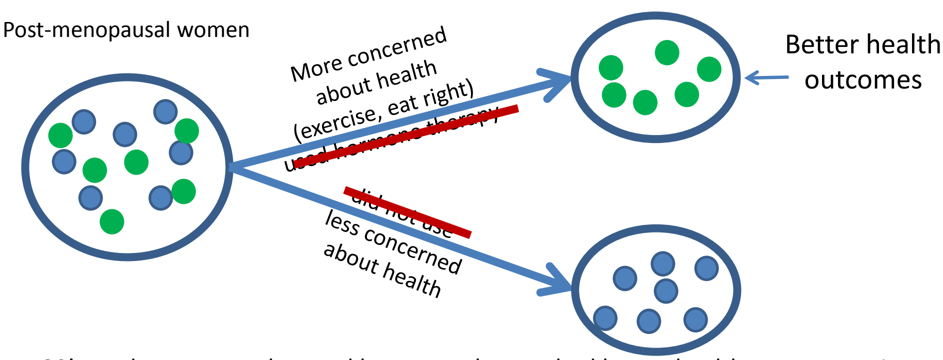
- Observed differences *might* be due to program, but might just be a difference between groups
- Selection bias can skew the results of the evaluation

Example: Post-menopausal hormone therapy



- 80's study: women who used hormone therapy had better health outcomes. As a result, doctors recommended it to all post-menopausal women.

Example: Post-menopausal hormone therapy



- 80's study: women who used hormone therapy had better health outcomes. As a result, doctors recommended it to all post-menopausal women.
- Rigorous RCT study: hormone therapy has ***negative*** impacts - what happened?
- **Selection bias** in the non-RCT study: women who chose to use hormone therapy were different types of women
- Better health outcomes were because the two groups were different, NOT because of hormone therapy

Why is evaluation of these programs hard?

- Behavior-based programs may be difficult to rigorously evaluate compared to other programs (e.g., appliance rebates):
  - **Savings are *relatively small*** (often 1-5%), so if an evaluation is biased (off by a few percentage points), could change conclusions about how effective the programs are
  - **Currently, less of a foundation for engineering estimates.** (What behaviors are people doing to save energy?)

Why is evaluation of these programs hard?

→Bad evaluation could lead to bad policy decisions

- Implement programs that are not cost effective
- Screening out programs that may be cost effective

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Outline

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- What are key guidelines on best practice methods (and why are RCTs the gold standard)?

"EM&V for Residential Behavior-Based Energy Efficiency Programs: Issues and Recommendations"

- This report provides guidance and best practices
  - For program design, analysis and evaluation methods

→ Ensure a **high degree of confidence** that estimated program energy savings impacts are **valid**

- Guidance is based on:
  - Consensus of researchers in many different fields and environments
  - Vetted by ~75 reviewers: technical, academics, program administrators, regulatory agencies, industry stakeholders

Outline

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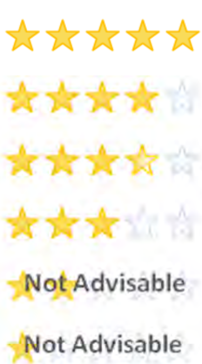
- **What are key guidelines on best practice methods (and why are RCTs the gold standard)?**

Key recommendation 1: use a randomized controlled trial (RCT)



- Randomized controlled trial (RCT)
- Regression discontinuity
- Variation in adoption
- Propensity score matching
- Non-propensity score matching
- Pre-post comparison

40

Key recommendation 1: use a randomized controlled trial (RCT)

★★★★★ Randomized controlled trial (RCT)

Regression discontinuity

- Primary recommendation – a program that is designed as a RCT results in:
  - Transparent, straightforward analysis
  - Robust, accurate, valid program impact estimates
  - **High degree of confidence in program evaluation**
  - RCTs are the gold standard

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Key recommendation 1: use a randomized controlled trial (RCT)

★★★★★ Randomized controlled trial (RCT)

Regression discontinuity

- Why is designing a program as a (RCT) so important?
  - RCT means that households are assigned to the program randomly (as opposed to household choice or screening criteria)
  - Solves selection bias

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Key recommendation 1: use a randomized controlled trial (RCT)

★★★★★ Randomized controlled trial (RCT)

★★★★☆ Regression discontinuity

- RCTs have many different forms
- Can be used for Opt-in, Opt-out programs

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Questions?

- Many guidelines and technical recommendations in the EM&V report:
  - SEE Action website, www.seeaction.energy.gov
  - Lawrence Berkeley National Lab website: behavioranalytics.lbl.gov
- LBNL and DOE research: http://emp.lbl.gov/reports/drsg
  - Specific report on opt-in opt-out:
  - http://emp.lbl.gov/publications/summary-utility-studies-smart-grid-investment-grant-consumer-behavior-study-analysis

Annika Todd: atodd@lbl.gov

Additional Recommendations

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Key recommendation 1: use a randomized controlled trial (RCT)

	Randomized controlled tri
	Regression discontinuity
	Variation in adoption
	Propensity score matching
Not Advisable	Non-propensity score matching
Not Advisable	Pre-post comparison

- If RCTs are not feasible, acceptable "quasi-experimental" methods
  - More opaque, complex analysis
  - Quasi-experimental methods try to correct for selection bias
  - Lower degree of confidence in validity of savings estimates

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Key recommendation 2: avoiding potential conflicts of interest

- **Problem:** potential for a conflict of interest to arise regarding the validity of savings estimates
- **Recommendation:**

★★★★★ A third-party evaluator transparently defines and implements:

- Program evaluation
- Assignment of households to control and treatment groups
- Data selection and cleaning

Not Advisable — Program implementer or sponsor implements any of the above

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Key recommendation 3: accounting for potential double counting of savings

- **Problem**: the same savings may be claimed by two programs (e.g., a behavioral program & appliance rebate program both claim savings from appliances)
- **Recommendation:** estimate this "double counted savings" overlap to the extent possible by comparing control to treatment group
  - Easier for programs that can be *tracked* at the household level (e.g. installation of insulation by a contractor)
  - Should account for the measurement period (e.g., accounting for seasonal load impacts), and the effective useful lifetime of installed measures (when lifetime savings are reported)
  - Program costs should be appropriately allocated along with double counted saving

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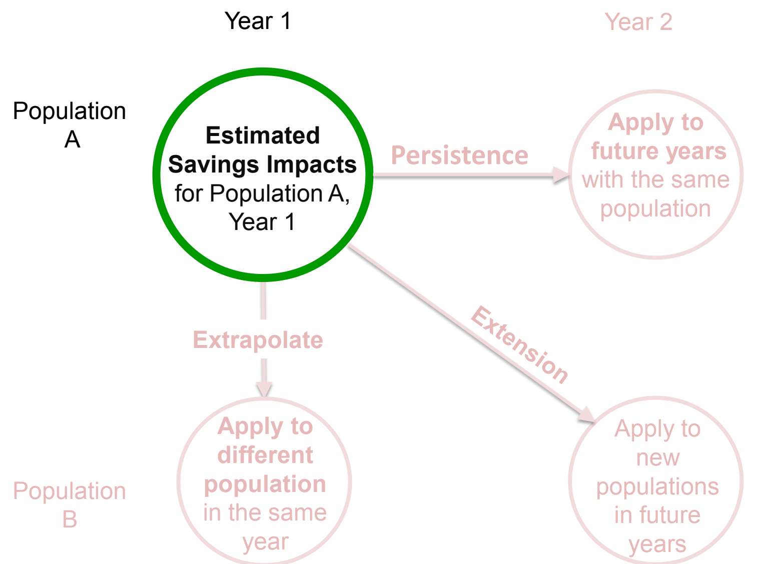
Key recommendations 1,2,3 address internal validity (for a given population, time frame)



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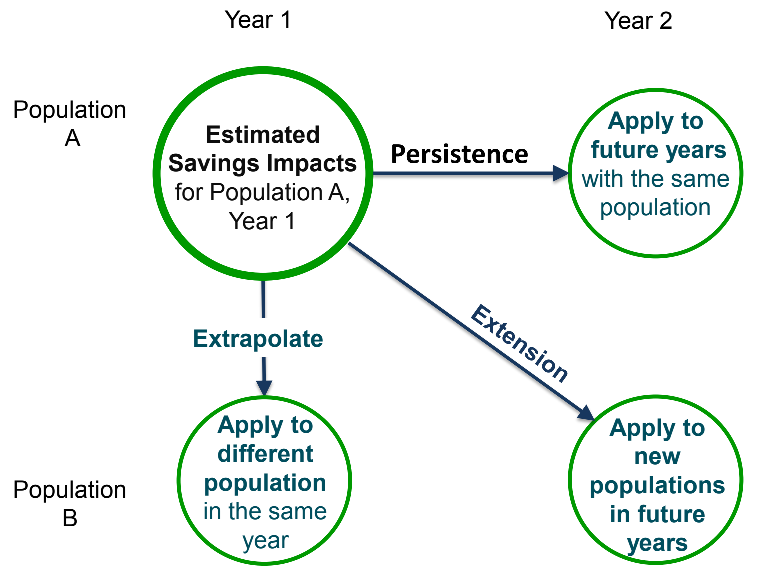
Recommendations for external validity: can the savings be applied to new situations?



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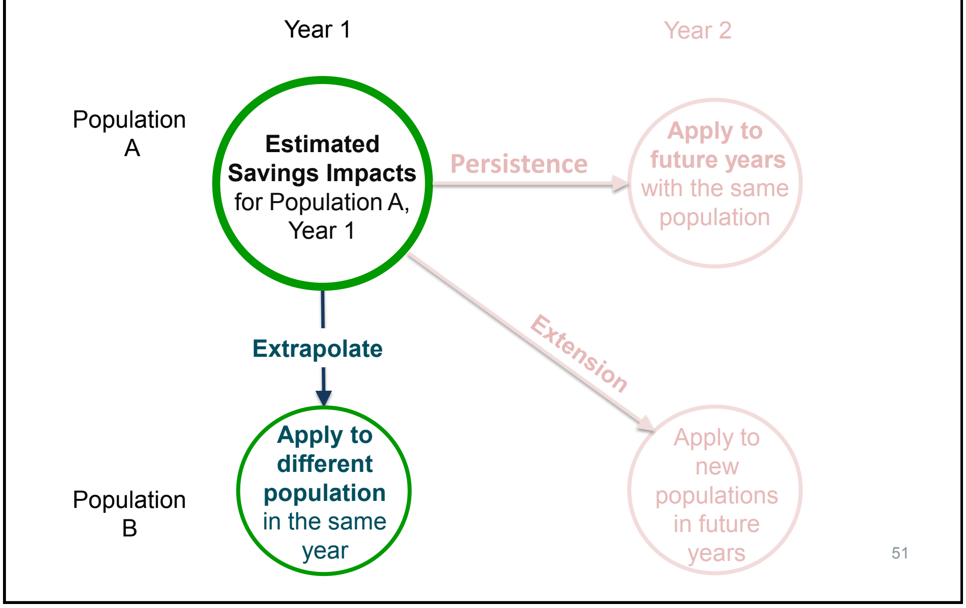
Are the savings applicable to different populations?



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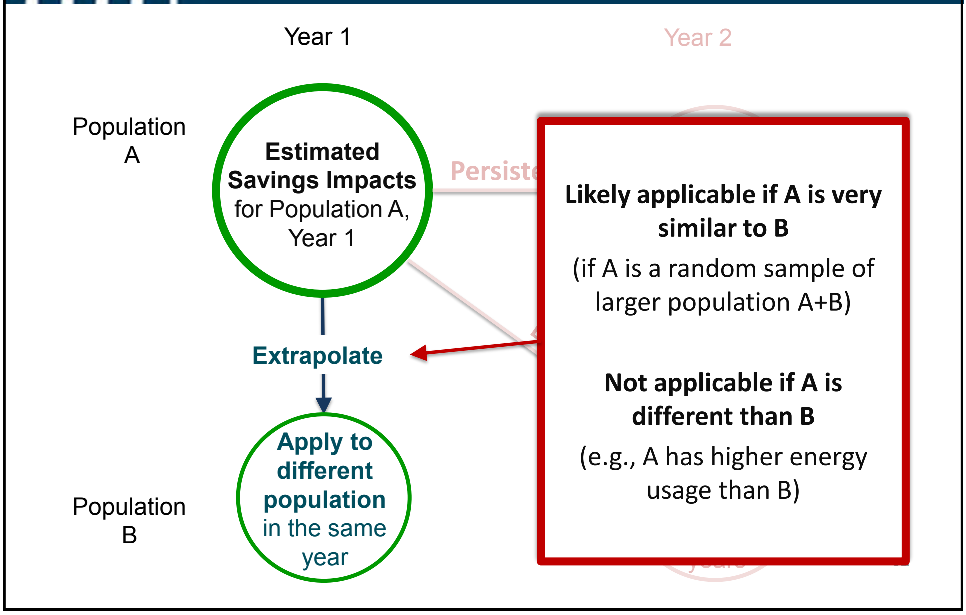
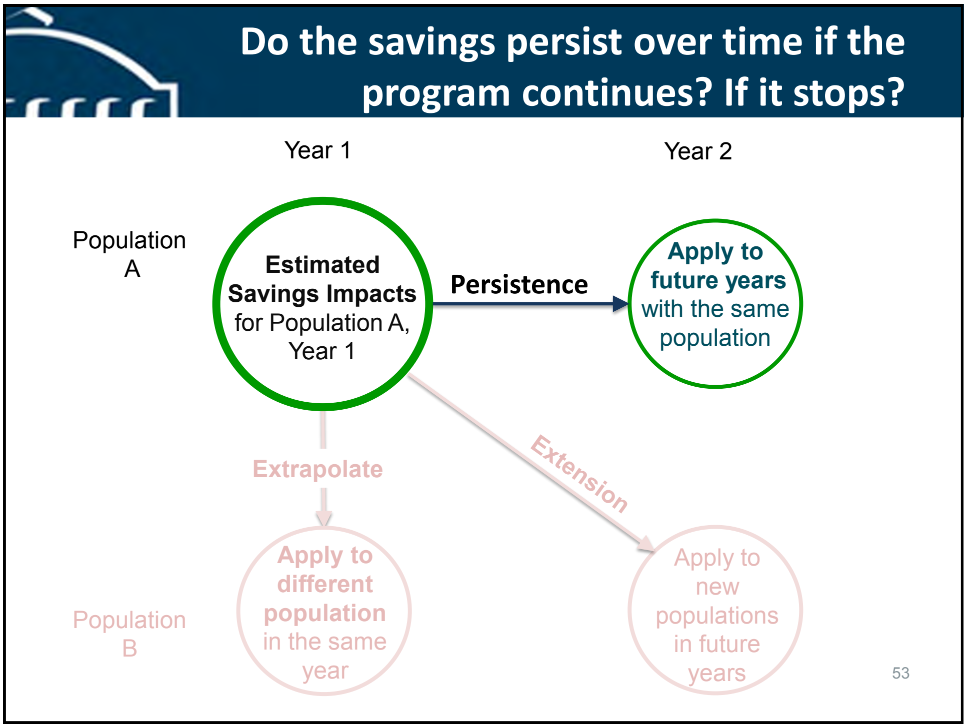
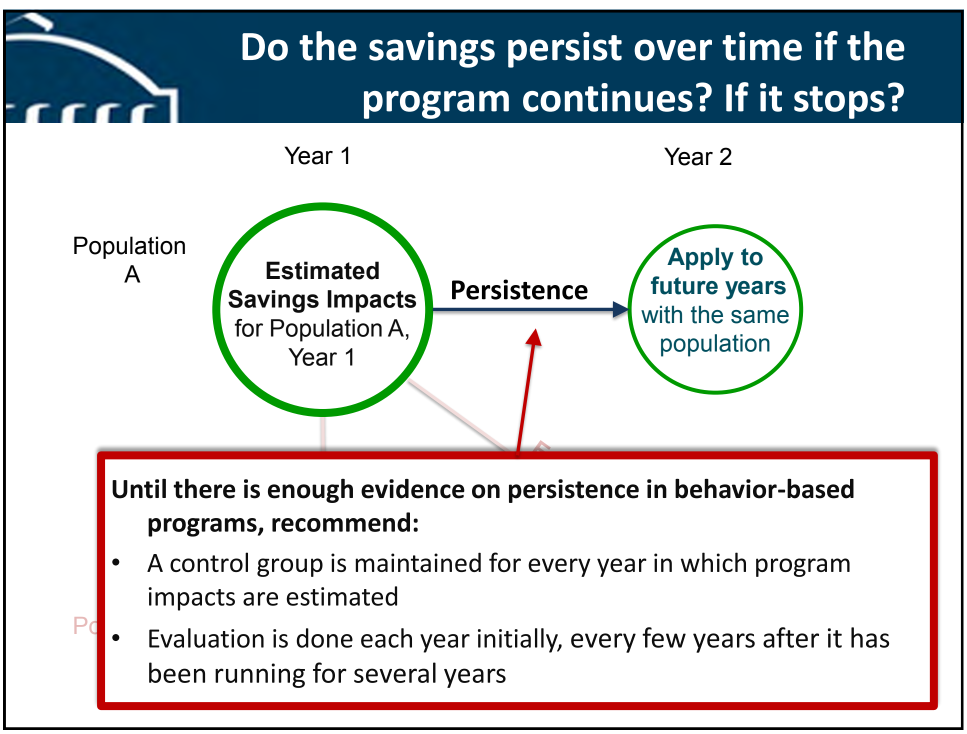
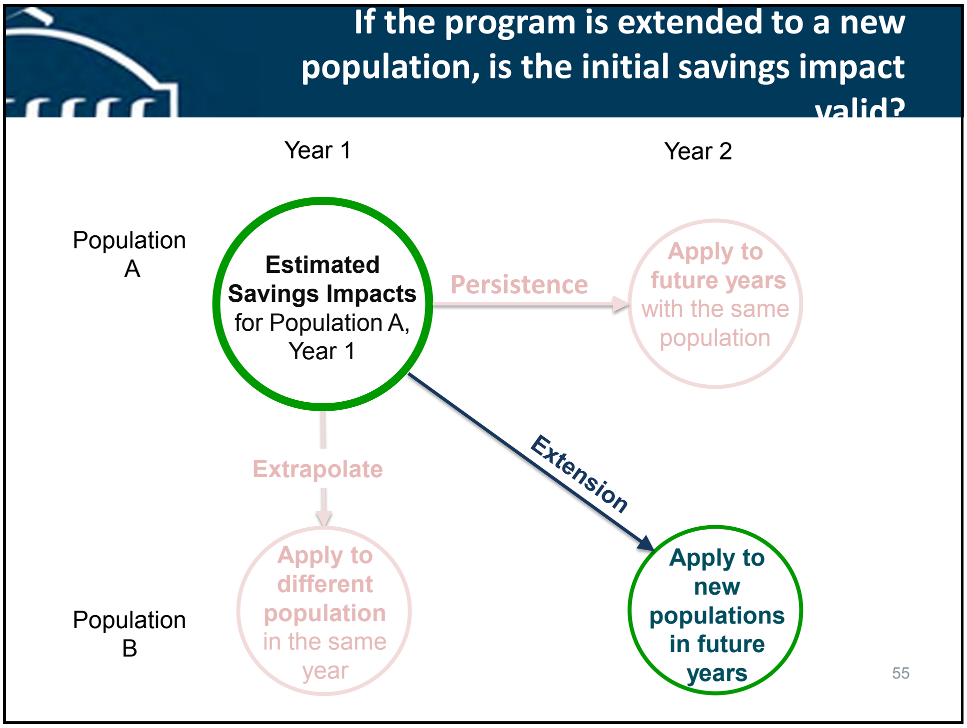
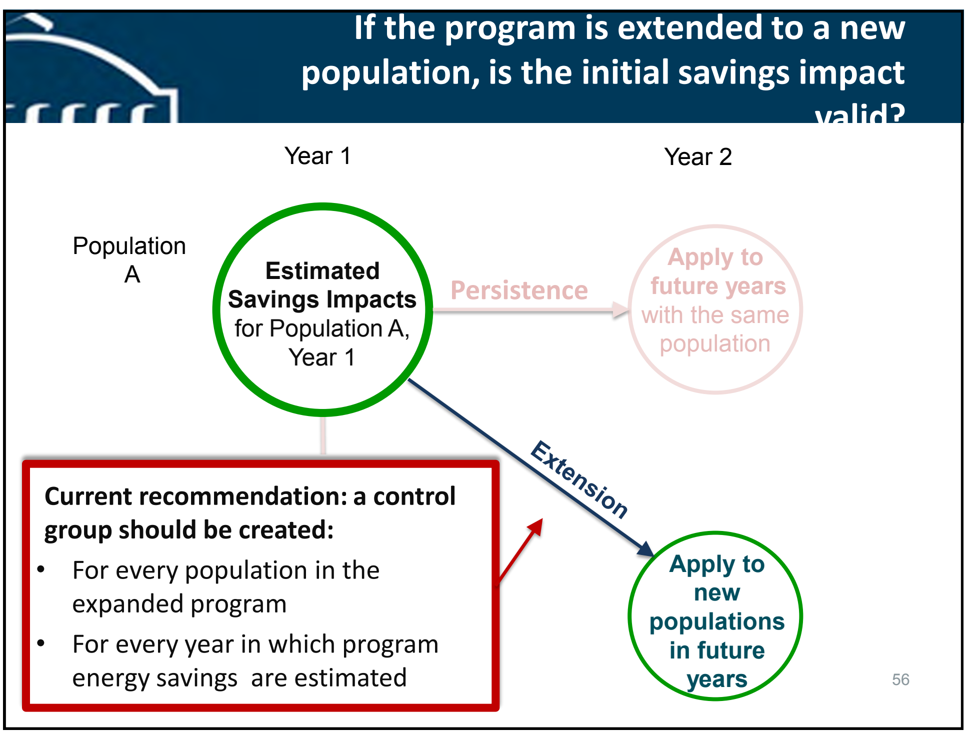
Are the savings applicable to different populations?




Do the savings persist over time if the program continues? If it stops?
Year 1
Year 2
Population A
Estimated Savings Impacts for Population A, Year 1
Persistence
Apply to future years with the same population
Extrapolate
Extension
Population B
Apply to different population in the same year
Apply to new populations in future years
53


Do the savings persist over time if the program continues? If it stops?
Year 1
Year 2
Population A
Estimated Savings Impacts for Population A, Year 1
Persistence
Apply to future years with the same population
Until there is enough evidence on persistence in behavior-based programs, recommend:
• A control group is maintained for every year in which program impacts are estimated
• Evaluation is done each year initially, every few years after it has been running for several years


If the program is extended to a new population, is the initial savings impact valid?
Year 1
Year 2
Population A
Estimated Savings Impacts for Population A, Year 1
Persistence
Apply to future years with the same population
Extension
Extrapolate
Apply to different population in the same year
Population B
Apply to new populations in future years
55


If the program is extended to a new population, is the initial savings impact valid?
Year 1
Year 2
Population A
Estimated Savings Impacts for Population A, Year 1
Persistence
Apply to future years with the same population
Extension
Current recommendation: a control group should be created:
• For every population in the expanded program
• For every year in which program energy savings are estimated
Apply to new populations in future years
56

In the future, can we move away from RCTs into a deemed savings approach?

Once we have multiple years of conclusive evidence:

- Move away from RCTs (can be costly), towards a deemed savings approach
- Credibly predict persistence and rollouts to new populations
- For both planning and claiming savings purposes

→ **We are not yet at this point!**

Year 2

Persistence

Apply to future years with the same population

Extension

Apply to new populations in future years

Extrapolate

Population B

Apply to different population in the same year

57

Conclusions & next steps

- **Main point:** if the recommended methods are used (gold standard is RCTs), then we can be confident that the program's energy savings are valid
- **This issue is timely**
  - Around 40 utilities are currently offering behavior-based EE programs, considering going system wide
- **New research provides insights into:**
  - Persistence of behavior-based programs
  - What behaviors are causing the savings

58

Additional Technical Recommendations

Additional internal validity recommendations

- **Problem**: how to ensure that the estimate of program impact savings is precise enough, not risky
- **Statistical significance recommendation**:
  - Define null hypothesis (the required threshold, e.g., cost effectiveness)
  - Estimate considered acceptable if statistically significant at 5% (i.e., 95% confidence)
  - 5% statistical significance *NOT* the same as 95/5

Additional internal validity recommendations

- **Historical data recommendation**: collect twelve months or more of historical data
  - Especially if program design is quasi-experimental
- **Analysis recommendation**: the model specification (econometric techniques, e.g., regressions) should:
  - Use panel data (many data points over time) vs. aggregated data
  - Not include interaction variables
  - If quasi-experimental, compare the *change* in energy usage vs. energy usage

61

Excluding Data from Households that Opt-out or Close Accounts

Data cleaning: which households to exclude

★★★★★	Only data from households that closed accounts are excluded*; households that opt-out of the treatment or control group are included in the analysis (although the program impact estimate may be transformed to represent the impact for households that did not opt-out, as long as it is transparently indicated).
Not Advisable	Data from households that closed their accounts are included*
Not Advisable	Households that opt-out are excluded from the analysis

**If there is a compelling reason to include households that closed their accounts and the analysis is undertaken correctly to deal with unbalanced data sets, then it may be advisable.*

62

Cluster Robust Standard Errors

Ensure that the standard errors are robust and account for clustering

★★★★★	Cluster Robust Standard Errors or Time Aggregated Data
Not Advisable	Non-Cluster Robust Standard Errors with non-Time Aggregated Data

63

Equivalency Check

Validate that the control and treatment group are equivalent

★★★★★	An equivalency check is performed with energy use data as well as household characteristics
★★★	An equivalency check is performed with energy use data
Not Advisable	An equivalency check is not performed

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BERKELEY LAB

LAWRENCE BERKELEY NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

A framework to describe occupant behavior in buildings

Presenter

Will Turner, LBNL

July 18th 2013

Contents…

- The problem
- What we are doing
- The concept
- The framework
- Some examples
- The application (XML schema)
- Summary

The problem…

- Green buildings often fail to meet expected performance
- Technology alone does not guarantee high performance
- Human behavior can contribute significantly to building energy performance and IEQ
- But human behavior often overlooked in building simulations
- Existing behavior models suffer from lack of a common language and compatibility

To illustrate the problem…

Drivers for shade/blind operation (from lit review):

1	Outdoor vertical solar radiation
2	Outdoor direct solar radiation
3	Outdoor diffuse horizontal solar radiation
4	Outdoor global horizontal solar radiation
5	Solar elevation angle
6	Solar azimuth angle
7	Solar profile angle
8	Type of shade device (manual/automated)
9	Lighting control (manual/automatic)
10	Façade orientation
11	Operable windows
12	HVAC system
13	Façade height
14	Private vs. shared office
15	Views to outside
16	Window geometry
17	Office geometry

18	Solar penetration depth
19	Transmitted solar radiation (magnitude and geometry)
20	Shading from vegetation
21	Time of day
22	Season
23	Workplace illuminance
24	Previous shade position
25	Indoor dry bulb temperature
26	Outdoor dry bulb temperature
27	Privacy
28	Occupancy (arrival, intermediate)
29	Maximum window illuminance
30	Mean window illuminance or source illuminance
31	Indoor dry bulb temperature
32	Outdoor dry bulb temperature
33	Outdoor mean radiant temperature
34	Outdoor total solar radiation

What we are doing…

- Standardize description of occupant behavior for building simulations
  - Literature review of occupant behavior models
  - Developing a technical framework
  - Describe a complete set of occupant behaviors related to building energy and IEQ
  - Allow incorporation of existing and future behavior models
- Develop XML schema

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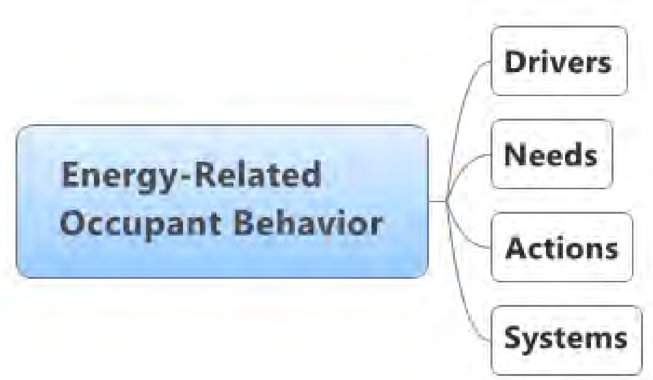
The concept…



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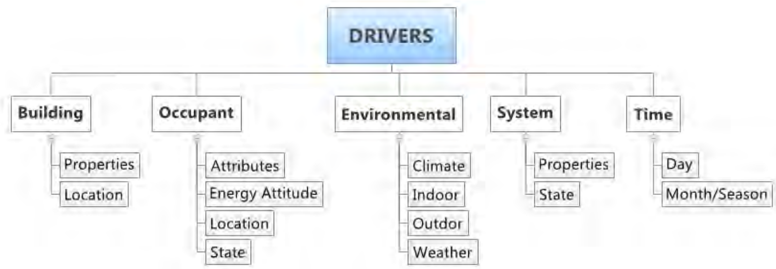
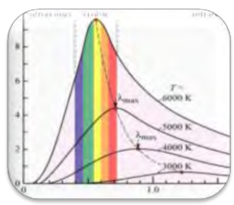
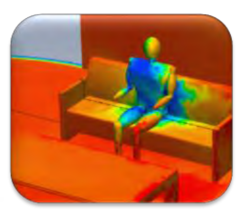
Drivers represent the stimulating factors that provoke energy-related occupant behavior





Needs represent the requirements of an occupant that must be met in order to ensure satisfaction with their environment



Actions are interactions with building systems or activities that an occupant can conduct in order to satisfy their needs

ACTIONS

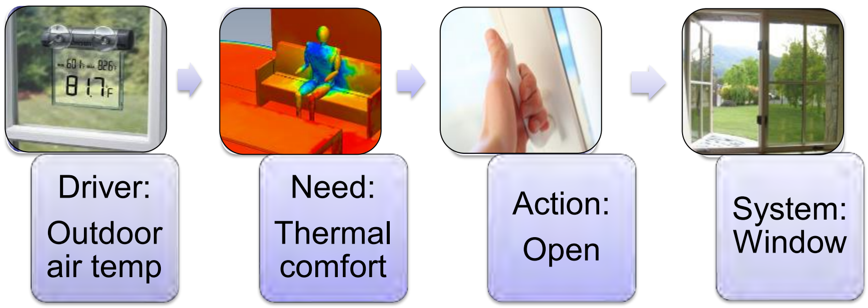
- Interact with system(s)
- Movement
- Inaction
- Report discomfort

Systems are the equipment or mechanisms with which an occupant may interact to restore comfort

SYSTEMS

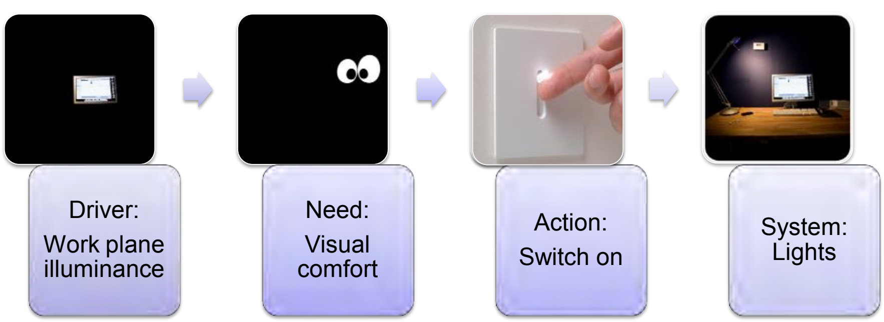
- Building transport
- Clothing
- Cooking
- Heating/ Cooling
- Hot water
- Lighting
- Openings
- Plug loads
- Solar shading
- Ventilation

Example 1 – Window opening



Nicol, J.F., 2001. Characterising occupant behaviour in buildings: towards a stochastical model of occupant use of windows, lights, blinds, heaters and fans. In Building Research & Information. Rio de Janeiro, Brazil, pp. 1073–1078.

Example 2 – Light operation



Hunt, D.R.G., 1980. Predicting artificial lighting use - a method based upon observed patterns of behaviour. *Lighting Research and Technology*, 12(1), pp.7–14. Available at: http://lrt.sagepub.com/cgi/doi/10.1177/096032718001200102 [Accessed June 5, 2013].

Example 3 – Complicated behavior 1/2

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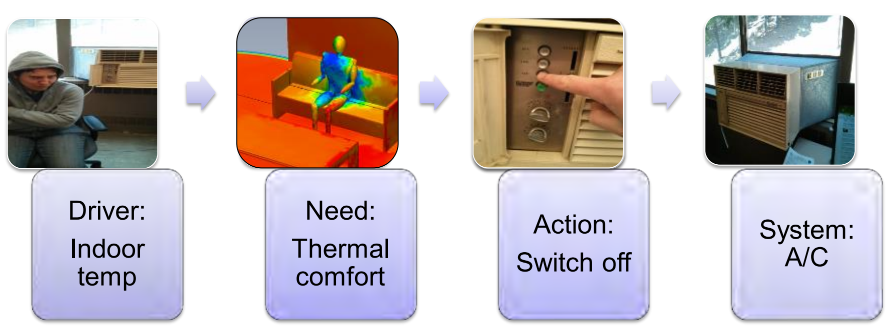
Example 3 – Complicated behavior 2/2



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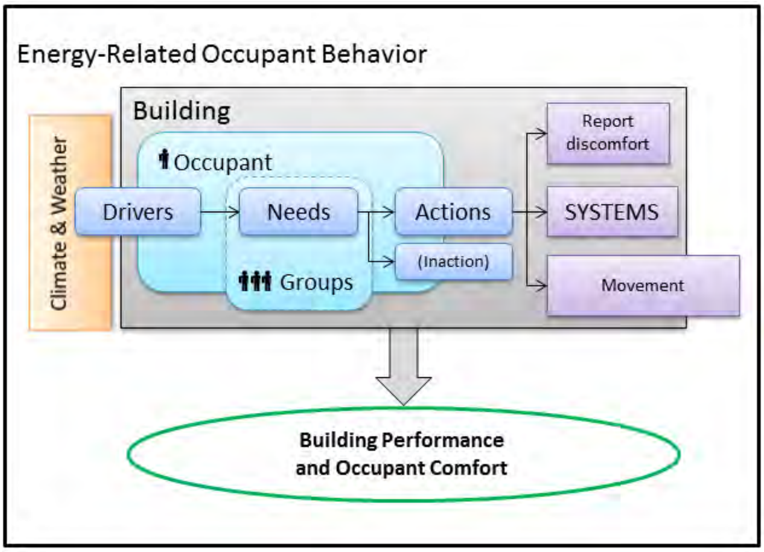
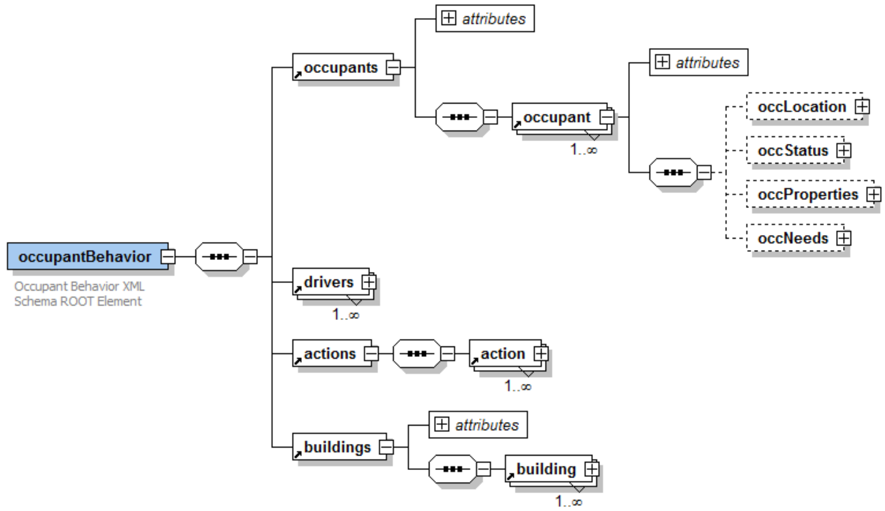
The DNAS framework



Applications for the framework

- Improve building simulation results to help:
  - Building design
  - Energy benchmarking and performance rating
  - Codes and standards
  - Policy decisions

The XML schema - *obXML*



Disclaimer!

- This is our first attempt at forming a framework
- Will only be useful if people use it (literally)
- Therefore, input and advice is very welcome so that we can improve the framework, and its utilization and adoption

Summary

- We are developing a framework to standardize the description of occupant behavior
- Standardizing occupant behavior will promote behavior model development and tool integration
- The application of the framework is building simulation – both energy and indoor environment
- We use a concept of drivers, needs, actions and systems
- An XML schema will facilitate the adoption of the framework


Building
Identifiers
Building ID
Name
Type
Skyscraper
Highrise
Multifamily
Detached
Semi-detached
Terraced
Factory
Hospital
School
Dwelling
Office
Residential/Commerical
Geographical
Latitude
Longitude
Elevation
IECC Climate Zone
Zip Code/Post code?
Country
Terrain
Properties
Volume
Conditioned floor area
Floors
Floor
Wings
Rooms
Room function
Max room occupants
Occupant IDs
Room systems
Room
RoomID
Construction
Date built
Energy Efficiency Level
Envelope tightness
OccupantPayBill
Gross Floor Area
Systems
Windows
Blinds
Lights
HVAC
Heating
Cooling
Ventilation
Internal transport
Plug loads
Portable fans
Portable heaters
Task lights
Others
Hot water
Cooking
ProcessEquipment
Occupants
Occupant IDs
Occupant locations
Floors
Floor
Rooms
Room


Occupant
Identifiers
Properties
Needs
Status
Location

A software module to simulate occupant movement

Xiaohang Feng
Tsinghua University / LBNL
07/18/2013

1. Background
2. Technical approach
3. Literature review
4. Selection of development tools
5. Software architecture
6. Application
7. Conclusions and future work

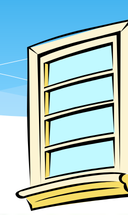
Background

* Occupancy has a great impact on building energy consumption, and is the basis of occupant behavior modeling, e.g. window opening/closing, HVAC system turning on/off, etc.

1. Some devices are controlled by occupancy sensors, e.g., lighting can be turned off if a space is unoccupied

Background

2. Occupant behavior varies between individuals, knowing who is in a space at a particular time is important



3. The number of occupants has an impact on the operation and performance of demand controlled systems

4. Some devices are attached to occupants, influencing the heat gains and energy use of a space

Background

* Simulating occupancy is fundamental for occupant behavior research. Our goal is to develop a software module for occupancy simulation, which can:

* 1) run stand-alone as an executable file;
* 2) be called by other simulation programs as a DLL;
* 3) be used for co-simulation with other simulation programs

Background

Occupancy models are required, and we categorize four types of occupancy models:

Building level – # of occupants
- Q: How many occupants are there in a building at a time?

Space level – occupied status
- Q: whether or not a space (room) is occupied?

Space level – # of occupants
- Q: How many occupants are there in a space at a time?

Occupant level - individual tracking
- Q: In which space an occupant is at a particular time?

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Technical Approach

Review and select models

↓

Select a development tool

↓

Develop software architecture

↓

Coding, testing and validation

↓

Application

1. Background
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Literature Review

* 1. Building level - # of occupants
  none found in the building energy domain
* 2. Space level – occupied status

Article	Pros	Cons
Modeling Occupancy Behavior for Energy Efficiency and Occupants Comfort Management in Intelligent Buildings (Tina Yu, 2010)	Relatively accurate, Existing algorithm	Require field data Limited to one occupant Less accurate for departure
Modeling occupancy in single person offices (Danni Wang et. Al, 2005)	Simple Matches with the observed Time varying	Limited to one occupant Occupancy intervals not fit well
Statistical analysis and modeling of occupancy patterns in open-plan offices using measured lighting-switch data (Wen-Kuei Chang et.al, 2013)	Apply to each occupant Easy to implement	Limited to one occupant No information when absent

Literature Review

3. Space level - # of occupants

Article	Pros	Cons
Space Layout in Occupant Behavior Simulation (Rhys Goldstein et. Al, 2011)	Space layout Different personas Possibilities related to distances	Detailed distance information Complicated schedules
Schedule-Calibrated Occupant Behavior Simulation (Rhys Goldstein et.al, 2010)	Quite accurate	Observed schedule needed Randomness
A generalised stochastic model for the simulation of occupant presence (Page et. Al, 2008)	No limitations to # of occupants Easy to implement	No information when absent
Customizing the Behavior of Interacting Occupants Using Personas (Rhys Goldstein et.al, 2010)	Interdependence of occupants	No spatial information

Literature Review

4. Occupant level - individual tracking

Article	Pros	Cons
A novel approach for building occupancy simulation (Chuang Wang et. al, 2011)	No constraint with the number of occupants and zones	Arithmetic speed problem
Occupant Dynamics: Towards a New Design Performance Measure. (Khaled Nassar et.al, 2007)	Randomness of walking Multiple zones and occupants	Calculation cost Detailed position of an occupant
Simulating the Sensing of Building Occupancy (Simon Breslav et.al, 2011)	Driver and action Independent modules	A little complex Much information to store
An Integrated Approach to Occupancy Modeling and Estimation in Commercial Buildings (Chenda Liao et. al, 2010)	Related with previous state Able to track when walking-around	Much information to input
User Simulation of Space Utilisation (Tabak Vincent, 2008)	Cover most activities	Divided into many categories Distance information

Literature Review

Summary:

* 1. Occupancy models often treat an occupant as an object, to study their presence or movement
* 2. For the building level occupancy modeling, no relevant literature was found in the domain of building energy simulation
* 3. For the room level, there are no direct models, instead number of occupants or occupancy status is found by summing the state or location of individual occupants
* 4. For the occupant level, there are detailed tracking models, but they need lots of user inputs which are sometimes hard to get

Tracking Model Introduction

* Core concept : Markov chains

Index of row: the state (room) occupied previously
Index of column: the state (room) occupied at present
Element: probability of transferring from state [index of row] to state [index of column]

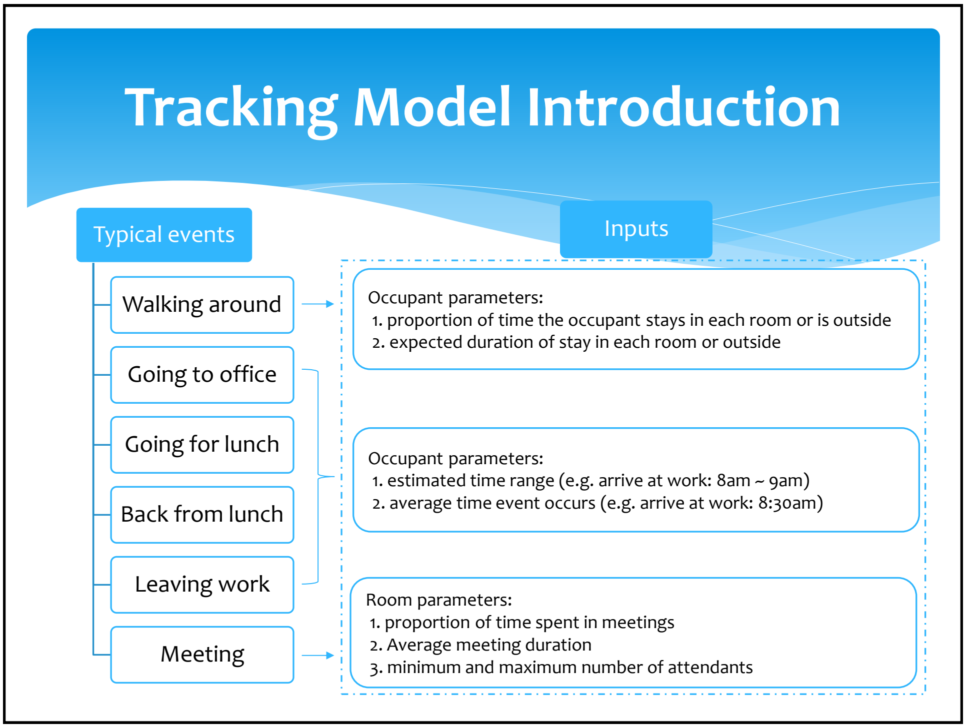
e.g.

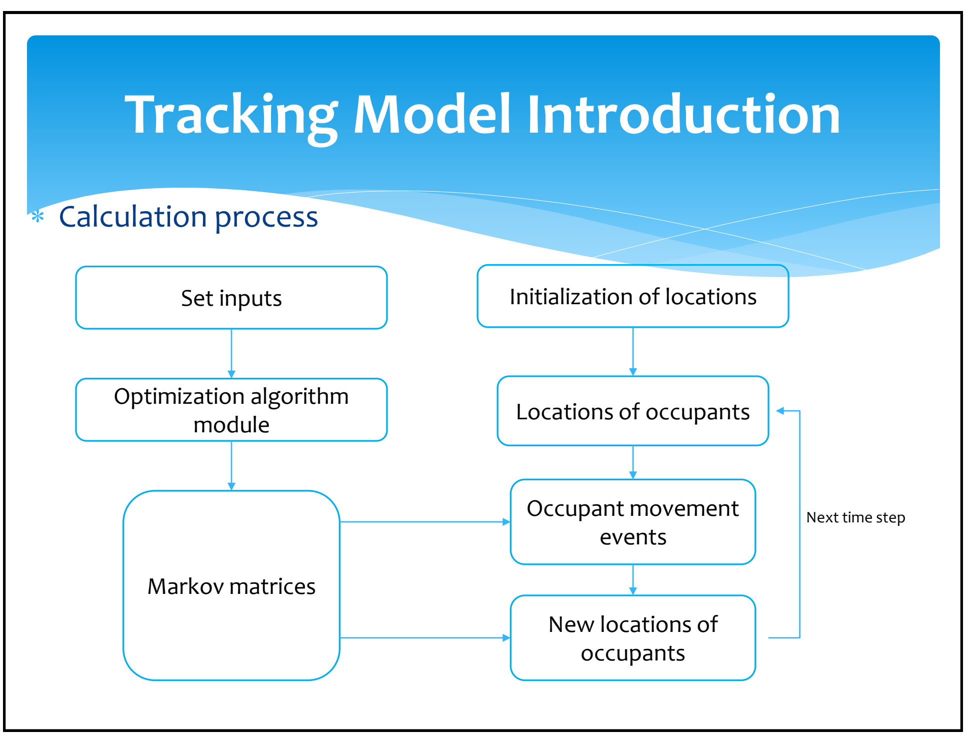
Room

$$\text{Room}\quad \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 0.2 & 0.3 & 0.5 \\ 2 & 0.3 & 0.4 & 0.3 \\ 3 & 0.1 & 0.6 & 0.3 \end{array}$$

0.5 denotes in room 1, there's a probability of 50% to transfer to room 3

Ref : Wang Chuang, Da Yan, and Yi Jiang. "A novel approach for building occupancy simulation." Building simulation. Vol. 4. No. 2. Tsinghua Press, 2011.


Tracking Model Introduction
Typical events
Inputs
Walking around
Going to office
Going for lunch
Back from lunch
Leaving work
Meeting
Occupant parameters:
1. proportion of time the occupant stays in each room or is outside
2. expected duration of stay in each room or outside
Occupant parameters:
1. estimated time range (e.g. arrive at work: 8am ~ 9am)
2. average time event occurs (e.g. arrive at work: 8:30am)
Room parameters:
1. proportion of time spent in meetings
2. Average meeting duration
3. minimum and maximum number of attendants


Tracking Model Introduction
Calculation process
Set inputs
Optimization algorithm module
Markov matrices
Initialization of locations
Locations of occupants
Occupant movement events
New locations of occupants
Next time step

1. Background
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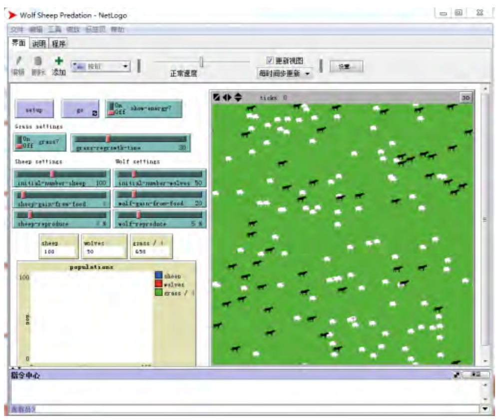
Development Tools

Agent based modeling:
A computational method that enables a researcher to create, analyze, and experiment with models composed of agents that interact within an environment.

High-level programming language:
A programming language with strong abstraction from the details of the computer. It may use natural language elements or may automate significant areas of computing systems, making the process of developing a program simpler and more understandable.

Object-oriented programming language:
A programming paradigm that represents concepts as "objects" that have data fields and associated procedures known as methods. Objects, which are usually instances of classes, are used to interact with one another to design applications and computer programs.

NetLogo

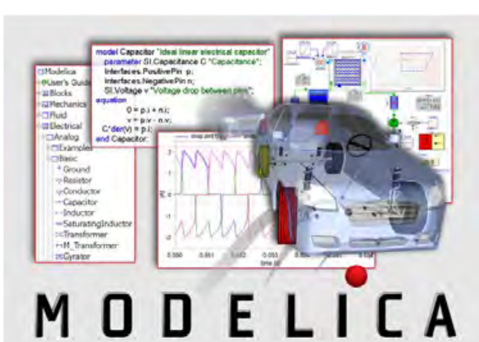


A programmable modeling environment for simulating natural and social phenomena.

Modelers can give instructions to hundreds or thousands of "agents" all operating independently.

This makes it possible to explore the connection between the micro-level behavior of individuals and the macro-level patterns that emerge from their interaction.

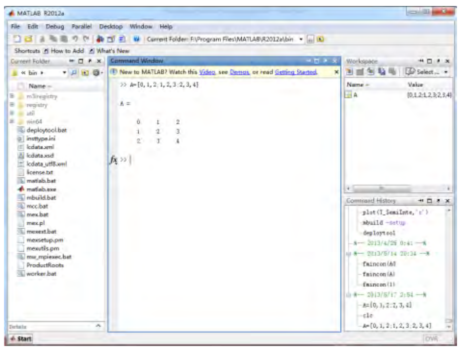
Modelica



Modelica is primarily a modeling language that allows specification of mathematical models of complex natural or man-made systems.

It's an object-oriented equation-based programming language, oriented toward computational applications with high complexity requiring high performance.

MATLAB

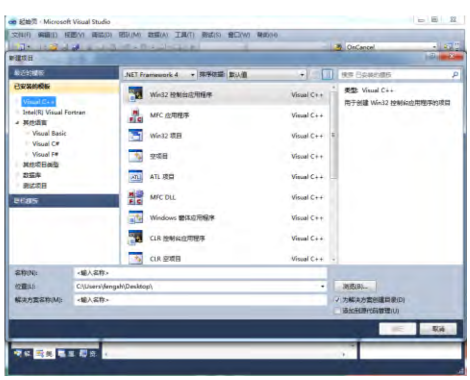


MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming.

Using MATLAB, you can analyze data, develop algorithms, and create models and applications.

The language, tools, and built-in math functions enable you to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages.

OOP languages



(C++ taken as an example)
C++ compiles directly to a machine's native code, allowing it to very fast, when optimized.

It offers remarkable support for procedural, generic, and object-oriented programming paradigms, with many other paradigms being possible as well.

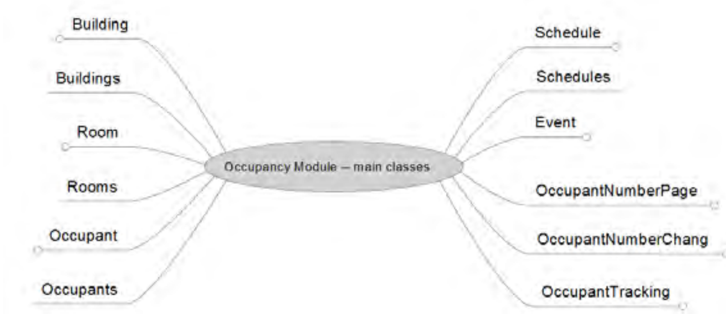
Development Tools

A comparison of development tools

Tools	Open source	Free	For co-simulation	Pros	Cons
NetLogo	Yes	Yes	Do not support	Agent-based Easy to develop Good Visualization	A simulation tool Not for development
Modelica	Some platforms	Some platforms	Planned, OpenModelica is available only as a master	Good at equations	Problem of extensibility
MATLAB	No	No	Supports, but only as master	Good at matrix	Cannot execute without the environment supports
OOP	—	platforms	needs more coding	Cross-platform	of development

C++ is chosen for its flexibility, cross platform capability and co-simulation support.

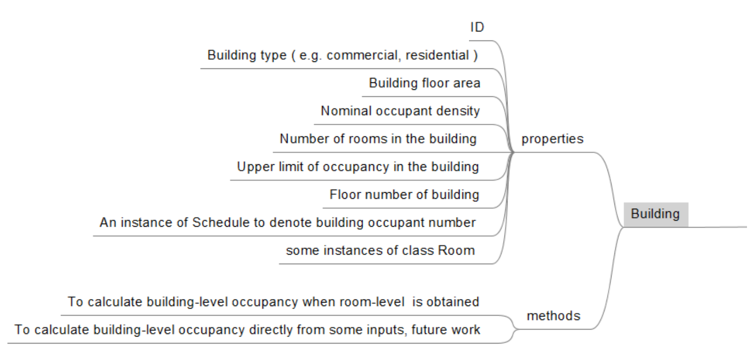
Software Architecture



Software Architecture

class CBuilding

// basic description of a building



Software Architecture

class CEvent

// complete description of an event

- Event
  - ID of an event
  - Description (e.g. meeting, going for lunch, etc)
  - Relevant room the event takes place
  - Time range
  - The proportion of the event taking place during a period
  - Time duration
  - Average time event occurs
  - Some instances of class Occupant involved
  - Probability to take place

1. Background
2. Technical approach
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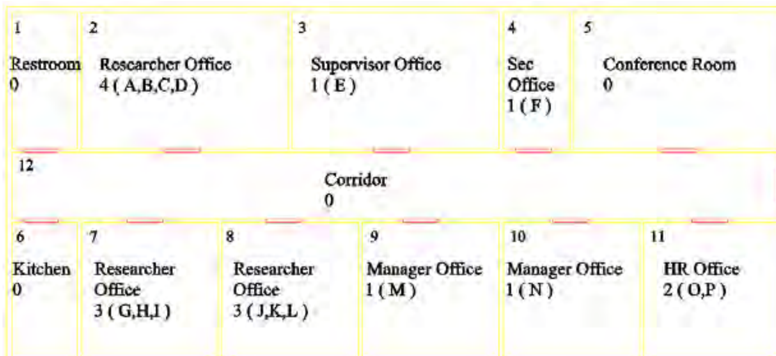
6. **Application**
7. Conclusions and future work

Application

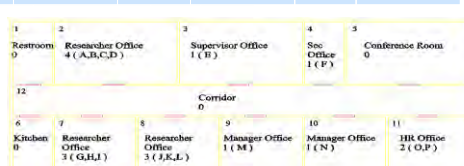
An example:



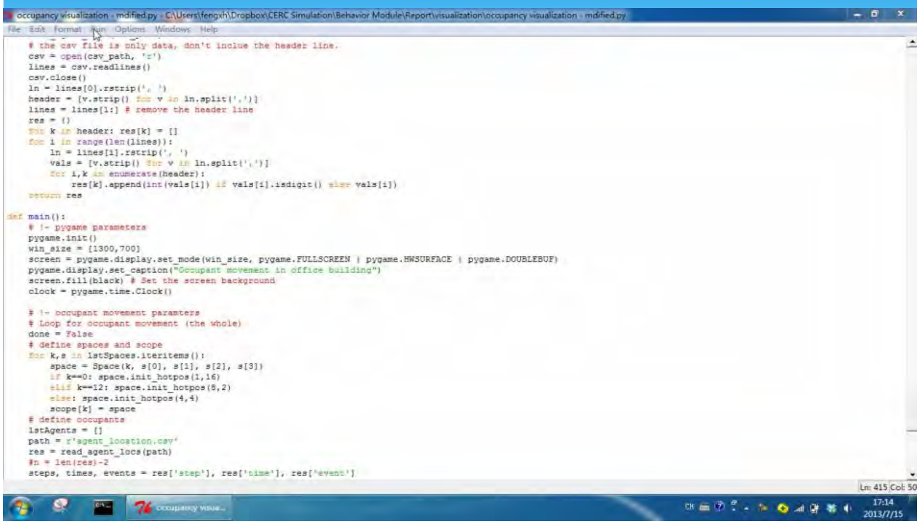
User Inputs

ID	Occupant	Room	Own office		Other offices		Accessory room		Outside	
			times	Proportion	times	Proportion	times	Proportion	times	Proportion
A~D	researcher	2	-	0.85	1	0.01	2	0.02	1	0.02
E	supervisor	3	-	0.57	1	0.01	2	0.02	3	0.30
F	secretary	4	-	0.63	1	0.03	2	0.02	2	0.10
G~I	researcher	7	-	0.85	1	0.01	2	0.02	1	0.02
J~L	researcher	8	-	0.85	1	0.01	2	0.02	1	0.02
M	manager	9	-	0.72	1	0.01	2	0.02	2	0.15
N	manager	10	-	0.72	1	0.01	2	0.02	2	0.15
O, P	HR staff	11	-	0.78	1	0.02	2	0.02	1	0.02

Occupant settings



Visualization



1. Background
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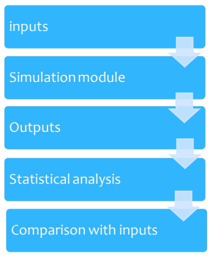
Conclusions and future work

1. There are various models on building occupancy, mainly from the view of occupants, and the inputs are usually numerous
2. Generic software architecture of an occupancy module has been built, in which a new model may be added with no or little changes of other components
3. An occupancy module based on a tracking model has been developed, which can be used as a DLL or an executable stand-alone file
4. Co-simulation with other simulation programs and implementations of two other models are to be done

THANK YOU

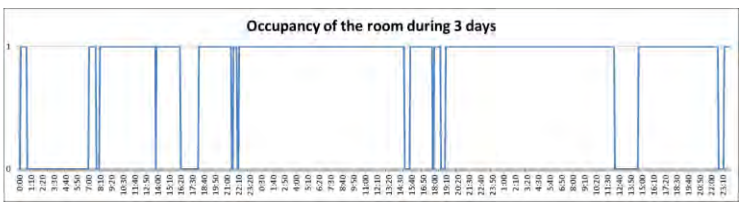
Validation



Simplest case:
1 room, 1 occupant, always moving into and out of the room

Inputs		
Time proportion	room	0.8
	outside	0.2
times	room	4
	outside	4

Statistical analysis of outputs		
Time proportion	room	0.79
	outside	0.21
Daily average times	room	3.8
	outside	3.8

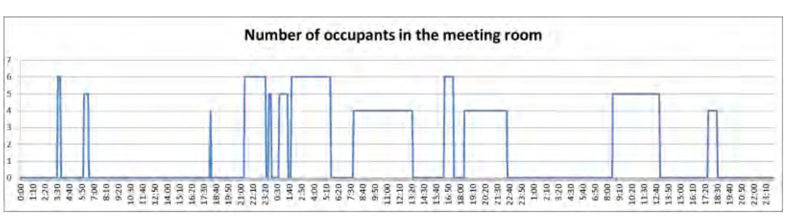


Validation

Case for testing meeting:
1 meeting room, each of 6 occupants having a meeting or not

Inputs	
Average using time	90min
Daily using times	4
Minimum attendance	3
Maximum attendance	6

Statistical analysis of outputs	
Average using time	85.3min
Daily using times	3.9
Minimum attendance	3
Maximum attendance	6

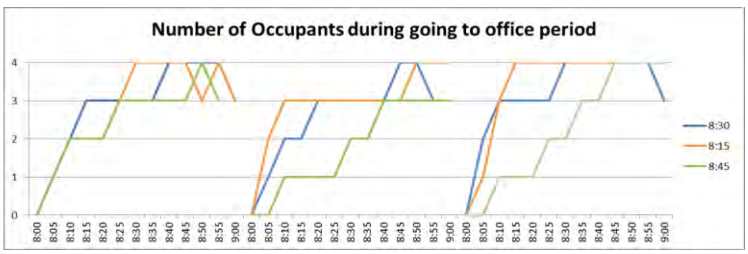


Validation

Test case for going to office:
1 office, with 4 occupants arriving at different times

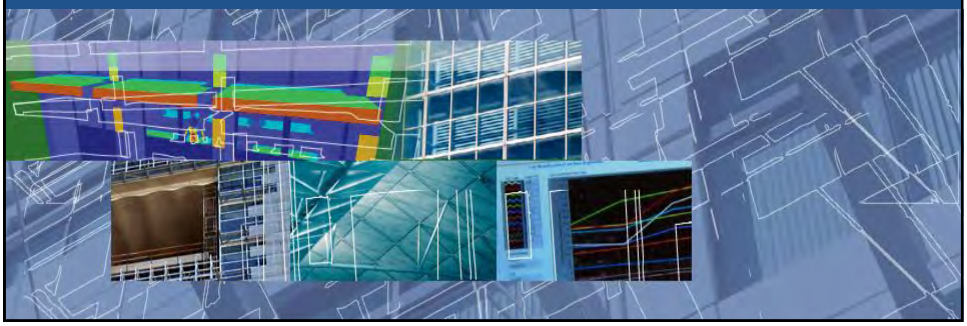
Inputs		
Time span	8:00~9:00	
Average arriving time	1	8:15
	2	8:30
	3	8:45

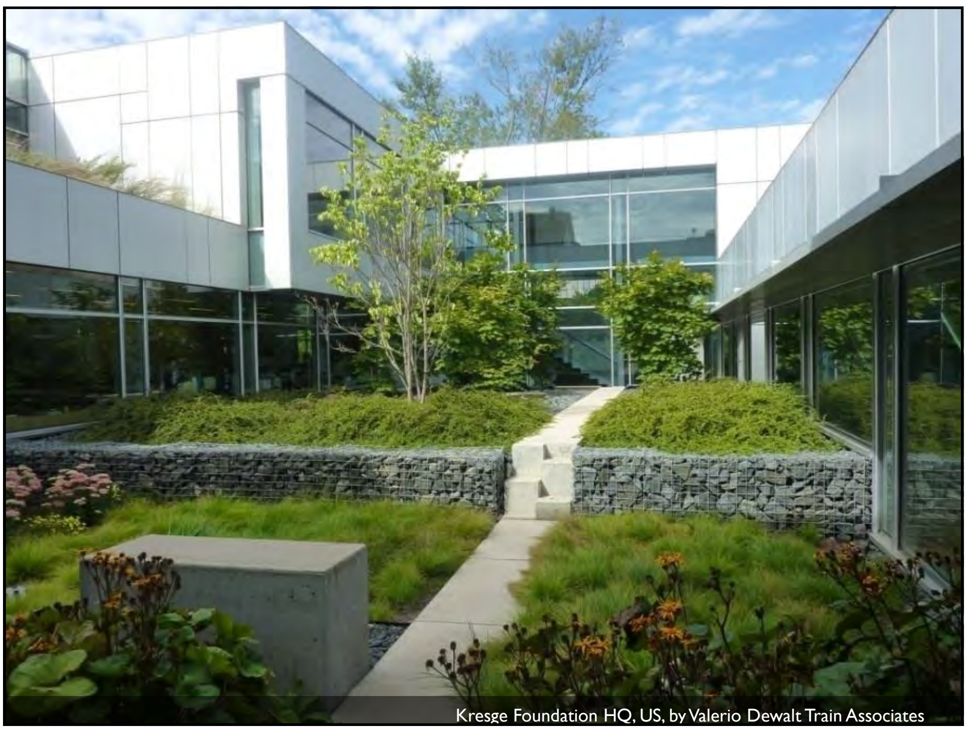
- It is more "difficult" for an occupant to enter the office as the average arriving time delays
- Other events, like going for lunch, leaving from work, can be validated in the same way



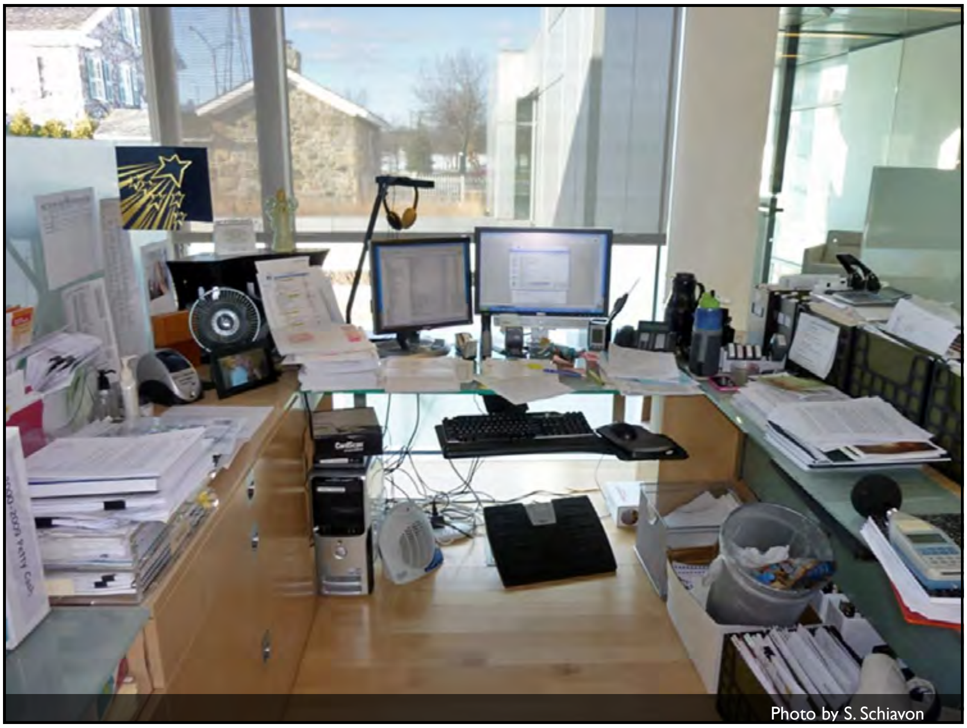
Occupant satisfaction and indoor environmental quality: What matter, LEED rating and clothing behavior

Stefano Schiavon
Center for the Built Environment (CBE)
University of California, Berkeley





Kresge Foundation HQ, US, by Valerio Dewalt Train Associates



Do we need a paradigm shift?

We should design indoor environments that are better than the best environment found in nature
— Ole Fanger

Project overview: What matter?

Objective

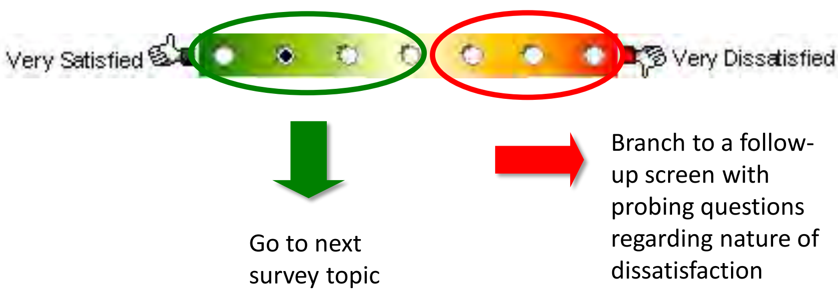
- Investigate which indoor environmental quality parameters and building features most affect occupant satisfaction and self-reported job performance

Approach

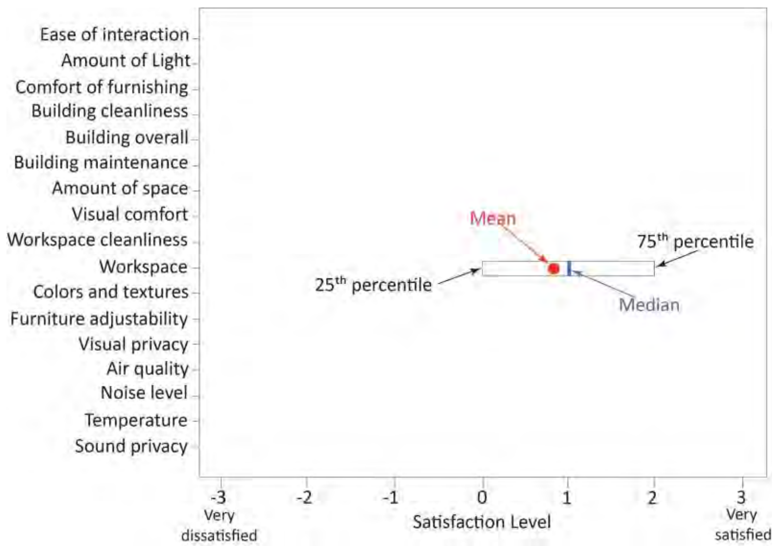
- 52,980 occupants responses in 351 office buildings
- How satisfied are you with '………..' in your workspace?
- Overall, does………enhance or interfere with your ability to get your job done?

CBE survey

Seven point satisfaction scale

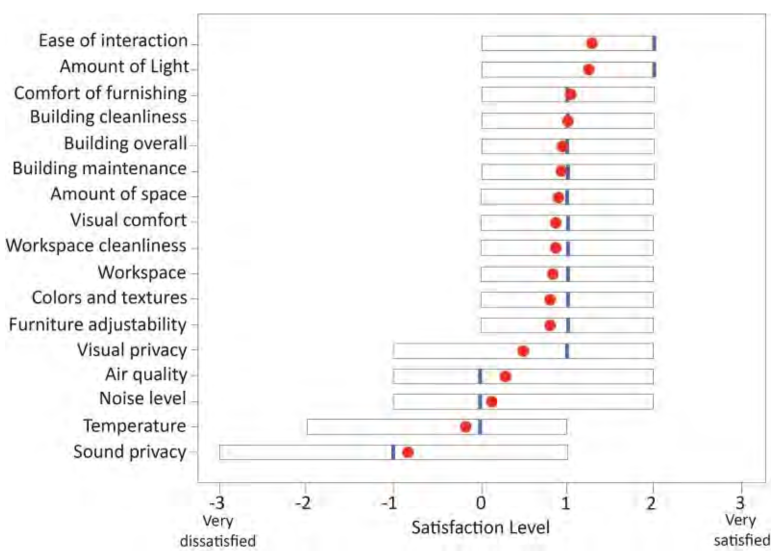


Building occupant satisfaction

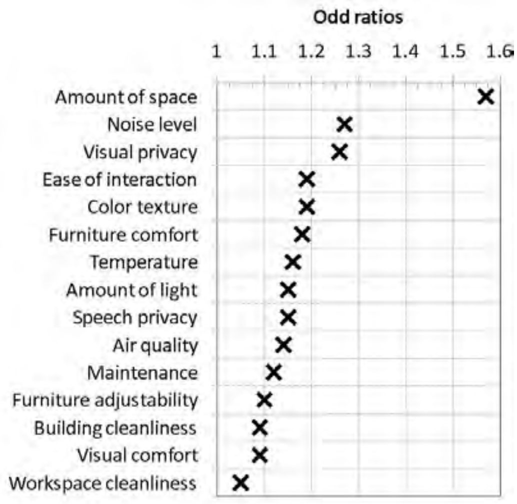


Building occupant satisfaction

CBE survey on 351 bldg. and 52,980 occupants

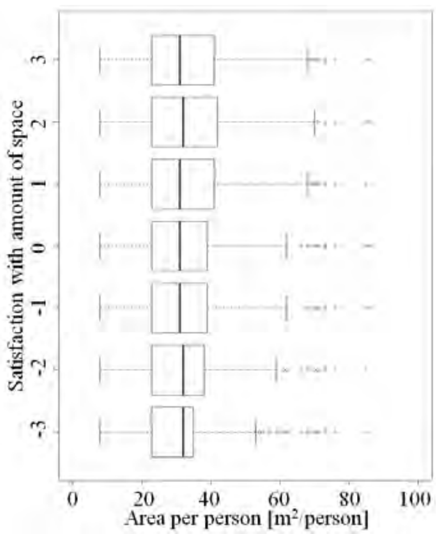


Occupant satisfaction and design features

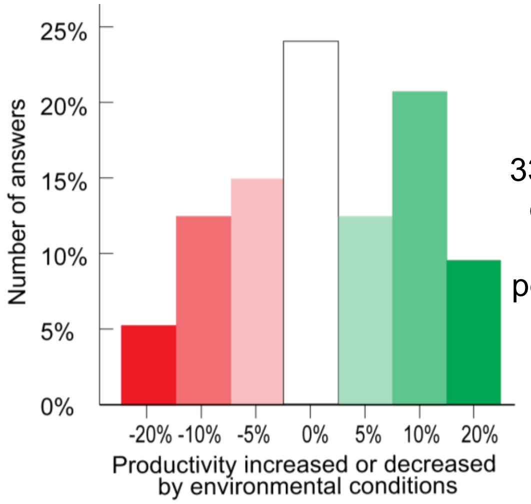


Amount of space, noise level and visual privacy are the parameters that affect the most occupant satisfaction

Occupant satisfaction and design features

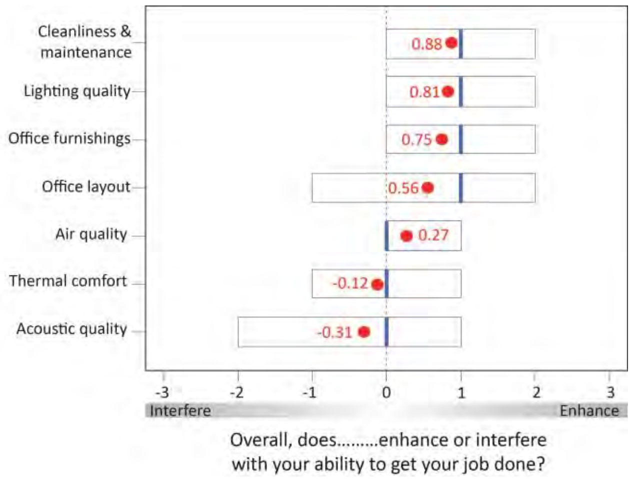


Self reported productivity



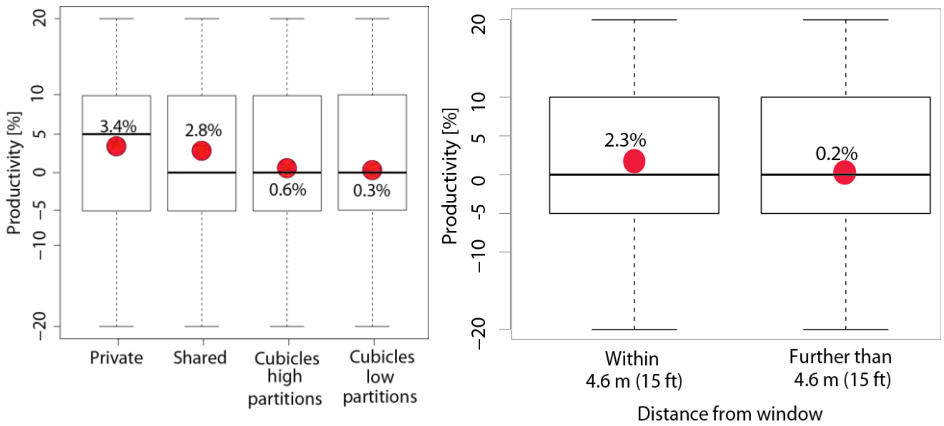
33% of occupants think that environmental conditions decrease their job performance by at least 5%

Self reported productivity



Acoustic quality and thermal comfort were indicated by the occupants to interfere with their ability to get the job done

Self-reported productivity and design features



Project overview: LEED vs non-LEED

Objective

- Investigate the relationship between LEED certification and occupant satisfaction
- Ascertain if LEED-certified buildings create a higher, equal or lower occupants' satisfaction

Approach

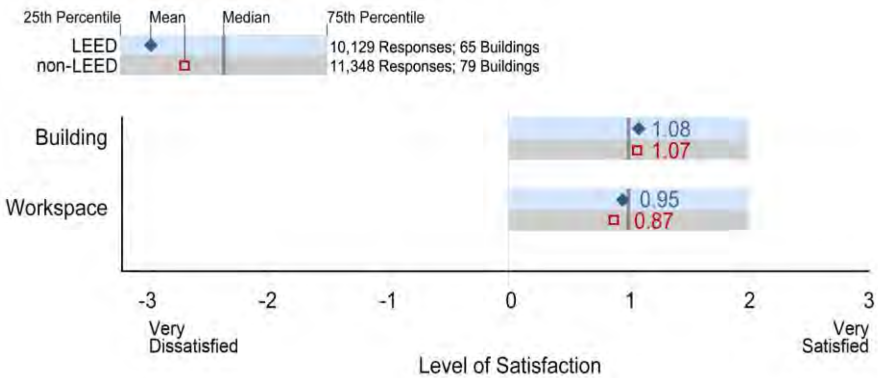
- Similar database than before
- LEED information were verified
- Building of similar age and size were compared

CBE database: Selection of buildings

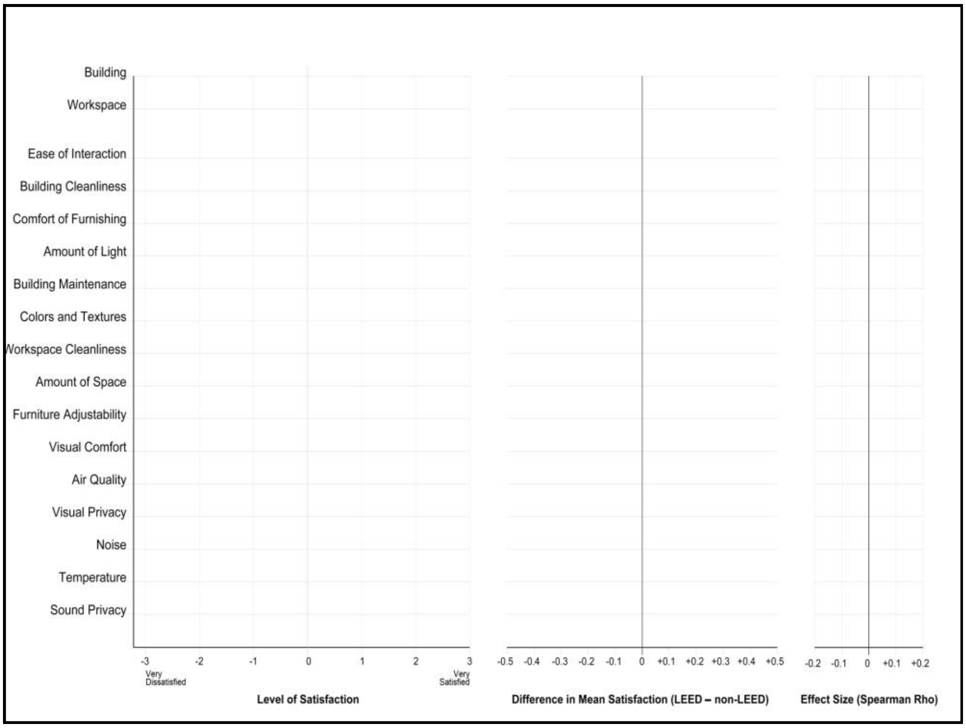
Dataset	LEED Buildings	Non-LEED Buildings	Total
Buildings	65	79	144
Occupant responses	10,129	11,348	21,477

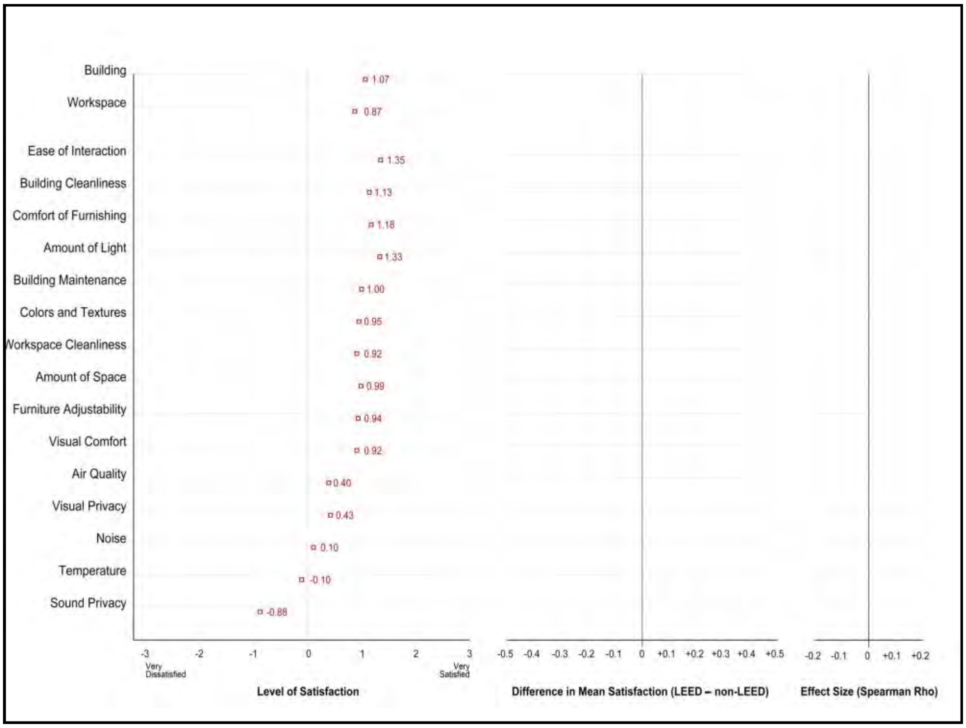
- 76% of the LEED answers are for NC certification
- 83% of the LEED answers are for version 2.0 and 2.1
- Groups are similar for 'non-environmental' factors

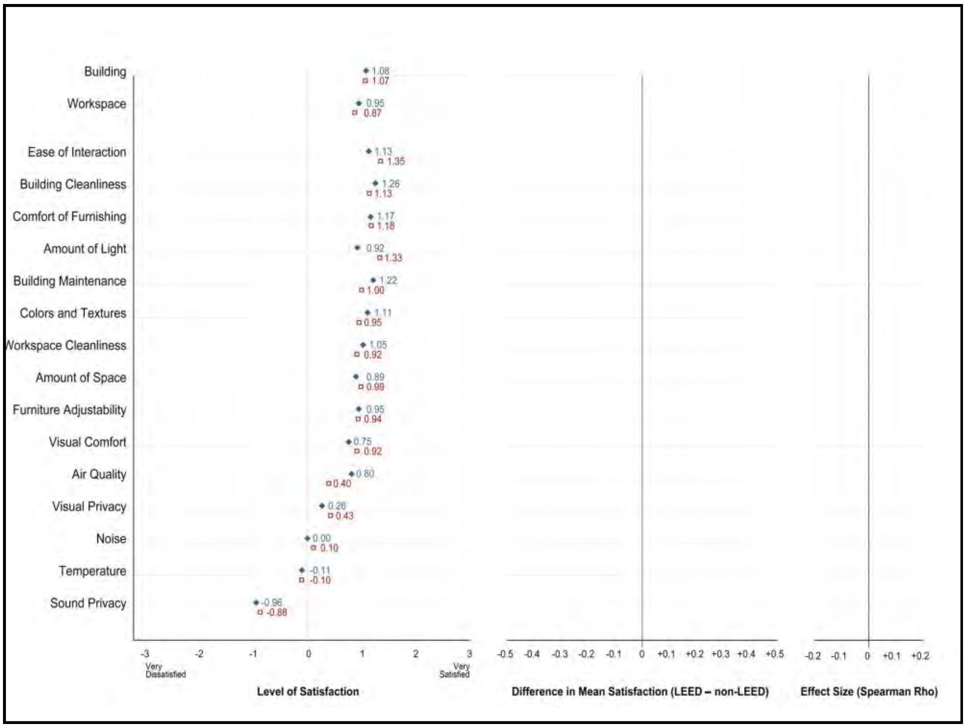
LEED vs non-LEED

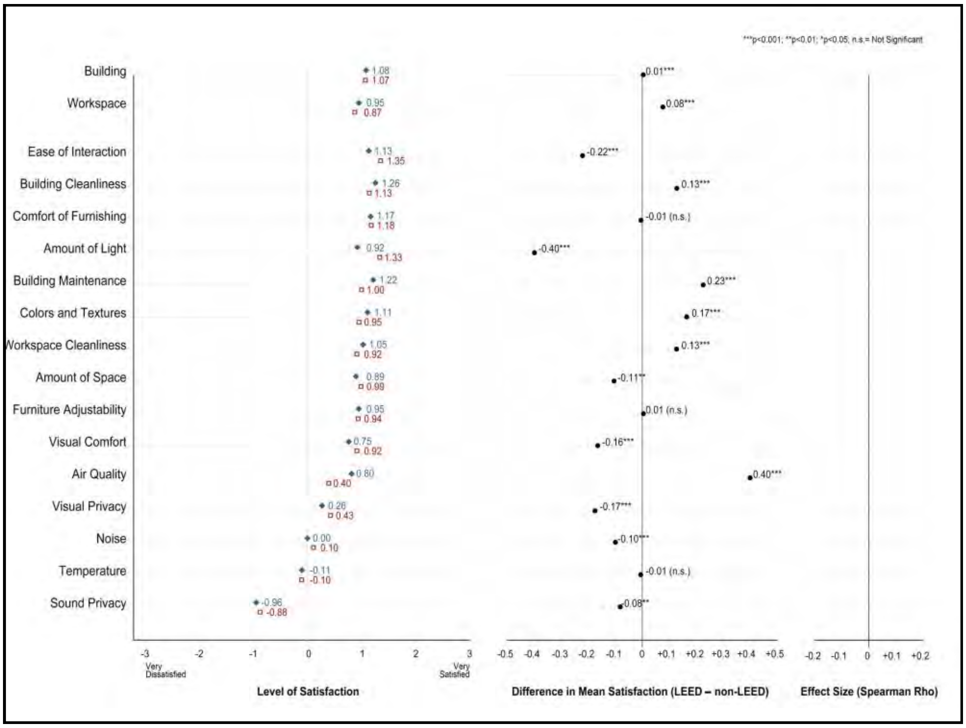


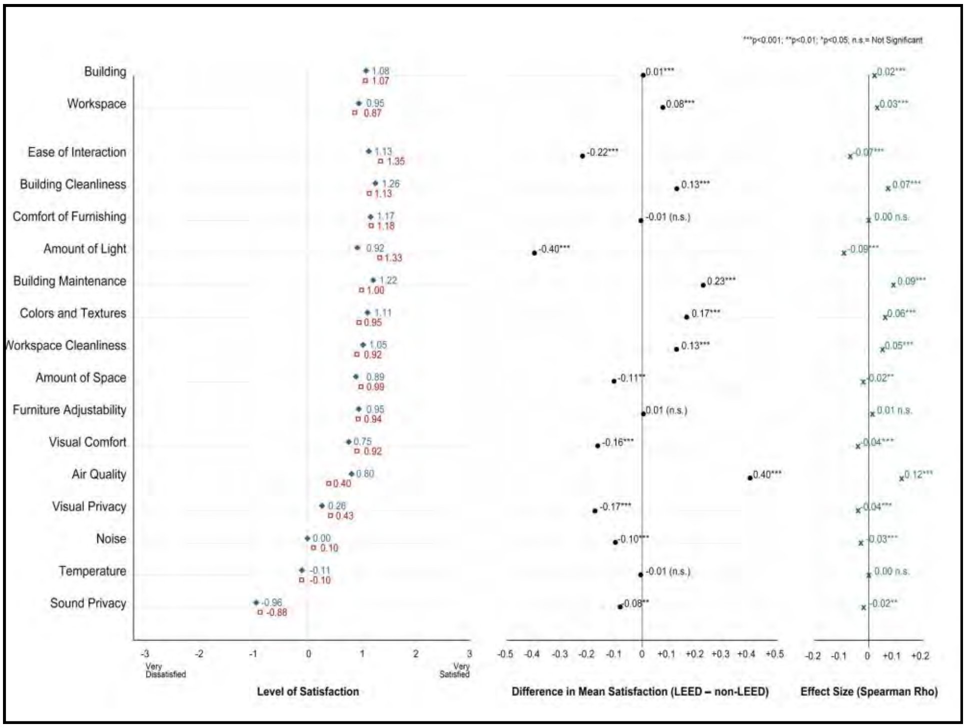
Altomonte S, Schiavon S. 2013. Building and Environment
http://escholarship.org/uc/item/4j61p7k5

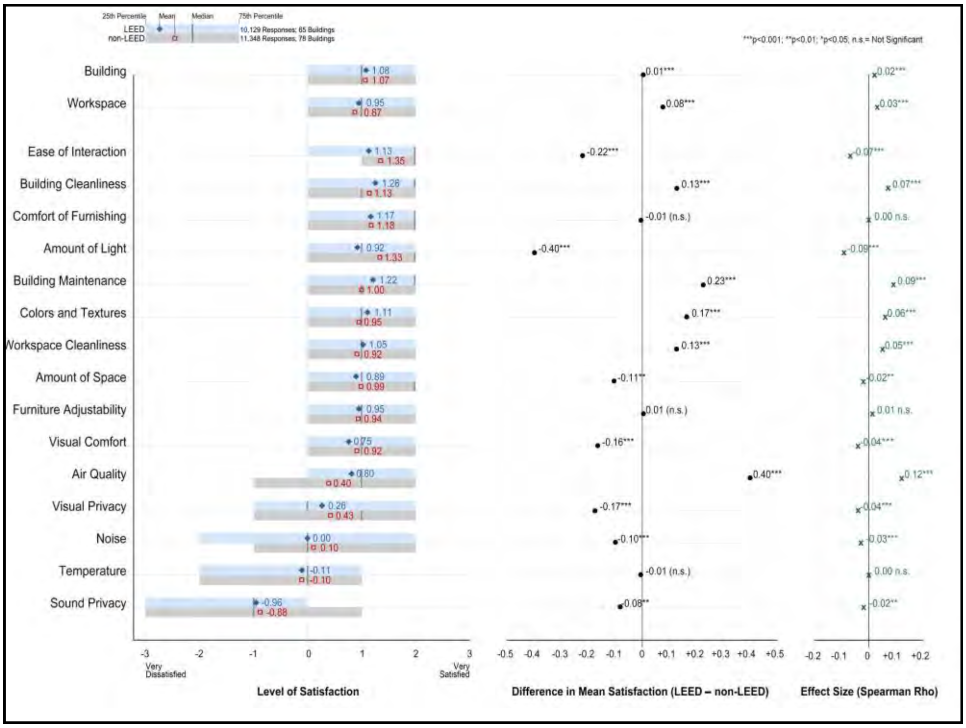

Building
Workspace
Ease of Interaction
Building Cleanliness
Comfort of Furnishing
Amount of Light
Building Maintenance
Colors and Textures
Workspace Cleanliness
Amount of Space
Furniture Adjustability
Visual Comfort
Air Quality
Visual Privacy
Noise
Temperature
Sound Privacy
-3 Very Dissatisfied
-2
-1
0
1
2
3 Very Satisfied
Level of Satisfaction
-0.5 -0.4 -0.3 -0.2 -0.1 0 +0.1 +0.2 +0.3 +0.4 +0.5
Difference in Mean Satisfaction (LEED – non-LEED)
-0.2 -0.1 0 +0.1 +0.2
Effect Size (Spearman Rho)

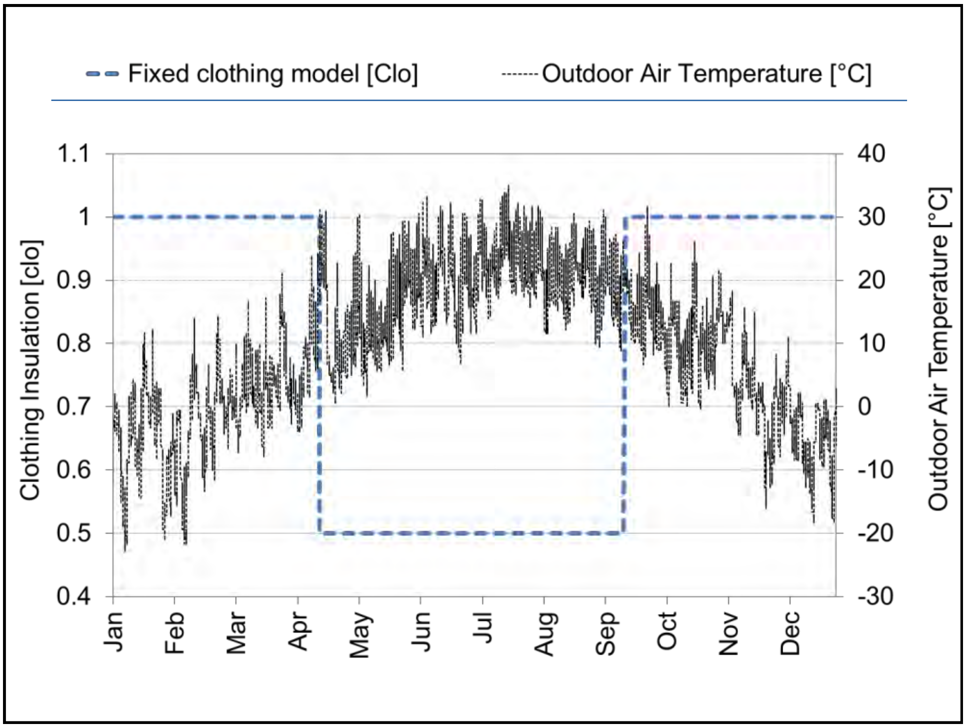

Building 1.07
Workspace 0.87
Ease of Interaction 1.35
Building Cleanliness 1.13
Comfort of Furnishing 1.18
Amount of Light 1.33
Building Maintenance 1.00
Colors and Textures 0.95
Workspace Cleanliness 0.92
Amount of Space 0.99
Furniture Adjustability 0.94
Visual Comfort 0.92
Air Quality 0.40
Visual Privacy 0.43
Noise 0.10
Temperature -0.10
Sound Privacy -0.88
-3 Very Dissatisfied
-2
-1
0
1
2
3 Very Satisfied
Level of Satisfaction
-0.5 -0.4 -0.3 -0.2 -0.1 0 +0.1 +0.2 +0.3 +0.4 +0.5
Difference in Mean Satisfaction (LEED – non-LEED)
-0.2 -0.1 0 +0.1 +0.2
Effect Size (Spearman Rho)


Building
Workspace
Ease of Interaction
Building Cleanliness
Comfort of Furnishing
Amount of Light
Building Maintenance
Colors and Textures
Workspace Cleanliness
Amount of Space
Furniture Adjustability
Visual Comfort
Air Quality
Visual Privacy
Noise
Temperature
Sound Privacy
Very Dissatisfied
Very Satisfied
Level of Satisfaction
Difference in Mean Satisfaction (LEED – non-LEED)
Effect Size (Spearman Rho)

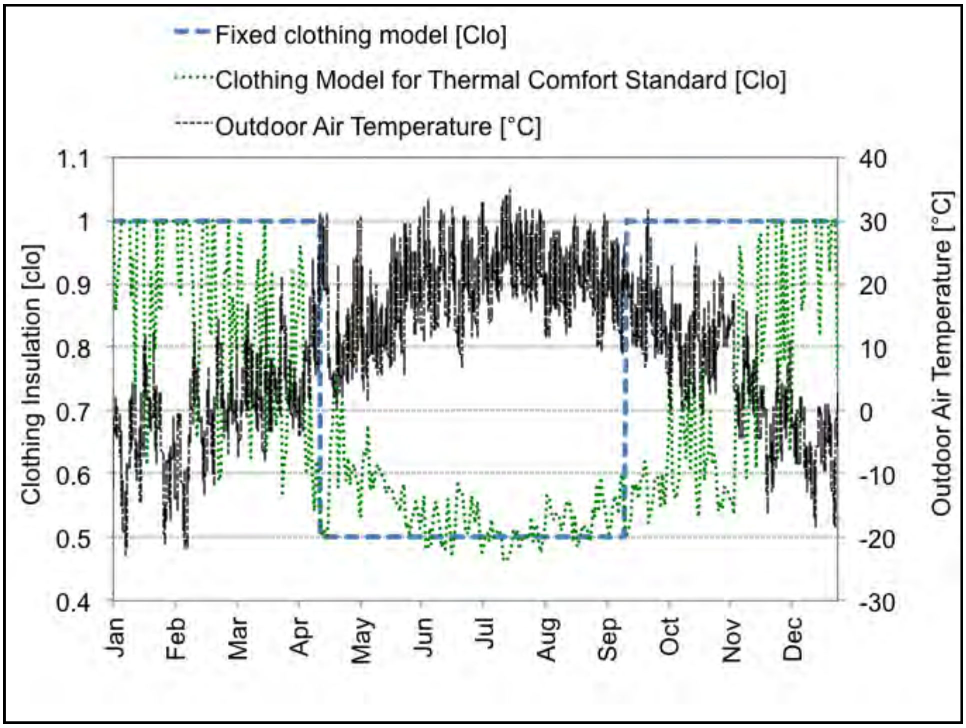

***p<0.001; **p<0.01; *p<0.05; n.s.= Not Significant
Building
Workspace
Ease of Interaction
Building Cleanliness
Comfort of Furnishing
Amount of Light
Building Maintenance
Colors and Textures
Workspace Cleanliness
Amount of Space
Furniture Adjustability
Visual Comfort
Air Quality
Visual Privacy
Noise
Temperature
Sound Privacy
0.01***
0.08***
-0.22***
0.13***
-0.01 (n.s.)
-0.40***
0.23***
0.17***
0.13***
-0.11**
0.01 (n.s.)
-0.16***
0.40***
-0.17***
-0.10***
-0.01 (n.s.)
-0.08**
Very Dissatisfied
Very Satisfied
Level of Satisfaction
Difference in Mean Satisfaction (LEED – non-LEED)
Effect Size (Spearman Rho)


***p<0.001; **p<0.01; *p<0.05; n.s.= Not Significant
Building
Workspace
Ease of Interaction
Building Cleanliness
Comfort of Furnishing
Amount of Light
Building Maintenance
Colors and Textures
Workspace Cleanliness
Amount of Space
Furniture Adjustability
Visual Comfort
Air Quality
Visual Privacy
Noise
Temperature
Sound Privacy
Very Dissatisfied
Very Satisfied
Level of Satisfaction
Difference in Mean Satisfaction (LEED – non-LEED)
Effect Size (Spearman Rho)


25th Percentile
Mean
Median
75th Percentile
LEED
non-LEED
10,129 Responses; 65 Buildings
11,348 Responses; 78 Buildings
***p<0.001; **p<0.01; *p<0.05; n.s.= Not Significant
Building
Workspace
Ease of Interaction
Building Cleanliness
Comfort of Furnishing
Amount of Light
Building Maintenance
Colors and Textures
Workspace Cleanliness
Amount of Space
Furniture Adjustability
Visual Comfort
Air Quality
Visual Privacy
Noise
Temperature
Sound Privacy
Very Dissatisfied
Very Satisfied
Level of Satisfaction
Difference in Mean Satisfaction (LEED – non-LEED)
Effect Size (Spearman Rho)



Fixed clothing model [Clo]
Outdoor Air Temperature [°C]
Clothing Insulation [clo]
Outdoor Air Temperature [°C]
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
40
30
20
10
0
-10
-20
-30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



Fixed clothing model [Clo]
Clothing Model for Thermal Comfort Standard [Clo]
Outdoor Air Temperature [°C]
Clothing Insulation [clo]
Outdoor Air Temperature [°C]
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
40
30
20
10
0
-10
-20
-30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Project overview: Clothing behavior

Background

- In building performance simulation and HVAC control, indoor comfort temperatures are calculated based on the assumption that the clothing insulation is equal to a constant value of 0.5 clo during the cooling season and 1 clo during heating season.

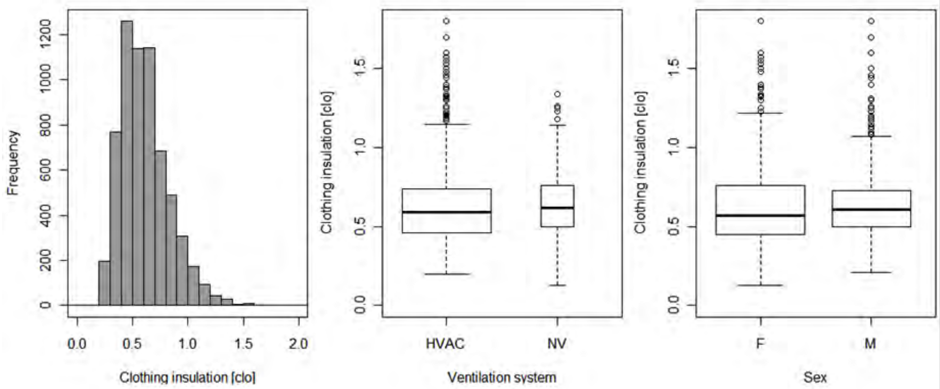
Objective

- Develop a model to predict the clothing insulation of occupants

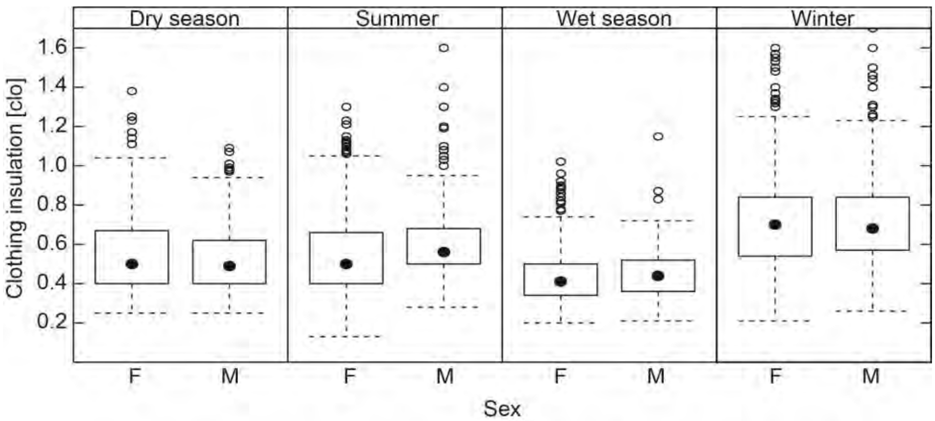
Approach

- 6333 observations obtained from RP-884 and RP-921 (only class I data)
- 20 variables included in the database (e.g. type of conditioning system, operative temperature, air velocity, outdoor air temperature, etc)
- Multivariable mixed regression (random effected caused by building)

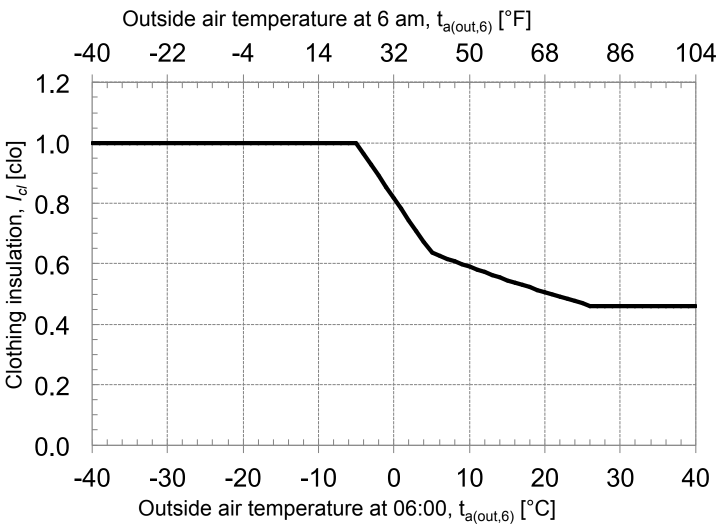
Clothing insulation results

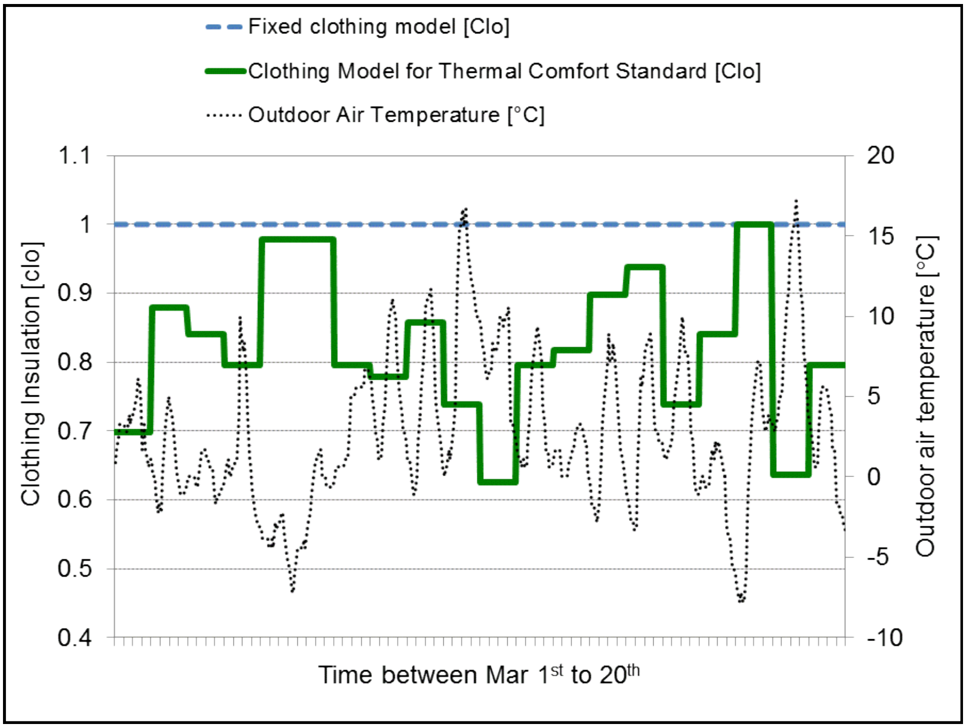


Clothing insulation results

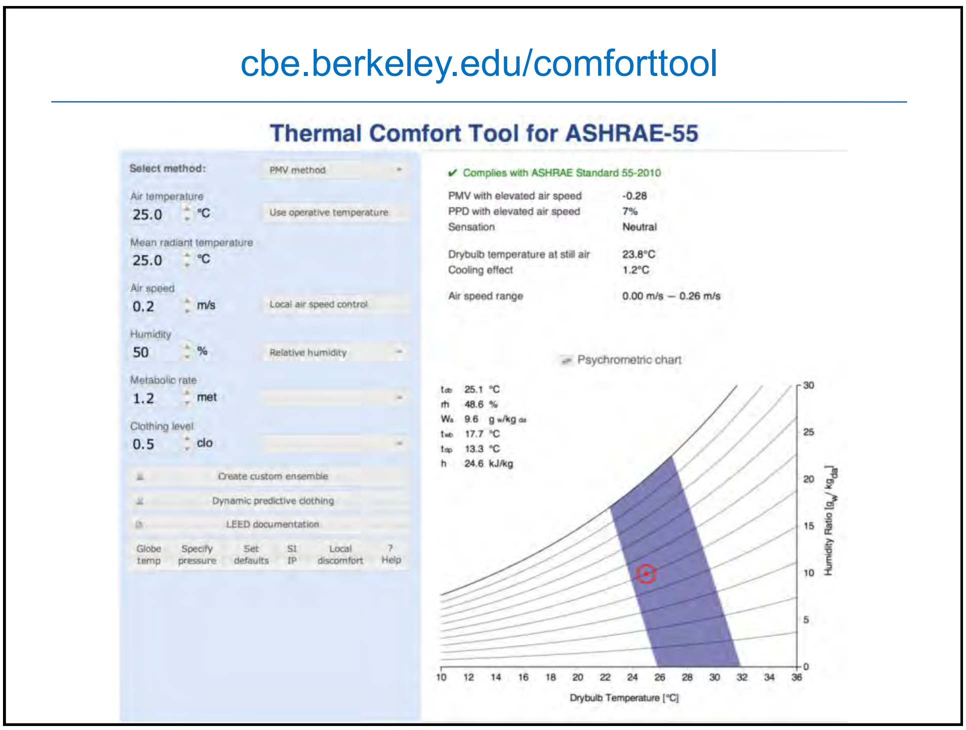


ASHRAE 55 Predictive clothing insulation model





Fixed clothing model [Clo]
Clothing Model for Thermal Comfort Standard [Clo]
Outdoor Air Temperature [°C]
Clothing Insulation [clo]
Outdoor air temperature [°C]
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
20
15
10
5
0
-5
-10
Time between Mar 1st to 20th



cbe.berkeley.edu/comforttool
Thermal Comfort Tool for ASHRAE-55
Select method:
PMV method
Air temperature
25.0 °C
Use operative temperature
Mean radiant temperature
25.0 °C
Air speed
0.2 m/s
Local air speed control
Humidity
50 %
Relative humidity
Metabolic rate
1.2 met
Clothing level
0.5 clo
Create custom ensemble
Dynamic predictive clothing
LEED documentation
Globe temp
Specify pressure
Set defaults
SI IP
Local discomfort
? Help
✔ Complies with ASHRAE Standard 55-2010
PMV with elevated air speed -0.28
PPD with elevated air speed 7%
Sensation Neutral
Drybulb temperature at still air 23.8°C
Cooling effect 1.2°C
Air speed range 0.00 m/s — 0.26 m/s
Psychrometric chart
Drybulb Temperature [°C]
Humidity Ratio [gw/kgda]

Center for the Built Environment

Building science laboratory founded at UC Berkeley in 1980

CBE established in 1997 with support and oversight from the National Science Foundation

Industry Advisory Board sponsors and guides the research agenda

Semi-annual meetings on April and October emphasize collaboration, shared goals, and problem solving

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Gail Brager
Luisa Caldas
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Research Staff
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Tyler Hoyt
Wilmer Pasut
Tom Webster
Hui Zhang

Partner Relations/Communications
David Lehrer

Program Administrator
Jessica Uhl

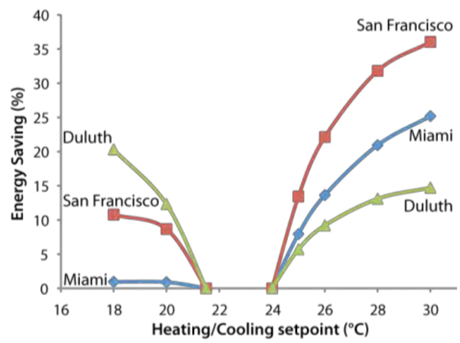
UC Berkeley Collaboration
Faculty and student researchers from architecture, engineering, business, computer science, and annual Visiting Scholars and Post-doc's



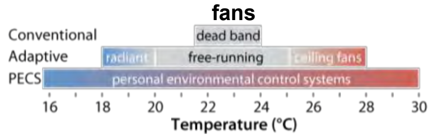

Saving energy with a wider dead band

- Wider dead band reduces HVAC energy 7-15% per degree C.
- Comfort solutions include personal comfort systems (PCS) and fans
- Provide comfort in less controlled or slowly responding systems, such as:
    - Mixed-mode and natural ventilation
    - Radiant cooling

Energy savings with wider dead band



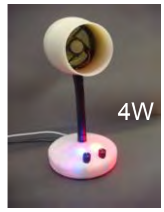
Expanded comfort ranges with PCS and fans



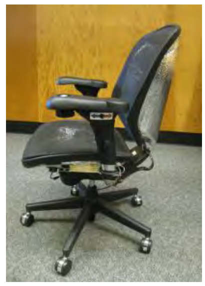
Personal comfort systems

Provides control and monitoring of:

- User settings for fan and foot warmer
- Ambient air temperature
- Occupancy



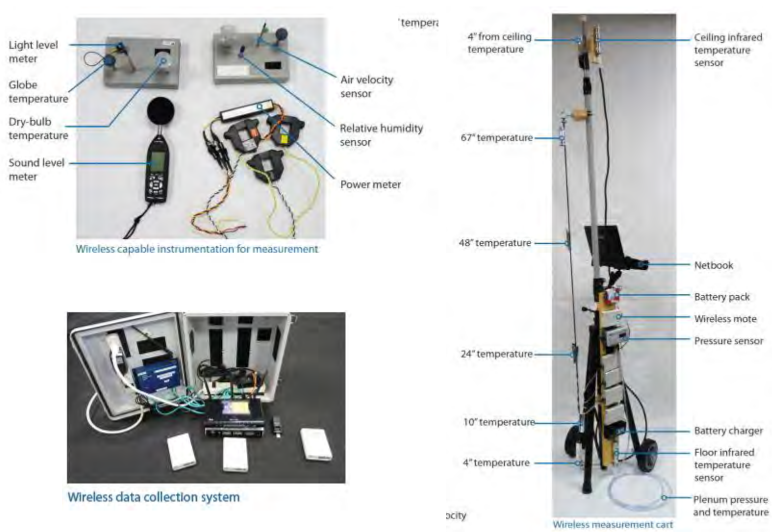
Fan and control unit



Foot warmer

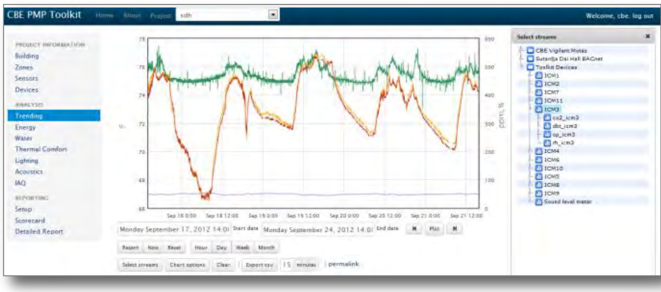
Heated/cooled chair

Wireless BPE toolkit components

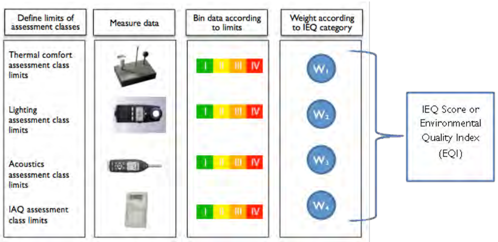


BPE analysis and visualization features

User interface for BPE toolkit uses sMAP protocol developed at UC Berkeley



Environmental quality index provides simplified scoring



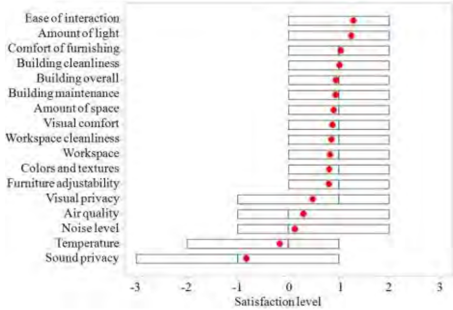
Visiting Scholar program

- We accept visiting scholars at any level
- At least 12 months
- Please send us:
  - CV
  - 1 page research plan
  - Period of stay
- http://cbe.berkeley.edu/aboutus/visiting-scholars.htm

Thank you

Stefano Schiavon
stefanoschiavon@berkeley.edu

www.cbe.berkeley.edu



Frontczak M, Schiavon S, Goins J, Arens E, Zhang H, and Wargocki P. April 2012. Quantitative relationships between occupant satisfaction and aspects of indoor environmental quality and building design. Indoor Air Journal, Volume 22, Issue 2, 119-131. http://dx.doi.org/10.1111/j.1600-0668.2011.00745.x http://escholarship.org/uc/item/1wc7t219

Altomonte S, Schiavon S. July 2013. Occupant satisfaction in LEED and non-LEED certified buildings. Building and Environment. Volume 68, 66-76. http://dx.doi.org/10.1016/j.buildenv.2013.06.008 http://escholarship.org/uc/item/4j61p7k5

Schiavon S, Lee KH. 2013. Dynamic predictive clothing insulation models based on outdoor air and indoor operative temperatures. Building and Environment. Volume 59, 250-260. http://dx.doi.org/10.1016/j.buildenv.2012.08.024 http://escholarship.org/uc/item/3338m9qf

Lee KH, Schiavon S. 2013, Influence of three dynamic predictive clothing insulation models on building energy use, HVAC sizing and thermal comfort. Submitted to Building and Environment. http://escholarship.org/uc/item/3sx6n876

Simulating Occupancy and Occupant Behavior

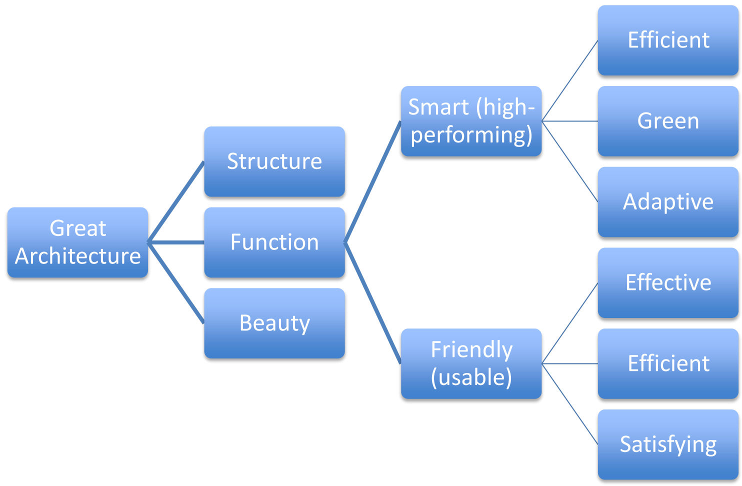
LBNL CERC – BEE Forum
July 18, 2013

Handi Chandra-Putra (Rutgers)

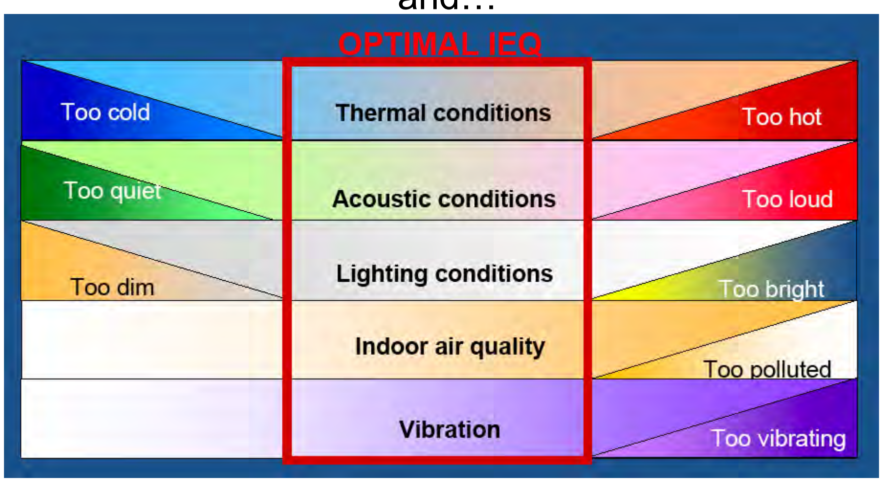
Outline

1. Smart building is not so smart after all.
2. POE is painful.
3. Building model is not a real building.
4. Occupant model is lacking of human intuition and recorded experience.

From Vitruvian to Smart & Friendly

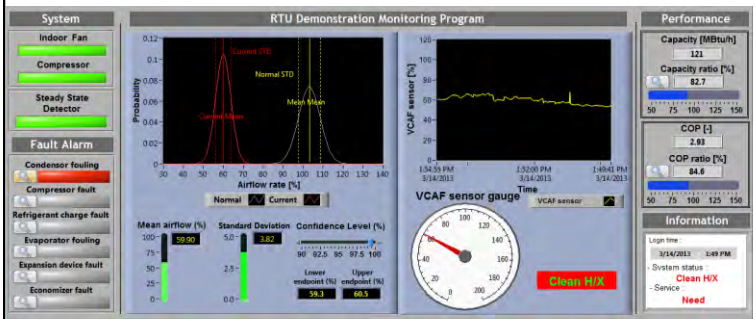


Optimal Performance: Cheap, Durable, Adaptable and…

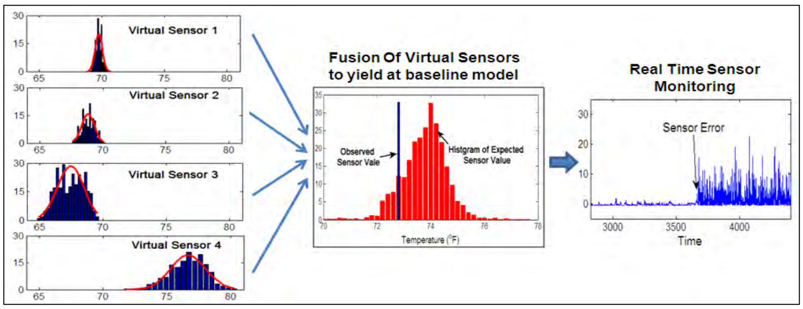


Stanton, Hedge et al. 2004. *Handbook of Human Factors and Ergonomics*, CRC Press. Cited in Alan Hedge. 2004. Linking Environmental Conditions to Productivity. Available at ergo.human.cornell.edu/Conferences/EECE_IEQ%20and%20Productivity_ABBR.pdf

Smart can empower

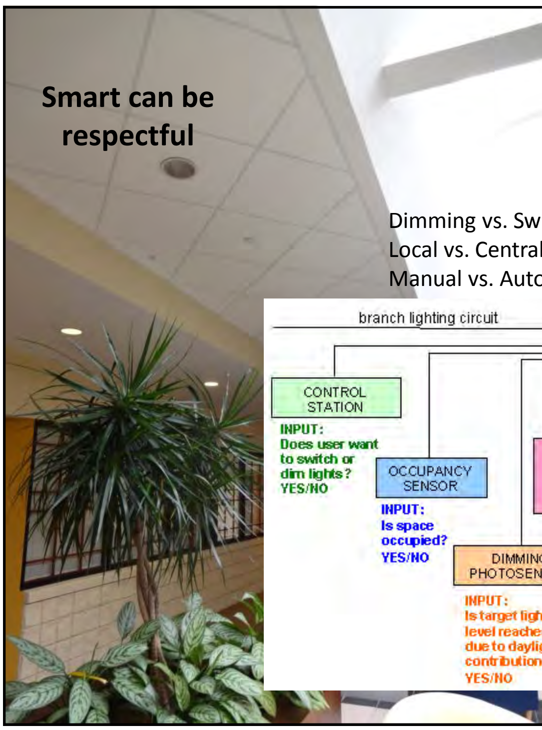


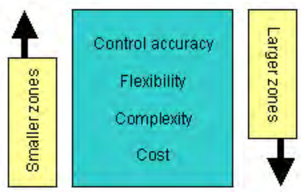
Identify nascent problem



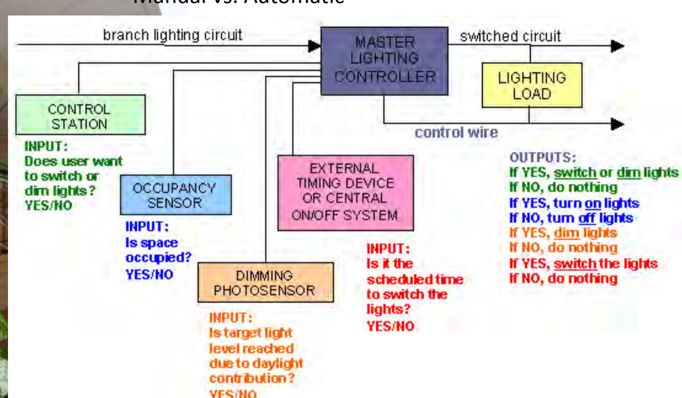
Identify bad data

Smart can be respectful

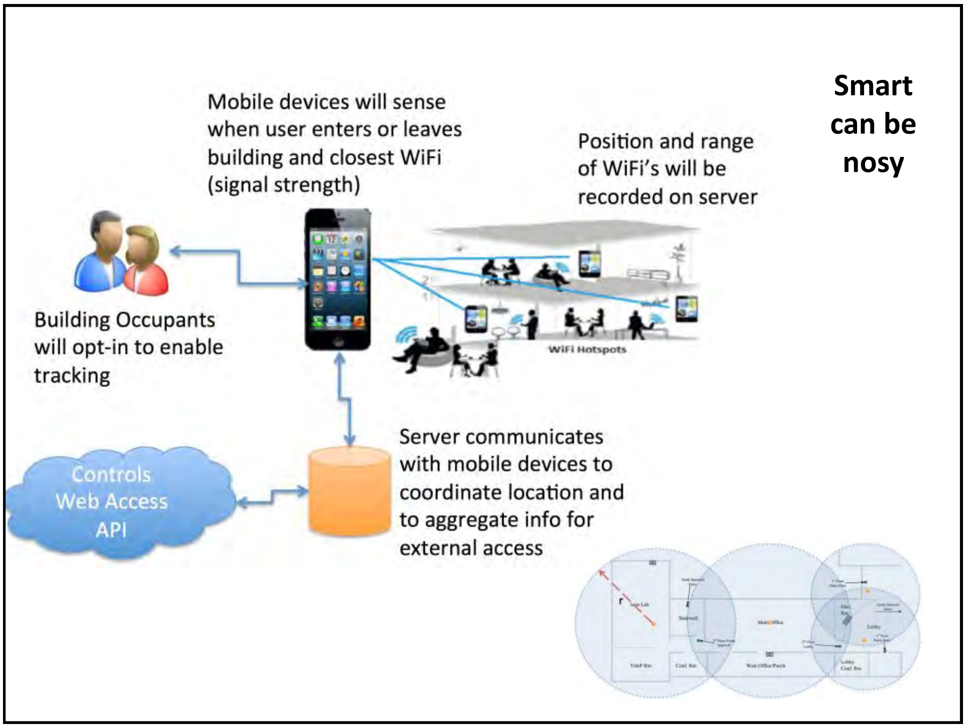


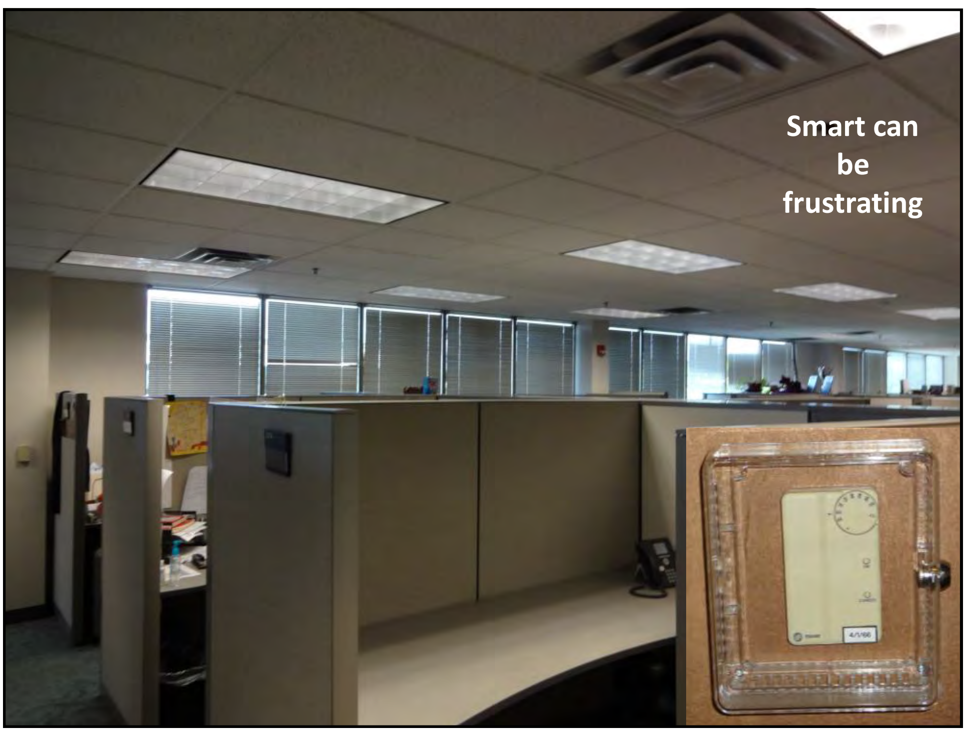


Dimming vs. Switching
Local vs. Centralized
Manual vs. Automatic

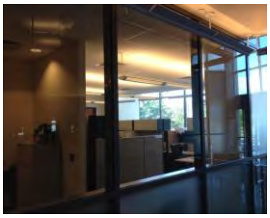


www.eng-forum.com/energy/lighting/introduction.htm


Smart can be nosy
Mobile devices will sense when user enters or leaves building and closest WiFi (signal strength)
Position and range of WiFi's will be recorded on server
Building Occupants will opt-in to enable tracking
WiFi Hotspots
Server communicates with mobile devices to coordinate location and to aggregate info for external access
Controls Web Access API


Smart can be frustrating

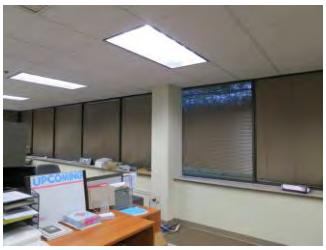
Adaptive Behavior



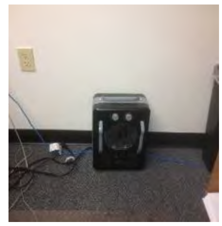
Fit out disconnects

Fans during
Christmas time

Layering
clothing



All lights
on, blinds
closed



Portable heaters

Energy Retrofits Research Design

Load Shedding / Demand – Response (DR) Interventions	*HVAC and Lighting Retrofits As Intervention*
• Sites 1 and 2 • Pre-test and Post-test online survey design • Demand Response events as interventions • Short daily am and pm surveys on DR and control (no DR) days • Walk-through site observations • Interviews (post-retrofit) • Building sensor data collection	• Sites 3 and 4 • Pre- Retrofit application interviews • Post-Retrofit interviews • Walk-through site observations • Workspace lighting & temperature measures

Research Sites

Site 1

Site 2

Greater Philadelphia Area (PA and NJ)

- Multi- and Single- tenanted buildings
- Institutionally owned
- Separate sites with buildings of different ages

Load Shed Protocol - Differences

Site 1	Site 2
Done incrementally, reducing lighting and/or heating/cooling by set amounts at predetermined times.	Done categorically, taking place at predetermined times.

Site 1

Shed Level	Lighting Reduction	Cooling Setpoint	Heating Setpoint
0	0%	74.5°F	71.5°F
1	5%	76.5°F	69.5°F
2	10%	78°F	67.5°F
3	15%	N/A	N/A

Site 2

Shed Level	Lighting Reduction	Cooling Setpoint	Heating Setpoint
None	0%	N/A	N/A
'Weekend' mode	100% (Hallways)	Off	N/A
HVAC Off	0%	Off	N/A
Midpoint	25% (Hallways)	76°F	N/A

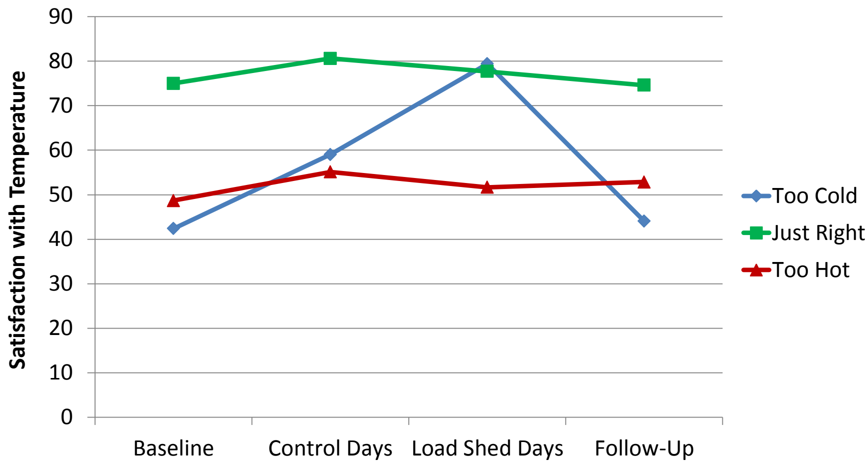
Site 1

Load Shedding: Temperature (Site 1)

- At baseline, we asked participants to compare actual temperature to their desired temperature.
- Participants found that temperature was either:
  - Too Cold (N = 15)
  - Just Right (N = 12)
  - Too Hot (N = 11)

- How did satisfaction change from baseline and control days to load shed days, and then to the follow-up, for these groups?

Load Shedding: Temperature (Site 1)

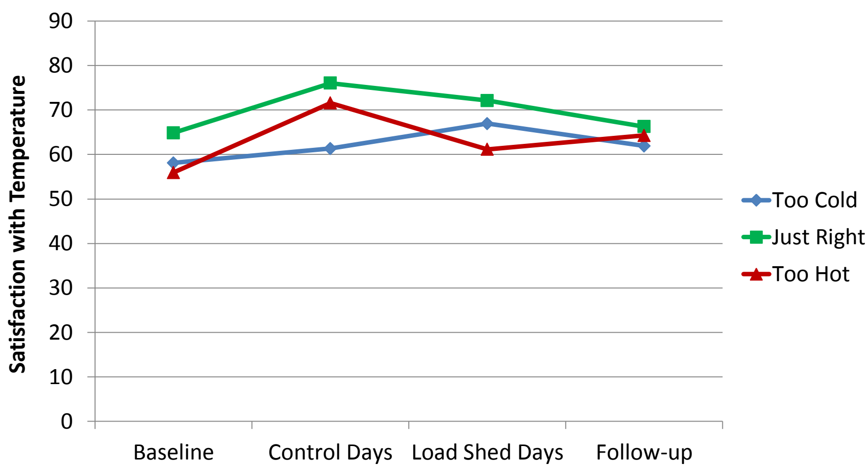


Site 2

Load Shedding: Temperature (Site 2)

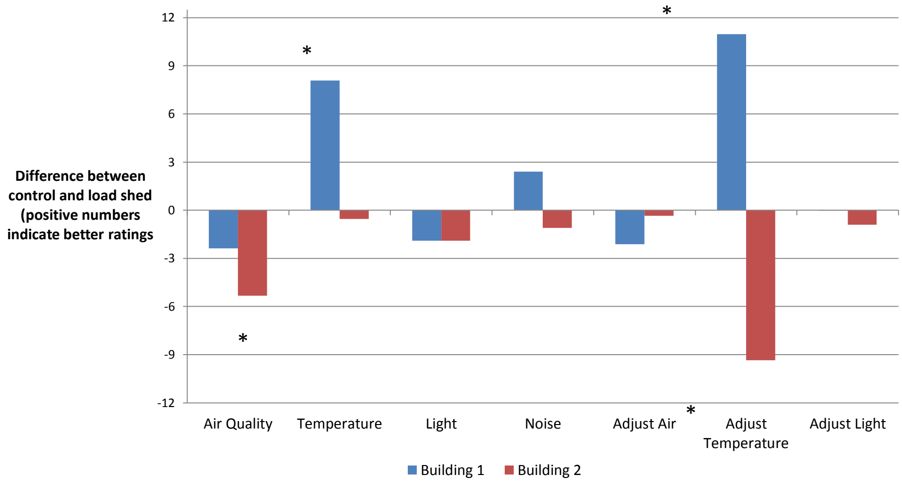
- At baseline, we asked participants to compare actual temperature to their desired temperature.
- Participants found that temperature was either:
  - Too Cold (N = 15)
  - Just Right (N = 25)
  - Too Hot (N = 18)
- How did satisfaction change from baseline and control days to load shed days, and then to the follow-up, for these groups?

Load Shedding: Temperature (Site 2)

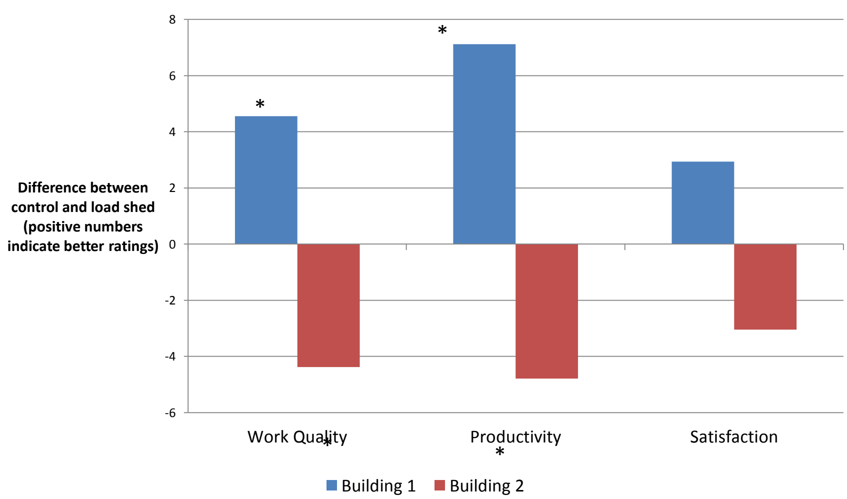


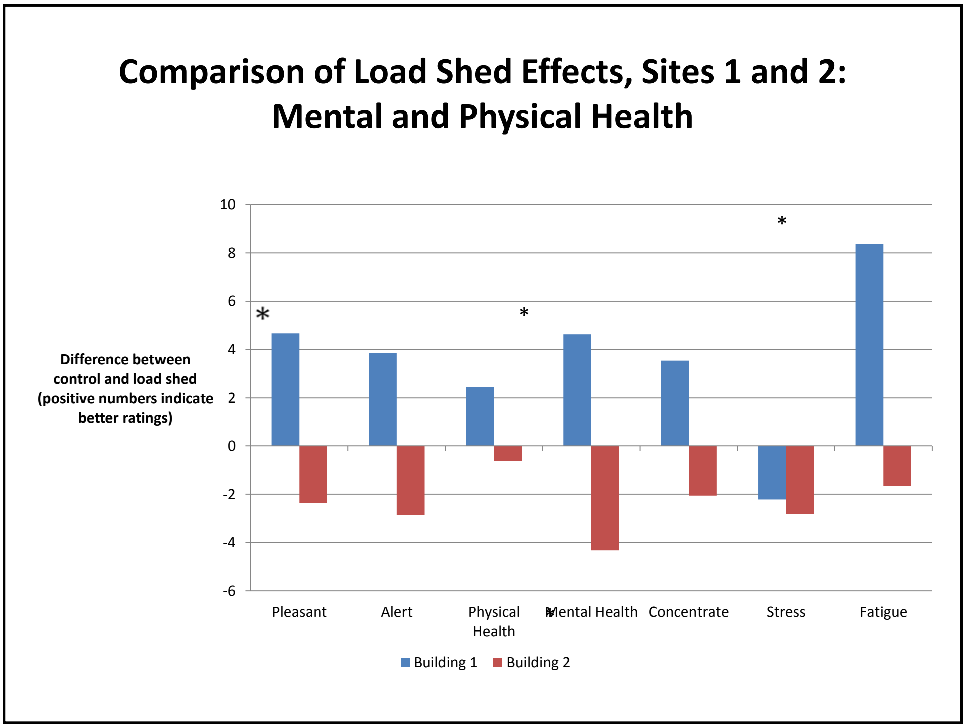
18

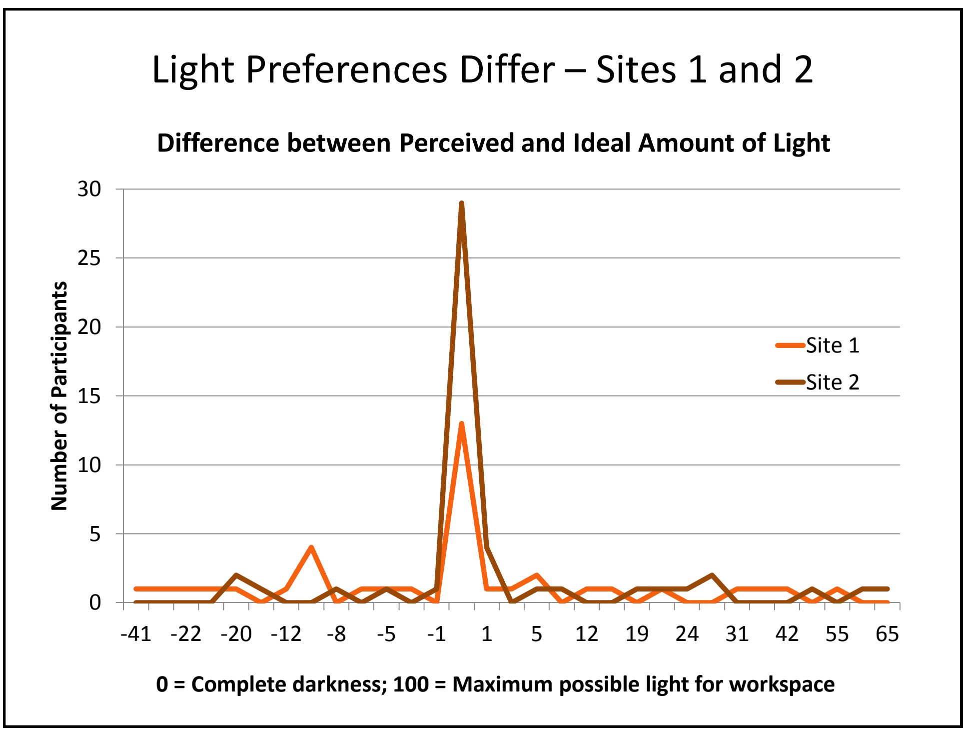
Comparison of Load Shed Effects, Sites 1 and 2: Satisfaction with Environmental Conditions

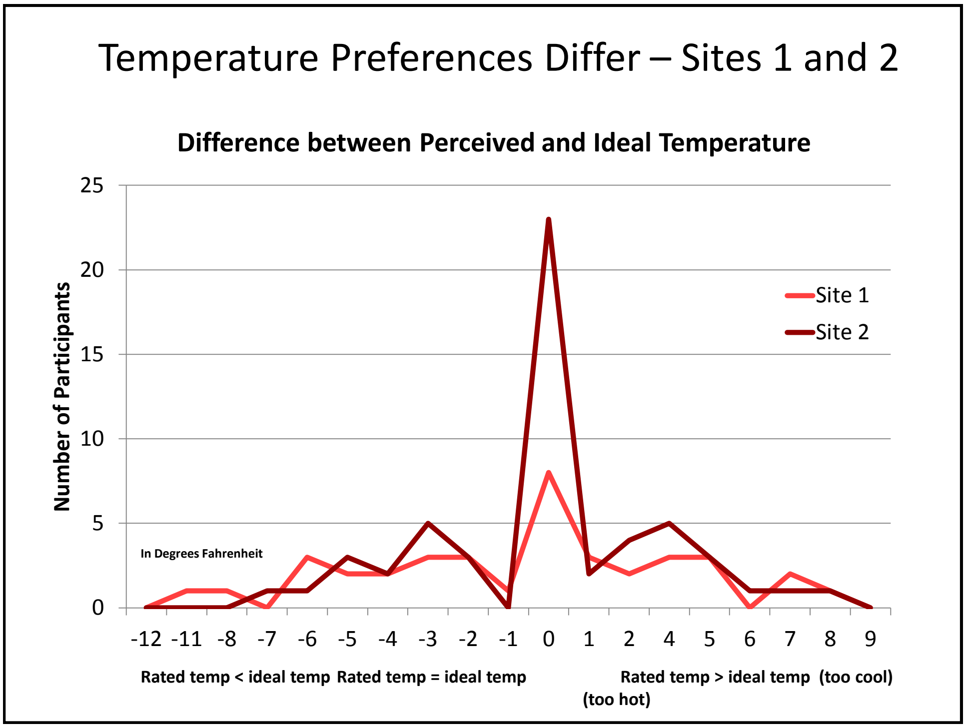


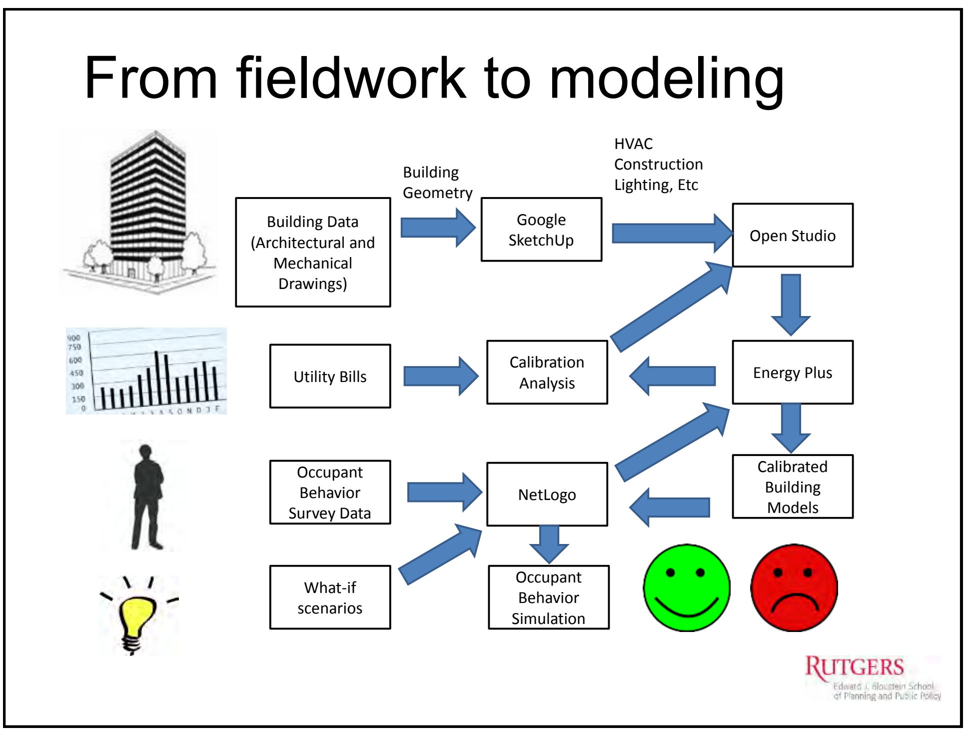
Comparison of Load Shed Effects, Sites 1 and 2: Productivity




Comparison of Load Shed Effects, Sites 1 and 2: Mental and Physical Health
10
8
6
4
2
0
-2
-4
-6
Difference between control and load shed (positive numbers indicate better ratings)
*
*
*
Pleasant
Alert
Physical Health
Mental Health
Concentrate
Stress
Fatigue
Building 1
Building 2

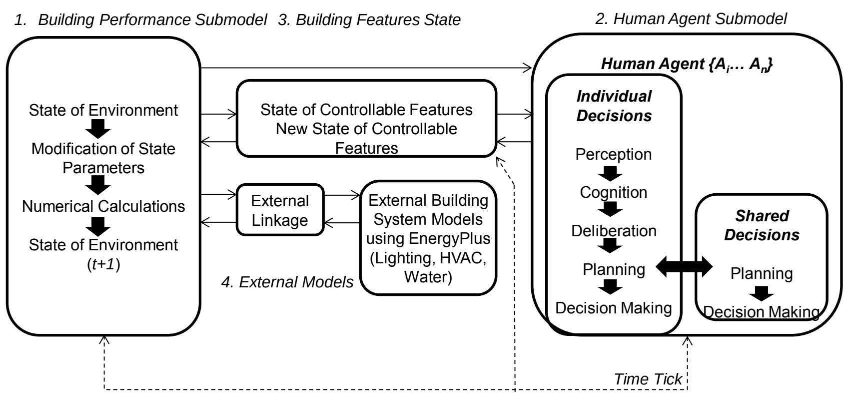

Light Preferences Differ – Sites 1 and 2
Difference between Perceived and Ideal Amount of Light
30
25
20
15
10
5
0
Number of Participants
Site 1
Site 2
-41
-22
-20
-12
-8
-5
-1
1
5
12
19
24
31
42
55
65
0 = Complete darkness; 100 = Maximum possible light for workspace


Temperature Preferences Differ – Sites 1 and 2
Difference between Perceived and Ideal Temperature
Number of Participants
0
5
10
15
20
25
Site 1
Site 2
In Degrees Fahrenheit
-12 -11 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 4 5 6 7 8 9
Rated temp < ideal temp Rated temp = ideal temp Rated temp > ideal temp (too cool)
(too hot)


From fieldwork to modeling
Building Data (Architectural and Mechanical Drawings)
Building Geometry
Google SketchUp
HVAC Construction Lighting, Etc
Open Studio
Utility Bills
Calibration Analysis
Energy Plus
Occupant Behavior Survey Data
NetLogo
Calibrated Building Models
What-if scenarios
Occupant Behavior Simulation
RUTGERS
Edward J. Bloustein School of Planning and Public Policy

Modeling system

- Detailed end-use behavioral studies of occupants in buildings
- Calibrated agent-based model of occupants interacting with building systems



RUTGERS

Building Parameters

READ (.csv)

- Mean Air Temperture
- Mean Radiant Temperature
- Relative Humidity
- Zone recirculation region average air velocity

- Luminance level at reference point #

- Zone Air CO2 concentration

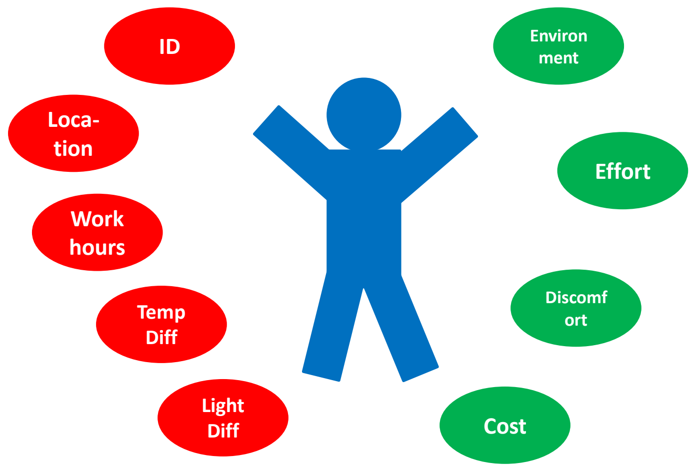
WRITE (.idf)

Occupancy Schedule:
- Number of People

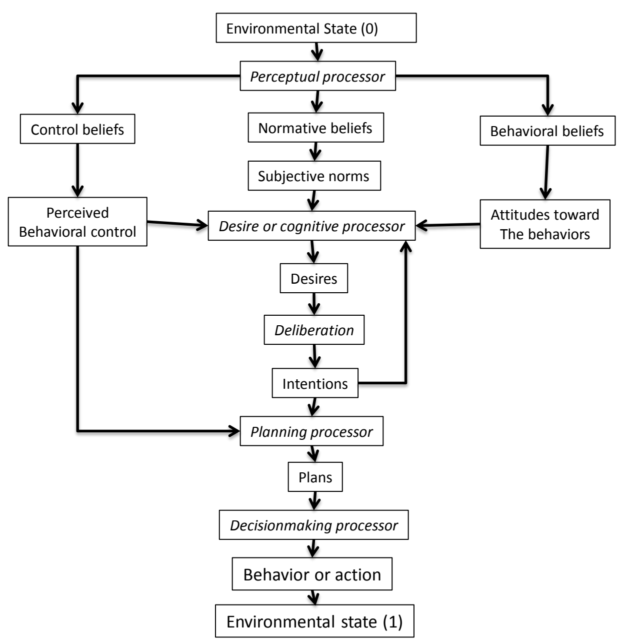
Thermal Adaptive Schedule:
- Temperature SP
- Temperature SP (Load Shedding)
- Space Heater
- Local Fan
- Activity Schedule
- Clothing Schedule

Lighting Adaptive Schedule:
- Overhead Light
- Task Light
- Windows Blinds

Agent's Attributes

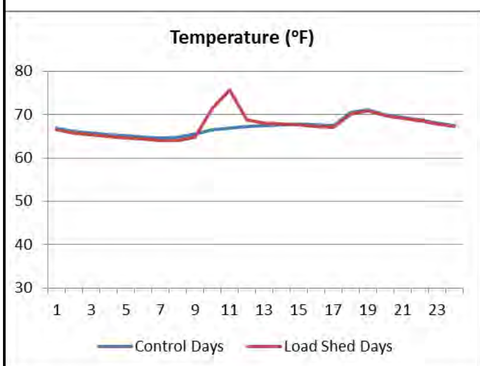


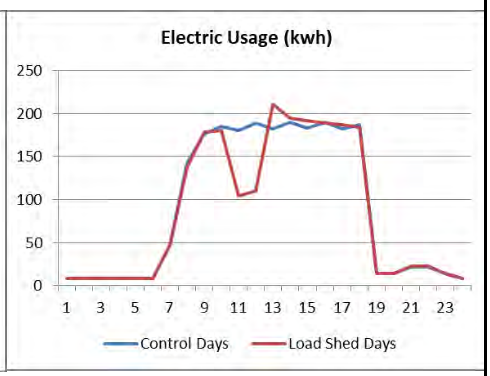
Belief-Desire-Intention (BDI) framework



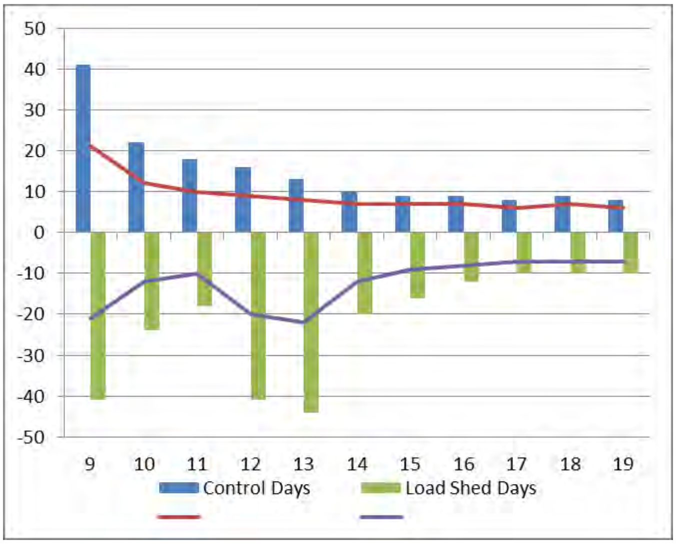
Site #1
Occupant Responses to Load Shedding

Simulated Summer Day: Control Days vs Load Shed Days

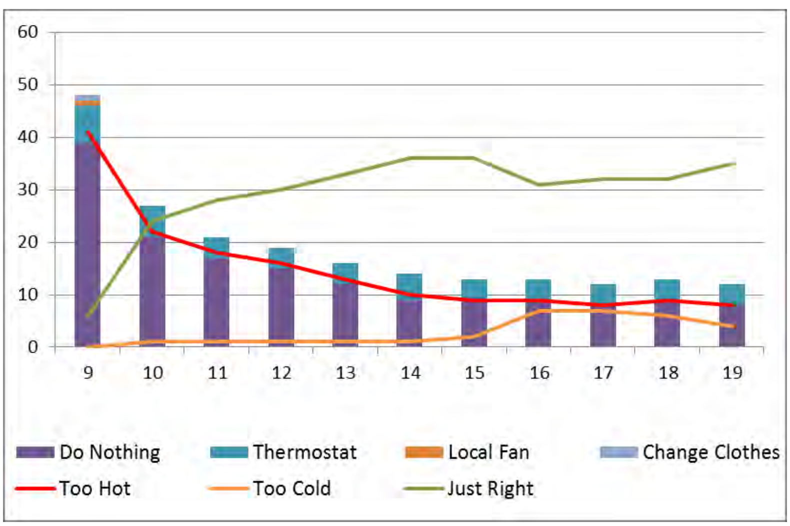




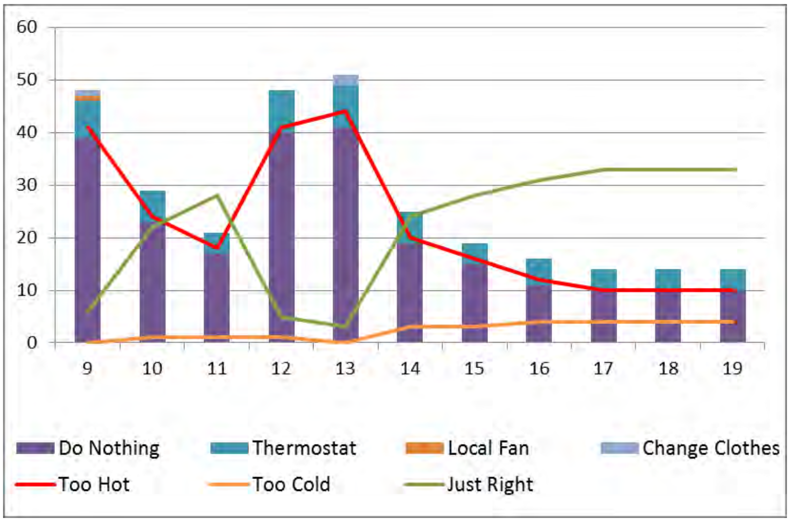
Comparisons of Discomfort and Effort, Control days and Load Shed days



Perception and Temperature Adaptive Behavior, Control Days

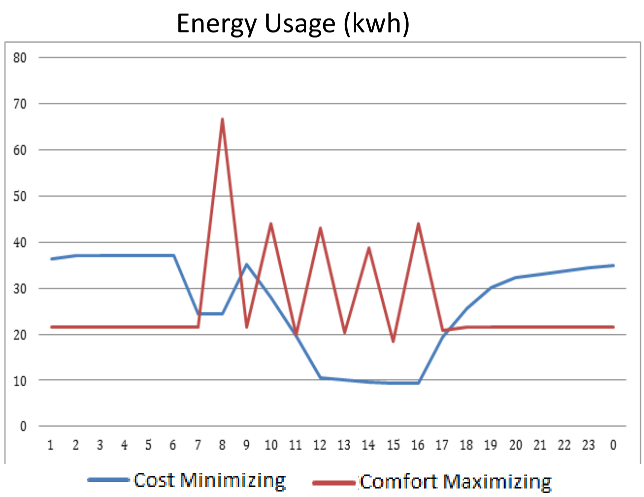


Perception and Temperature Adaptive Behavior, Load Shed Days

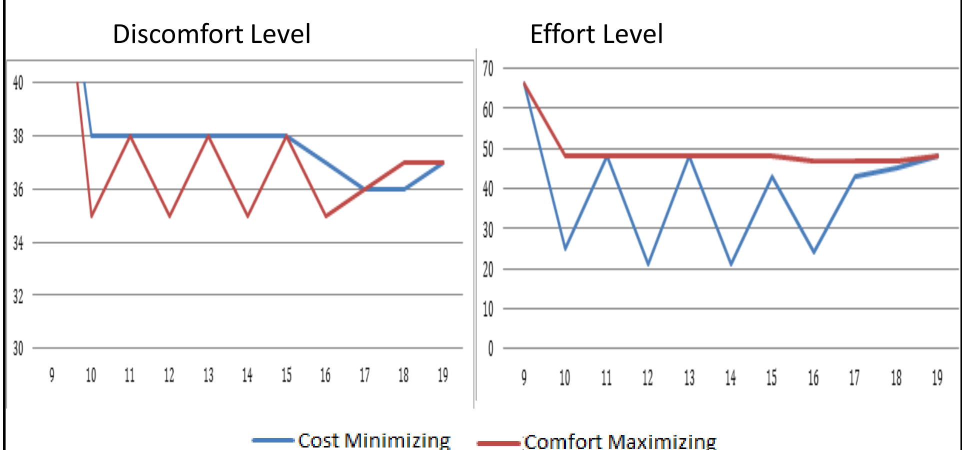


Site #2
Misaligned Incentives in Multi-tenanted Buildings

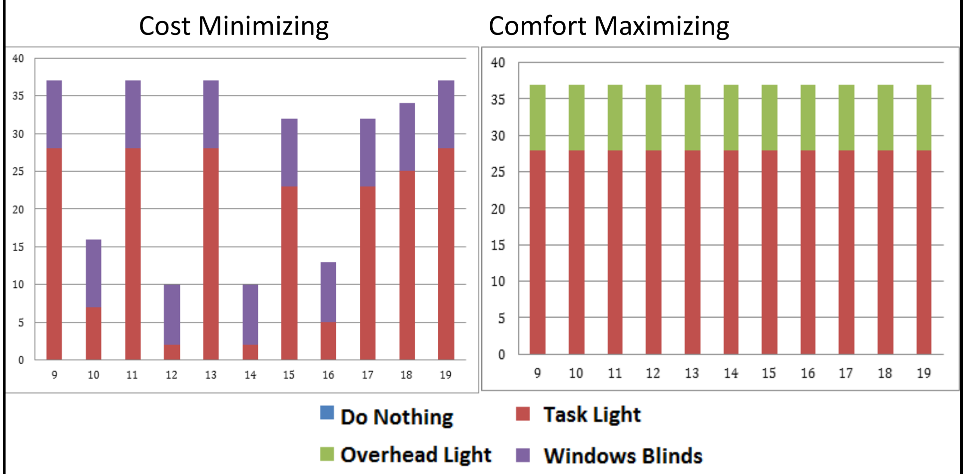
Simulated Cost Minimizing and Comfort Maximizing



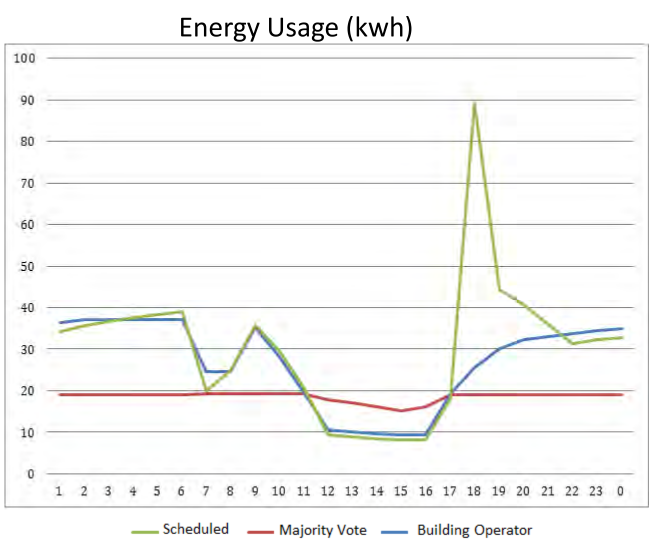
Cost Minimizing and Comfort Maximizing



Cost Minimizing and Comfort Maximizing

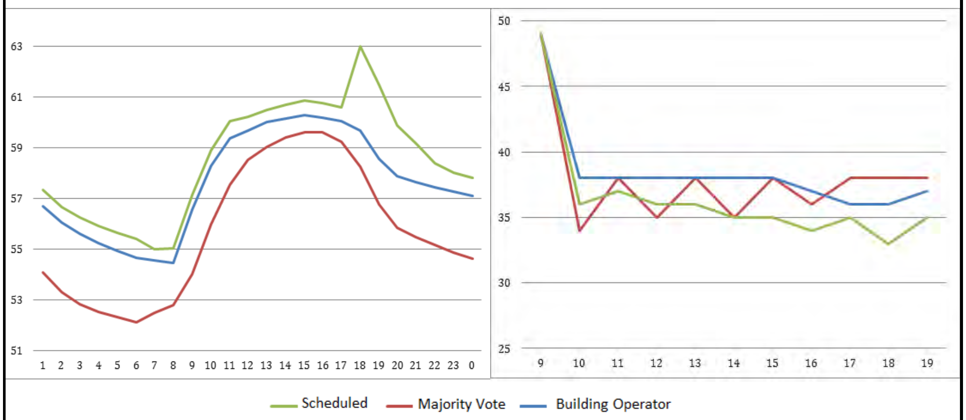


Locus of Control: winter days



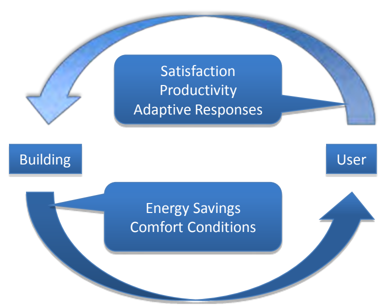
Locus of Control: Temperature and Discomfort

Temperature (°F)   Discomfort Level



Research Conclusions

- Smart buildings are innovative, can perform well
- Usability determines success of innovations, so measure it
- People value personal control, so provide some
- Dynamic relationship gains importance
- Emerging tools help jointly improve performance & usability



Research Conclusions

- Fieldwork confirms that occupant behavior is an important consideration in the design of AER in commercial buildings.
- Simulation modeling results are calibrated and validated.
- Simulation modeling approach is useful to explore “what-if” space thoroughly before carrying out the retrofit.

Thank You

For more information…

greenbuilding.rutgers.edu

OCCUPANT BEHAVIOR IN INDIAN COMMERCIAL BUILDINGS

Reshma Singh
July 2013

BERKELEY LAB

1. The Indian Commercial Buildings context
2. An untapped energy savings opportunity
3. A behavior framework
4. Anecdotal evidence from Indian exemplary buildings
5. Conclusions

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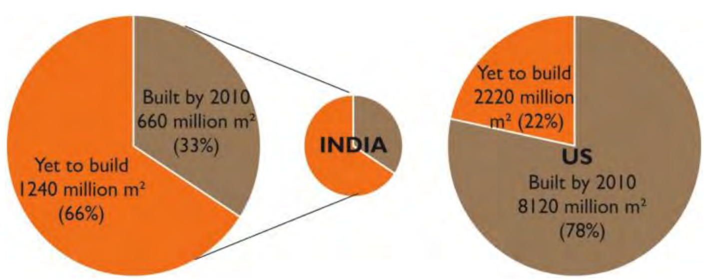
1. Indian Commercial Buildings context



- India's commercial stock in 2030: 1.9 B m^2
- New Construction Focus
  - a new Chicago added every year

- U.S. commercial stock in 2030: 10.3 B m^2
- Retrofit Focus

Sources: ECO III Benchmarking; EIA; LBNL CBERD project

1. Indian Commercial Buildings context -Western-style aspirations

Juxtaposition of various building typologies and construction systems:
Development Alternatives Building, Delhi (right) and neighboring office building (left) under construction

1. Indian Commercial Buildings context

3X average current EUI

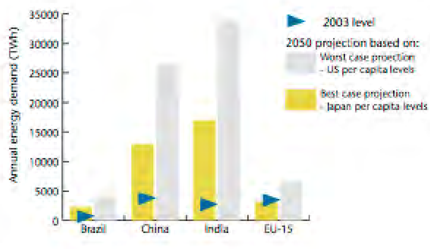
Cultural conditioning to one-third the space per occupant wrt US

3X stock by 2030

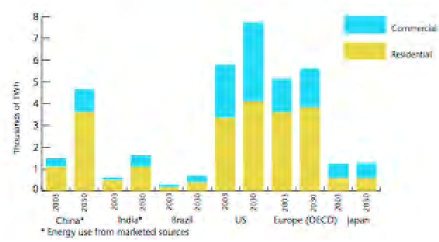
Explosion in Energy Consumption

Business reasons for 3X number of shifts

1. Indian Commercial Buildings context



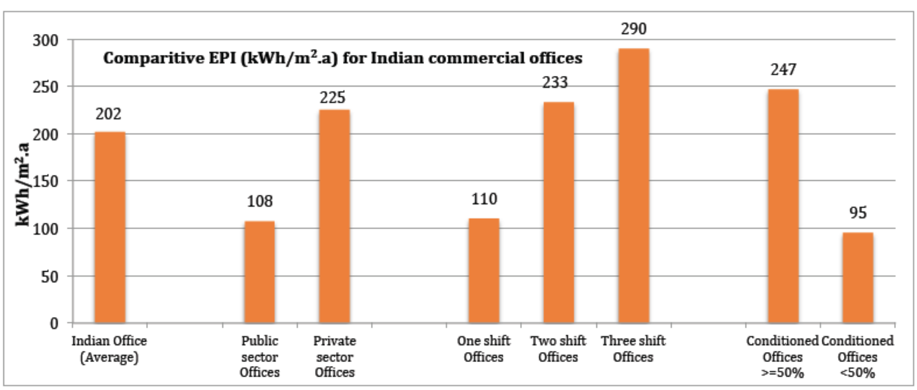
Best and worst case projections of site energy demand



Building energy projection by region- 2003/2030

Source: World Business Council for Sustainable Development

1. Indian Commercial Buildings context



Source: Best Practices Guide for High-performance Indian Office Buildings, Singh et al

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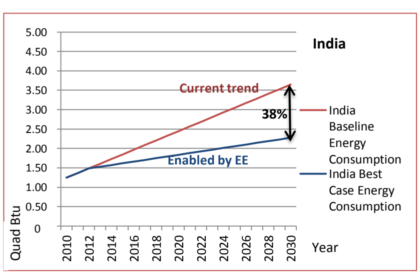
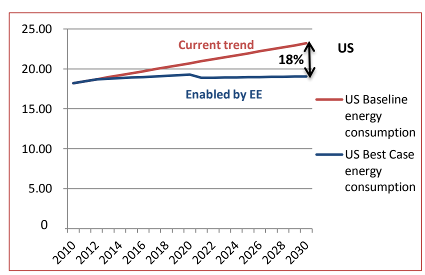
2. An untapped energy savings opportunity



India: Technical energy saving potential of 209 TW/year (40% savings) in India assuming a 60% reduction in energy use for new construction, and a conservative 10% reduction through retrofits from average benchmarked value of 273 kWh/sq m/year



US: Technical energy saving potential of 1167 TW/year (36% savings) in the U.S. assuming a retrofit target of 20% reduction in energy consumption by 2020, 30% by 2030, and a 60% reduction in new construction from average benchmarked value of 315 kWh/sq m/year

2. An untapped energy savings opportunity

Source: Anna Carolina Menezes, CIBSE

End-use pie in a typical Indian IT building,
Source: Best Practices Guide for High Performance Indian Office Buildings

40-50% energy savings is in the hands of people occupying and operating the building

2. An untapped energy savings opportunity:

Barriers to energy efficiency

1. Saving energy can carry ambiguous cultural connotations
2. Behavioral impediments in energy saving activities- survey results*
   - 36% do not want to lose comfort
   - 25% think that their action will just be a drop in the ocean
   - 25% say that they cannot afford it
   - 22% say its too much effort

Source: World Business Council for Sustainable Development
* Survey % numbers from Belgian study of 1000 households

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3. A Behavior Framework

Behavior of Operational Stakeholders

- Owner/ Developer
- Tenant/Occupant
- Facilities Operator

With a variety of motivations for energy savings

- Clients mandate
- Authorities requirements
- Consultants esthetics
- Trends (going with the flow)
- Necessity (last resort)

In a hierarchy of building spaces

1. Common to all tenants/ owner maintained

e.g. lobby, restaurant, facilities like gym

2. Tenanted usable space

- Shared - breakout, conference, café
- Offices/retail/work zones
- Intimate/personal space

3. A Behavior Framework

Behavioral Attitude

- Following Grandma's advice for frugality

- Habits

-Feeling of doing something good and positive

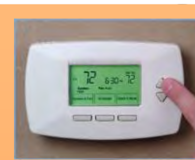
Subjective Norms

- Advertising / social media campaigns

-Energy labeling of appliances

- Advice on EE equipment/behavior

- Education



Perceived Behavioral Control

- Using meters, monitors for feedback that can cut energy consumption upto 20%

- Accessible and non-disruptive controls

- The perception of control: e.g. on-off switches for plugs, lights and fans, operable windows and controllable shades

- The perception of choice: of types of spaces

Theory of Planned Behavior: Behavioral drivers for energy efficiency

Behavior framework developed by Icek Azjen, U Mass Amherst

1. The Indian Commercial Buildings context
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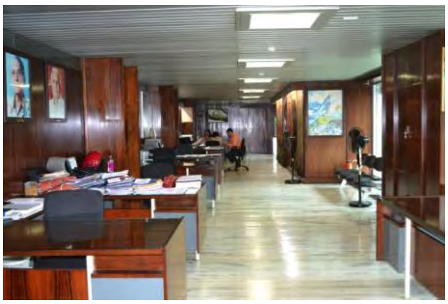
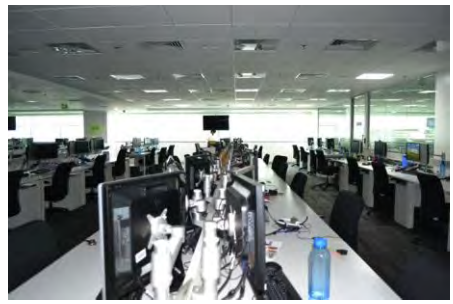
4. **Anecdotal evidence from Indian exemplary buildings**
5. Conclusions

4. Anecdotal evidence from India: Behavioral Attitudes



Godrej Bhavan, Mumbai



Generic BPO office

4.A.1 Frugality of space and resource utilization is a cultural norm
--while having high productivity

4. Anecdotal evidence from India: Behavioral Attitudes

Nirlon Knowledge Park, Mumbai

4.A.1 Frugality of space and resource utilization is a cultural norm;
--availability of cheaper human resources allows for more hands-on maintenance of systems

4. Anecdotal evidence from India: Behavioral Attitudes



4.A.2 Treating the mundane as sacred

4. Anecdotal evidence from India: Behavioral Attitudes

Suzlon One Earth, Pune

Suzlon One Earth, Pune

IRRAD, Delhi

Paryavaran Bhavan, Delhi

4.A.3 Ready acceptance of hybrid and naturally ventilated common spaces even in hot weather

4. Anecdotal evidence from India: Behavioral Attitudes

IRRAD, Delhi

4.A.4 Preferred space to work and interact-- semi-outdoor courtyards, verandahs, breezeways

4. Anecdotal evidence from India: Behavioral Attitudes

India Habitat Center, Delhi

4.A.4: Preferred space for interaction is still the semi-outdoors

4. Anecdotal evidence from India: Subjective norms

IRRAD, Delhi

Suzlon One Earth, Pune

4.N.1 Textures and materials with low embodied energy create a *common* vocabulary for the occupants to resonate with- towards energy savings and sustainable practices

4. Anecdotal evidence from India: Subjective norms

Infosys, Pune new campus

Nirlon Knowledge Park, Mumbai

4.N.2 Acceptance of campus level decisions such as pedestrianization, green cores, the use of shared bicycles and umbrellas is a matter of pride and loyalty. This trickles through to individual actions for energy savings.

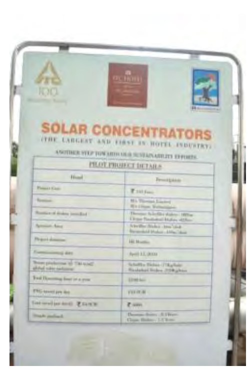
4. Anecdotal evidence from India: Subjective norms

Infosys, Pune new campus

ITC Green Center

4.N.2 Acceptance of campus level “green” decisions such as for energy, water and waste informs and reinforces individual actions towards the same shared goals.

4. Anecdotal evidence from India: Subjective norms



ITC Maurya, Delhi

4.N.2 Acceptance of campus level “green” decisions such as for energy, water and waste informs and reinforces individual actions towards the same shared goals.

4. Anecdotal evidence from India: Subjective norms

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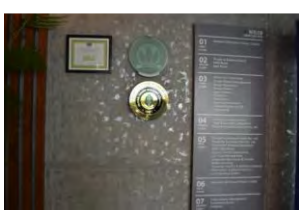
4. Anecdotal evidence from India: Subjective norms



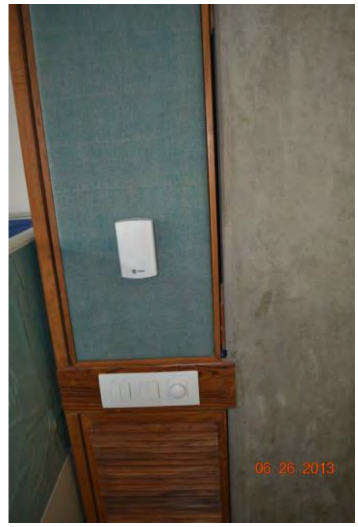
LEED India- Design based rating

Bureau of Energy Efficiency's Star Rating – EPI based rating

GRIHA- Operational Rating

4.N.3 Education of occupants on green labeling and rating systems for takes it beyond a marketing/CSR strategy

4. Anecdotal evidence from India: Perceived individual control

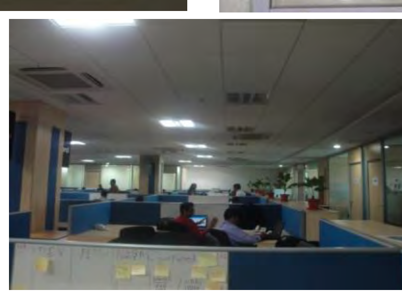


4.C.1 Perception of individual control- On-off switches for fans, task-lights and plugs that are easily accessible within the workplace and whose use is not disruptive to other occupants.

4. Anecdotal evidence from India: Perceived individual control

Suzlon One Earth, Pune

Sears Holdings, Pune



Sears Holdings, Pune

4.C.1 Perception of individual control- Sophisticated controls used for temperature setpoints (with wider range of acceptable setpoints), hard-wired lighting, conference room use etc

4. Anecdotal evidence from India: Perceived individual control

4.C.1 Perception of individual control- operable windows, shading of view window with manual control. Occupants need to be EDUCATED as to when to open and close windows, raise and lower shades, and otherwise control some of the non automated means of controlling the effects of the sun and wind on the interior environments of the building. Leads to feeling of ownership and engagement, like in your home.

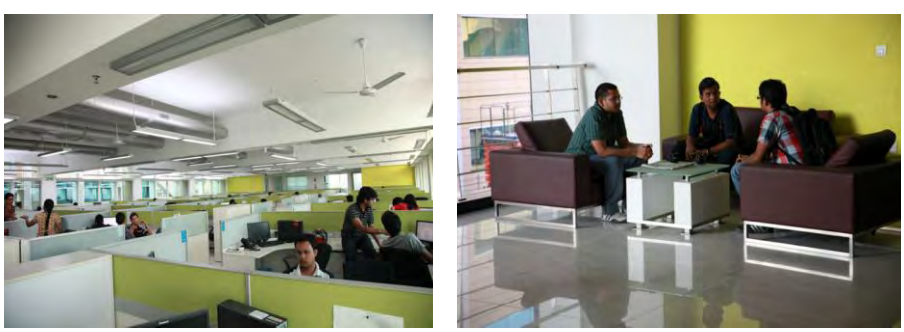
4. Anecdotal evidence from India: Perceived individual control

4.C.1 Perception of individual control- operable windows

4. Anecdotal evidence from India: Perceived individual choice

4.C.2 Perception of individual choice- A hierarchy of spaces provided through a layering of inside-outside spaces, levels of privacy/publicness/light and the creation of comfortable microclimates in some smaller office/institutional buildings

4. Anecdotal evidence from India: Perceived individual choice



4.C.2 Perception of individual choice- A hierarchy of spaces provided through a layering of inside-outside spaces, levels of privacy/publicness/light and the creation of comfortable microclimates in some smaller office/institutional buildings

1. The Indian Commercial Buildings context
2. An untapped energy savings opportunity
3. A behavior framework
4. Anecdotal evidence from Indian exemplary buildings
5. Conclusions

5. Conclusions: Framework for Next steps

1. Evaluate effective approaches to save energy related to occupant behavior
2. Study variations in energy use by different tenants occupying the same building
3. Evaluate the robustness of suites of EEMs as a function of occupant behavior
4. Identify the biggest points of waste/faults due to occupant behavior
5. Analyze how occupant behavior impacts design option selections, and ways of representing operation patterns into prototypes and energy simulations

Action based model for occupant behaviors in buildings

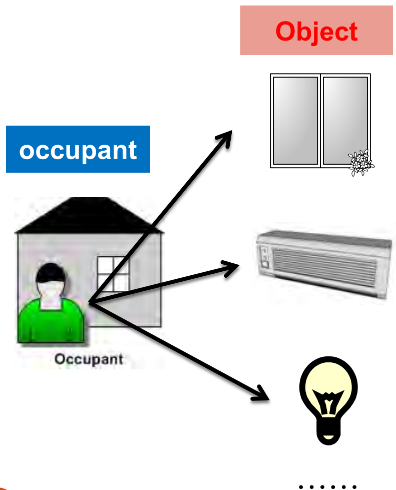
Chuang Wang
Tsinghua University
2013/7/19

1

Background

2

Occupant behaviors (OB) in buildings



- Energy-related behaviors
  - Open/Close window
  - Adjust curtain/blinds
  - Turn on/off air conditioner (AC)
  - Turn on/off light
  - Turn on/off equipment (computers, etc.)

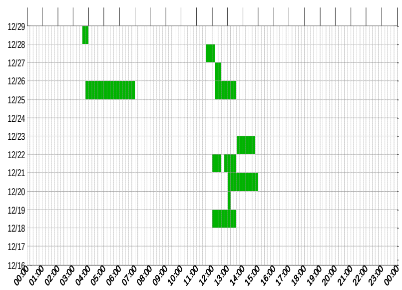
3

How to consider OB in simulation?

- OB is typically included in building energy modeling by setting the heating, cooling, lighting and equipment schedules.
- Fixed schedule: the deterministic sequential states of device: window, curtain, light, AC, equipment, etc.

4

Observations for actual schedules



The lighting schedule
measured in a single office

The AC operated hours per day
measured in a living room of a
multi-family building

How to model the random, environment-related (feedback) nature?

5

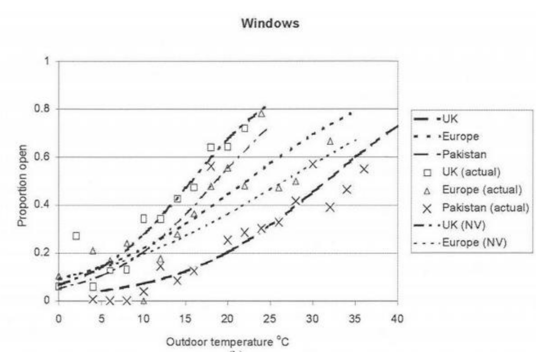
Windows status and probability

- Predict window state - open or closed - at a certain condition (indoor temp. outdoor temp. etc.)

P (Y=1 | x1, x2, x3…)

$$\mathrm{Log}\{p / (1 - p)\} = a + bx$$

$$p = e^{(a+bx)} / (1 + e^{(a+bx)})$$



- Nicol JF, Humphreys MA. A Stochastic approach to thermal comfort-occupant behaviour and energy use in buildings. ASHRAE Transactions 2004;110(2):554–68.

6

State transition probability

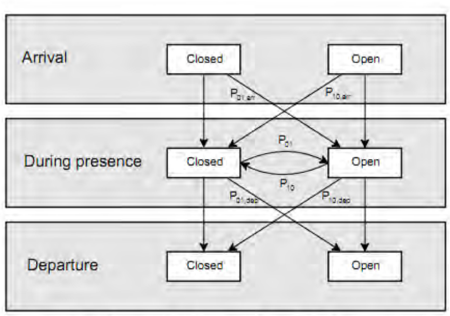
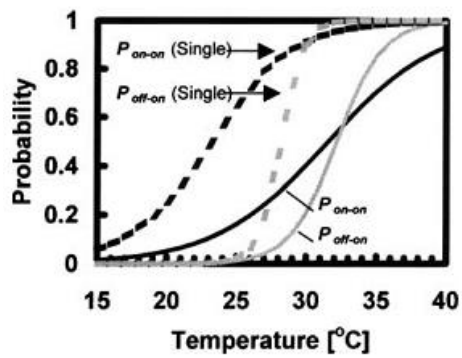


Figure 4 General scheme of the Markov process



- Frederic Haldi, Darren Robinson. Interactions with window openings by office occupants. Building and Environment, 44 (2009): 2378–2395
- Jun Tanimoto, Aya Hagishima. State transition probability for the Markov Model dealing with on/off cooling schedule in dwellings. Energy and Buildings, 37 (2005): 181–187

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Summary: findings of OB models

- Uncertainty: probability
- Multiple driving factors: independent and interactions
- Relation between different OB
  - Open window and turn on AC: close window if AC on.
- Personalized
  - Driven by occupant
  - Difference between different persons
  - Distribution of multitude cannot used for case study
  - Typical patterns for individual behaviors are necessary

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Action based model

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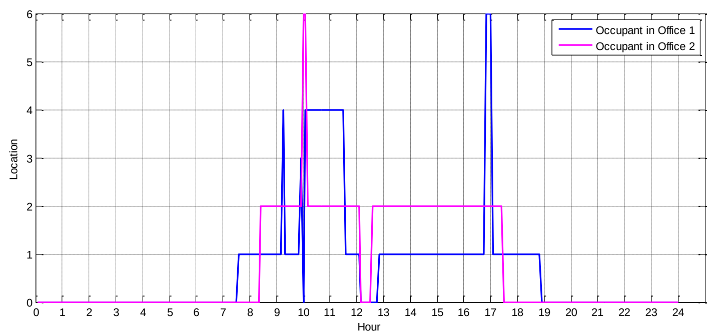
Basic Ideas for OB modeling

- Occupancy state should be modeled first
- Action oriented rather than state oriented
- The objects: window, curtain, AC, lighting, etc.

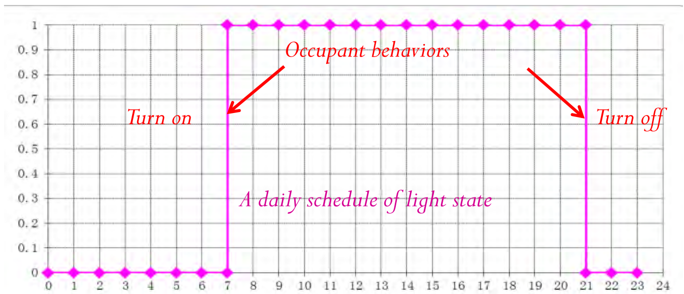
Why we need occupancy state

- OB is strongly connected with occupancy state
- OB only happen where occupants locates.
- Occupant movement model: determine the location of occupant (in which room)



Define OB by actions

- **OBs → actions on objects (AC, light, etc.) → object states**



- OBs ↔ the state change of object
- State based model → Action Based model
- defined on occupant: Provide a personalized description

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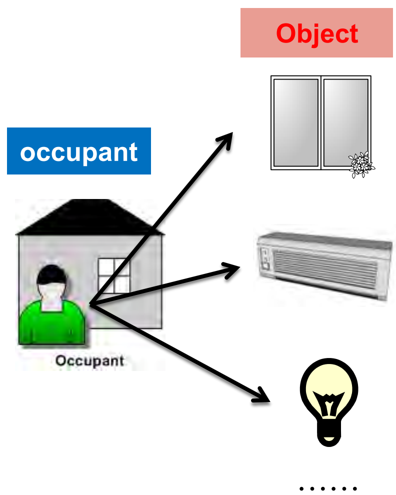
OBs need to be researched



- Actions on window:
  - Open window
  - Close window
- Actions on AC:
  - Turn on AC
  - Turn off AC
  - Adjust set point
- Actions on light:
  - Turn on light
  - Turn off light
- Others…

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Study framework of OB modeling

- Simulation of occupy & moving situation
  - A stochastic dynamic process
  - To replace schedules for both residents & offices
  - A number of typical families modes should be defined
  - A number of typical offices with different functions should be defined
- Simulate the actions of occupant rather than the state of devices
  - Open/close windows rather than window state
  - Turn on/off lights rather than the state of lights
  - A number of typical occupants with different behaviors can be defined and simulated

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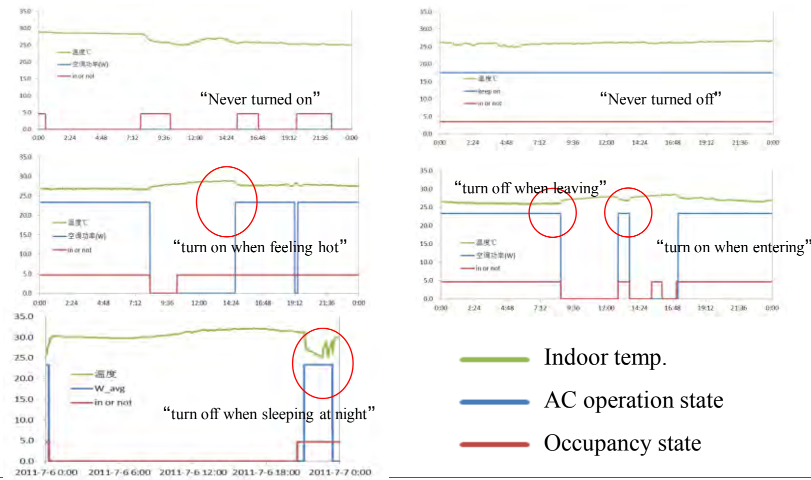
How to describe actions of OB

- Based on real phenomena from measurement and everyday experience - Typical AC behaviors



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Physical driving forces and behavior patterns

- Time related:
  - entering a room
  - leaving a room
- Environment related (feedback):
  - Indoor temperature, humidity, luminance, CO_2 density
  - Outdoor temperature, smell, noise etc.
- Random related:
  - TV set, etc.

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Uniform description of action

- State change of object = **P**(system status, object state)
  - P: expressed by a set of conditional probability, represent how occupant do change on object under any condition
  - system status (triggers): occupancy (time), indoor environment, outdoor conditions, other objects' state.
  - object state: the current state of object
- Two (different) actions for a two-state object, e.g. light:
  - Turn on light
  - Turn off light
- Typical patterns for each action
- A pair (or set) of actions for each energy-related OB item.

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Example: Turn on light model

No.	Pattern description	Mathematical model
1	Always turn on light as soon as enter the office	$P = 1$, when entering
2	Turn on light randomly when enter the office	$P = p$, when entering
3	Turn on light when feel dark	$P = \dfrac{1}{1+e^{-k(L-L_0)}}$, when occupied

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Example: Turn off light model

No.	Pattern description	Mathematical model
1	Never turn off light, till other turn off	$P = 0$, when leaving
2	Turn off light when leaving when leaving the office	$P = p$, when leaving
3	Turn off light when feeling bright	$P = \dfrac{1}{1+e^{-k(L-L_0)}}$, when occupied

- **Patterns can be independent (combined) or mutually-exclusive**
- **Can sup** ____)
- **Obtain t** **by measurement**

$$P = \begin{cases} p, & \text{when leaving} \\ 1/\left(1+e^{-k(L-L_0)}\right), & \text{when occupied} \end{cases}$$

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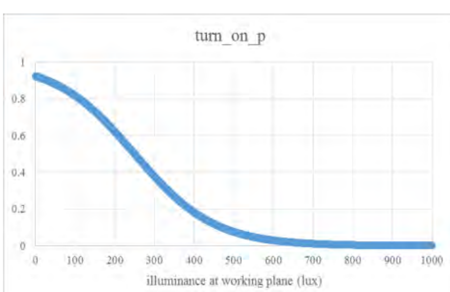
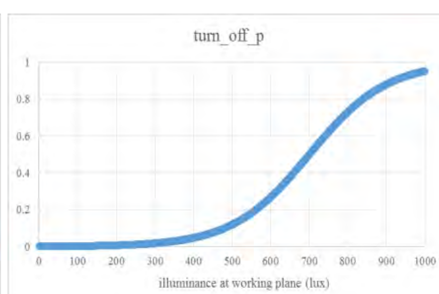
Environment-related probability function of turn on/off light

Turn on light



Turn off light



- P decrease with illuminance
- P → 1 if dark
- P → 0 if bright

- P increase with illuminance
- P → 1 if bright
- P → 0 if dark

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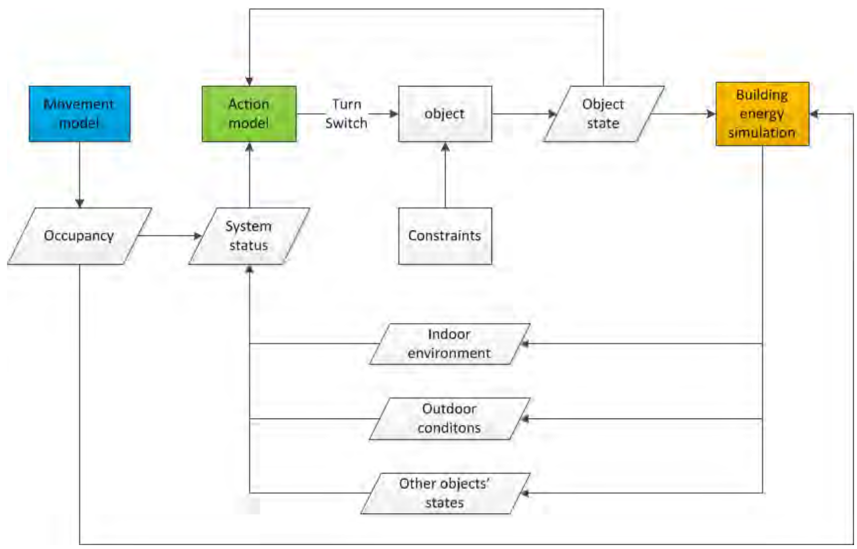
Integrated simulation



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Benefits from action based model

- Uniform personalized definition
  - Calculable: pattern and characteristic parameters
  - Understandable: input/output, physical relationship and phenomena
  - Flexible: easy to add new patterns
- Investigation
  - Questionnaire for patterns
  - Measurement for pattern characteristic parameters.

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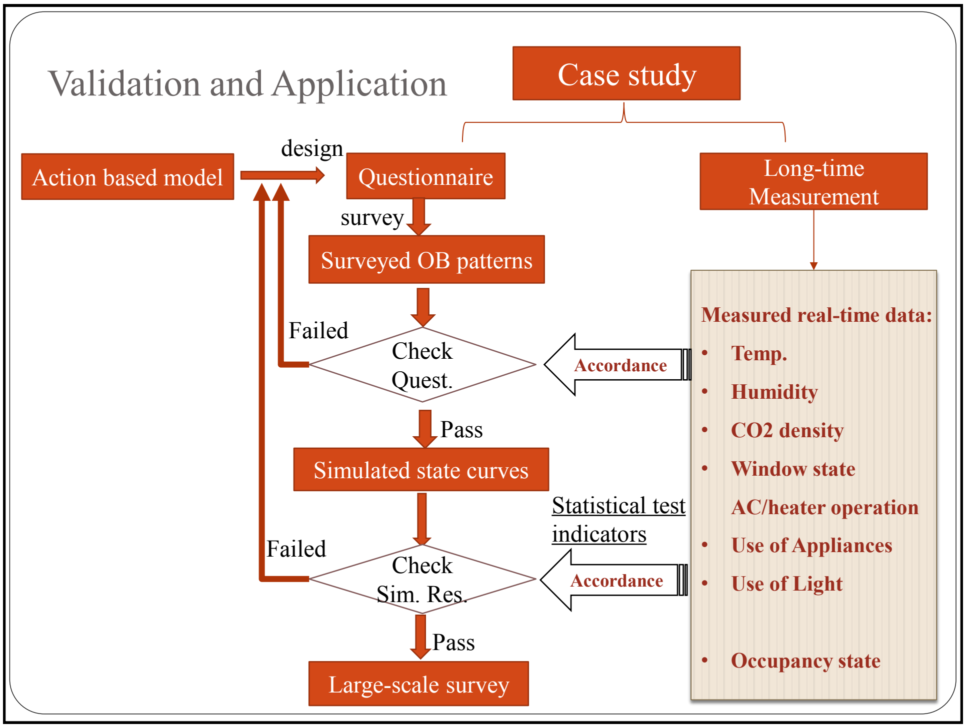

Case Study

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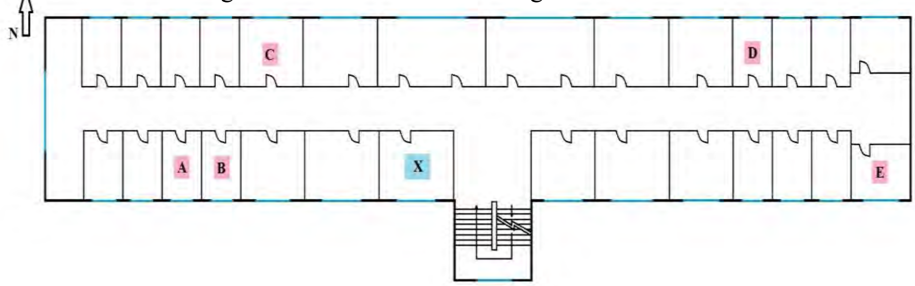
Lighting use of office building

- **Site:** five single offices of a office building



- **Period:** some weeks during 2012.4.25—2012.6.3
- **Measurement:** (1) power meters for lighting energy consumption in every minute; (2) illuminance meters for vertical and horizontal illumination; (3) surveillance videos for personnel movement. Q
- **Questionnaire**s for occupant lighting use habit.

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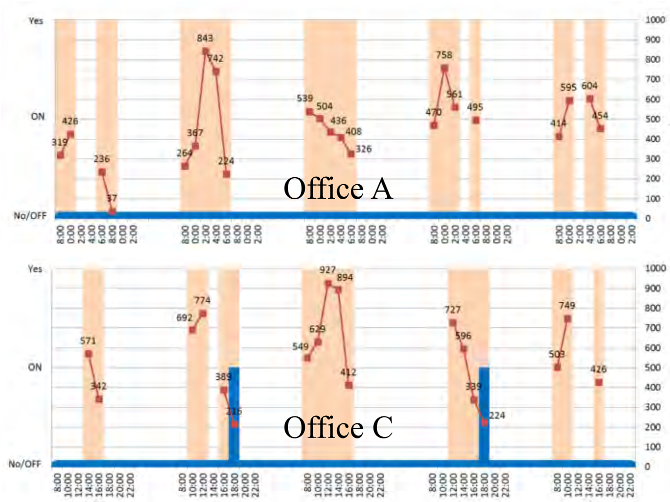
Observations vs. Questionnaire



From questionnaire:

- Turn on light when feeling dark.
- Turn off light when leaving at the end of work and feeling bright.

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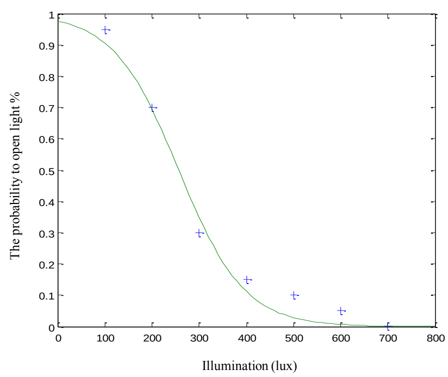
Fitting for pattern parameters (office C)

- Turn on light

$$P = \frac{1}{1+e^{-k(L-L_0)}}, \text{ when occupied}$$



$$P_{open} = \frac{1}{1+e^{-3.7136+0.0145x}}$$

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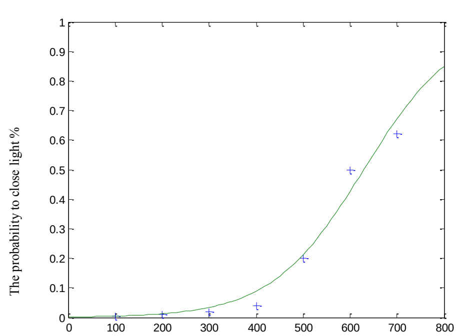
Fitting for pattern parameters (office C)

- Turn off light

$$P = \begin{cases} p, & \text{when leaving at the end of work} \\ 1\big/\left(1+e^{-k(L-L_0)}\right), & \text{when occupied} \end{cases}$$



$$p = 0.9$$

$$P_{close} = \frac{1}{1+e^{6.3862-0.0101x}}$$

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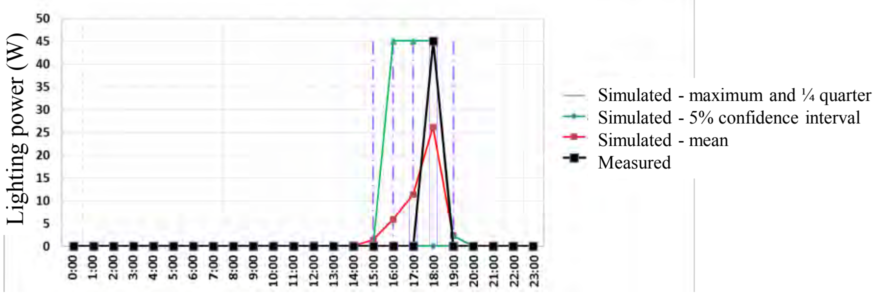
Simulation vs. Observations (office C)

- Lighting operation curve (a typical day)



- Lighting power

Average day lighting energy consumption in simulation (kWh)	Average day lighting energy consumption in actual measurement (kWh)	Standard Deviation (kWh)
0.048	0.045	0.0082

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General research planning for OB study

- Quantitative description of OB
  - Movement in office & at home
  - Probability functions for changing object state
- Large scale survey for OB
- Define a number of typical OB's that can cover most real behaviors
- Develop OB models and integrated with BES
- OB can be simulated as weather data in building simulation
  - People with different OB can be put in buildings in simulation

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We have paid great attention on weather data in building simulation, we should pay more attention on OB in order to understand the real phenomena in buildings and make our simulation output more close to the real world.

Thank you

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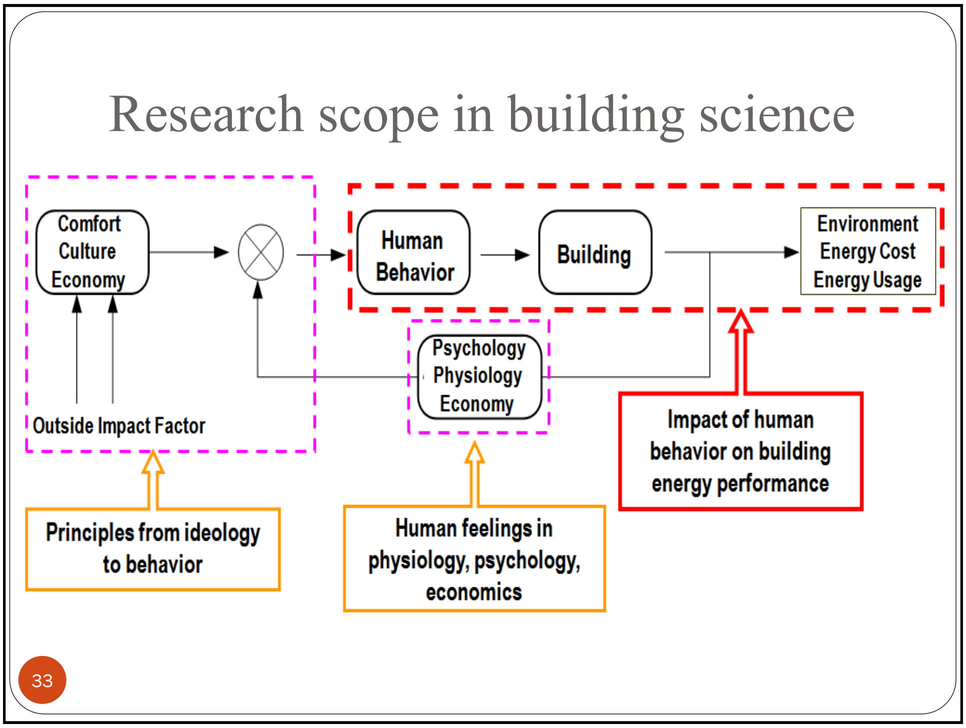
Research scope in building science
Comfort
Culture
Economy
Human
Behavior
Building
Environment
Energy Cost
Energy Usage
Psychology
Physiology
Economy
Outside Impact Factor
Impact of human behavior on building energy performance
Principles from ideology to behavior
Human feelings in physiology, psychology, economics
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